1. Can you provide a list of all boards, councils, commissions, working groups, and FACAs currently active at the Department? For each, can you please provide members, meeting schedules, and authority (statutory or otherwise) under which they were created?

   Response: Yes, attached is a list of major boards, councils, commissions, working groups, and FACAs currently active at the Department.

Department of Energy's Federal Advisory Committees (FACA) (active)

Advanced Scientific Computing Advisory Committee (ASCAC) - Agency Authority

Meeting Schedule – Quarterly

ASCAC Members:

Martin Berzins	Vinton G. Cerf	Barbara M.P. Chapman
Jacqueline Chen	Silvia Crivelli	John E. Dolbow
Jack J. Dongarra	Thom Dunning	Timothy Germann
Susan Gregurick	Anthony Hey	Gwendolyn L. Huntoon
David Levermore	Juan C. Meza	John Negele
Linda R. Petzold	Daniel Reed	Vivek Sarkar
Dean N. Williams	Krysta Svore	Richard Lethin
Satoschi Matsuoka		

Appliance Standards and Rulemaking Federal Advisory Committee (ASRAC) - Agency Authority

Established by Executive Order 13563 – Improving Regulation and Regulatory Review

Meeting Schedule: Semiannually (or as needed)

Working Groups (WG): Manufactured Housing Working Group, Miscellaneous Refrigeration Equipment Working Group, Central Air Conditioners and Heat Pumps Working Group, Walk-in Coolers and Freezers Working Group, Dedicated Service Pool Pumps, and Circulator Pumps Working Group

WG Meeting Schedules: several times throughout the year (based on the need)

ASRAC Members:

Ashley Armstrong		
Mark Connelly	Andrew de Laski	Kristin Driskell
David Gatto	Noah Horowitz	Diane Jakobs
Patrick Keal	Kelley Kline	Deborah Miller
Michelle Sim	Michael Wolf	David Winningham

Basic Energy Sciences Advisory Committee (BESAC) - Agency Authority

Meeting Schedule: Semiannually

BESAC Members:

Simon Bare	Dawn Bonnell	Gordon Brown
Sylvia Ceyer	Sue Chalk	Cuenya Beatriz
Peris Drell	Bruce Gates	Ernie Hall
Sharon Hammes-Schiffer	John Hemminger	Bruce Kay

Stephen Leone	Monica Olivera de la Cruz	Philippe Piot
Mark Ratner	Anthony Rollett	Frances Ross
Gary Rubloff	Maria Santore	Esther Takeuchi
Douglas Tobias	John Tranquada	

Biological and Environmental Research Advisory Committee (BERAC) - Agency Authority

Meeting Schedule: Semiannually

BERAC Members:

Sarah Assmann	Dennis Baldocchi	James Ehleringer
Bruce Hungate	Andrzej Joachimiak	Cheryl Kuske
Ruby Leung	Gerald Meehl	Jerry Melillo
Gloria Muday	David Randall	James Randerson
Karen Remington	G. Robertson	Karen Schlauch
David Segre	Jacqueline Shanks	David Stahl
David Stahl	Judy Wall	Minghua Zhang

Biomass Research and Development Technical Advisory Committee – Statutory Authority

Established by the Biomass Research and Development Act of 2000, re-authorized in the Agriculture Risk Protection Act, Title III

Meeting Schedule: Quarterly

Biomass Members:

Dean Benjamin	Esteban Chornet	Vonnie Estes
Manuel Garcia Perez	Emily Heaton	Joseph James
Coleman Jones	Bruce McCarl	Shellie Miller
Marina Moses	Neil Murphy	Kimberly Ogden
Anna Rath	Patricia Scanlan	Abolghasem Shahbazi
Kelly Tiller	Alan Weber	Don Stevens
Ray Miller	Bryan Paul	Steve Csonka
Christine Mc Kiernan	Man Kit Lau	

Defense Programs Advisory Committee (DPAC) - Agency Authority

Meeting Schedule: Periodically; approximately two to four times per year

DPAC Members:

John Casani	Julie Cizewski	Jill Dahlburg
Paul Dimotakis	John Immele	Stephen Johnson
Jeff Quintenz	Chris Yeaw	

DOE/NSF Nuclear Science Advisory Committee (NSAC) – Agency Authority

Established by NSF Circular #109, Rev. #3

Meeting Schedule: Periodically; as often as two to four times per year

NSAC Members:

Paul Benny	Helen Caines	Gordon Cates
Abhay Deshpande	Frederic Fahey	George Fuller
John Hardy	Karsten Heeger	David Hertzog
Roy Holt	Kate Jones	Cynthia Keppel
Suzanne Lapi	Michael Lisa	Jeffery Nico
Filomena Nunes	Daniel Phillips	Mark Pitt
Krishna Rajagopal	Martin Savage	Michael Wiescher

Electricity Advisory Committee (EAC) - Agency Authority

Agency Authority to assist in the implementation of the Energy Policy Act (EPACT) of 2005; implement provisions of Energy Independence and Security Act of 2007

Meetings: Quarterly

EAC Members:

John Adams	Ake Almgren	William Ball
Anjan Bose	Laney Brown	Marilyn Brown
Merwin Brown	Paula Carmody	Jay Caspary
Paul Centolella	Carlos Coe	Richard Cowart
Phyllis Currie	Gordon Feller	Clark Gellings
Mark Lauby	Jim Lazar	Janice Lin
M. Morgan	Jeff Morris	Rolf Nordstrom
Nancy Pfund	Anne Pramaggiore	Paul Roberti
Heather Sanders	Chris Shelton	Pam Silberstein
Sue Tierney	David Till	Rebecca Wagner
Audrey Zibelman	Carl Zichella	

Environmental Management Advisory Board (EMAB) - Agency authority

Meetings: Semiannually

EMAB Members:

Paul Dabbar	Jane Hedges	Carolyn Huntoon
Frazer Lockhart	Tracy Mustin	Josiah Pinkham
Beverly Ramsey	Timothy Runyon	Robert Thompson
Shelly Wilson		

Environmental Management Site-Specific Advisory Board (EM SSAB) - Agency Authority

Sites and Meetings:

- EM SSAB at Hanford (**Hanford Advisory Board**) meets on a quarterly basis

- EM SSAB in Idaho (**Idaho National Laboratory Site EM Citizens Advisory Board**) meets on a quarterly basis
- EM SSAB in Nevada (**Nevada Site-Specific Advisory Board**) meets on a bi-monthly basis
- EM SSAB in Northern New Mexico (**Northern New Mexico Citizens' Advisory Board**) meets on a bi-monthly basis
- EM SSAB in Oak Ridge (**Oak Ridge Site Specific Advisory Board**) meets on a monthly basis
- EM SSAB at Paducah (**Paducah CAB**) meets on a quarterly basis
- EM SSAB at Portsmouth (**Portsmouth Site Specific Advisory Board**) meets on a bi-monthly basis
- EM SSAB at Savannah River **(Savannah River Site Citizens Advisory Board**) meets on a bi-monthly basis

EM SSAB Members:

EM SSAB at Hanford (Primary Members):

Gabriel Bohnee	Gary Bouchey	Antone Brooks	Pamela Brown-Larsen
Janice Catrell	Shelley Cimon	Alissa Cordner	Robert Davis
Samuel Decter	Yonas Denissie	Thomas Galioto	Garu Garnant
Floyd Hodges	Rebecca Holland	Stephen Hudson	Emmitt Jackson
Russell Jim	Alexandre Klementiev	Gregory Korshin	Susan Leckband
Robert Legard	Elizabeth Mattson	Kristen McNall	Armand Minthorn
Melanie Myers-Magnuson	Ken Niles	Robert Parks	Jerry Peltier
Gerald Pollet	Robert Suyama	Gene Van Liew	

EM SSAB at Hanford (Alternate Members):

Mark Benjamin	David Bernhard	Richard Bloom	Mike Bossé
Amoret Bunn	Garret Busselman	Shannon Cram	Dirk Dunning
Dale Engstrom	Charles Johnson	Paul Kison	Paige Knight
Michael Korenko	Phil Lemley	Larry Lockrem	Rodolfo Mendoza
Stephen Metzger	Casey Mitchell	David Molnaa	Emmett Moore
Alex Nazarali	Eduardo Pacherco	Vincent Panesko	Nikolas Peterson
David Rowland	Daniel Serres	Daniel Solitz	Marery Swint
Drew Thomas	Tony Umek	Jean Vanni	Helen Wheatley
Stephen Wiegman			

EM SSAB in Idaho:

Robert Bodell	Herbert Bohrer	Melvin Branter
Bradley Christensen	Marvin Fielding	Kristen Jensen
Talia Martin	Trilby McAffee	Betsy McBride

William Roberts	Catherine Roemer	

EM SSAB in Nevada:

Michael Anderson	Saia Amina Anderson	Arcadia Bolanos
Francis Bonesteel	Michael D'Alessio	Karen Eastman
Pennie Edmond	Raynond Elgin	Charles Fullen
Richard Gardner	Donald Neill	Autumn Pietras
Edward Rosemark	Steve Rosenbaum	William Sears
Cecilia Synder	Richard Stephans	Jack Sypolt
Richard Twiddy	Dina Williamson-Erdag	

EM SSAB in Northern New Mexico:

Carla Abeyta	Cherylin Atcitty	Christopher Baca
Nona Girardi	Louis Gonzales	Angelica Gurulé
Diahann Lopez-Cordova	Daniel J. Madalena	Gerard J. Martinez y Valencia
Daniel Mayfield	Alex Puglisi	Angel Quintana
Ashley Sanderson	Steven Santistevan	Douglas Sayre
Stephen G. Schmelling	Jospeh C. Tiano, Jr	Irene Tse-Pe
Carlos Valdez	Michael A. Valerio	Mona Varela

EM SSAB in Oak Ridge:

Leon Baker	Katheryn Bales	Christopher Beatty
Richard Burroughs	Martha Deaderick	James Ford
Maria Gonzalez	David Hemelright	Paul Holdren
Howard Holmes	Gregory Paulus	Belinda Price
Elizabeth Ross	Mary Smalling	Deni Sobek
Fredric Swindler	Venita Thomas	Edmundo Trujillo
Rudolf Weigel	Dennis Wilson	Phillip Yager

EM SSAB at Paducah:

Charles Allen	Doreen Barger	Cindy Butterbaugh
Victoria Caldwell	Judy Clayton	Basil Drossos
Nancy Duff	Celestine Emerson	Lesley Garrett
Thomas Grassham	Michael Kemp	Jessica Morgan
William Murphy	Cindy Ragland	Richard Rushing
Kenneth Wheeler	Patrick White	Bessie Young

EM SSAB at Portsmouth:

Lisa Bennett	Robert Berry	Eric A. Braun
Bradley Burns	Maddeline C. Caudill	Carlton L. Cave
Al Don Cisco	Dennis Foreman	Carl R. Hartley
Ronda J. Kinnamon	Neil E. Leist	Bernard S. Neal

Irma C. Payne	Cynthia M. Quillen	Jimmey Smalley
Judy Vollrath	Gregory Stepp	

EM SSAB at Savannah River:

John G. Allensworth	Thomas K. Barnes	Louie C. Chavis
Susan E. Corbett	Robert Doerr	Dawn L. Gillas
David F. Hoel	Eleanor Hopson	Virginia B. Jones
Daniel Kaminski	James Lyon	John McMichael, Jr.
Clinton E. Nangle	Cathy Patterson	Larry Powell
William Rhoten	Earl Sheppard	Harold F. Simon
George E. Snyder	Nina Spinelli	Edward Sturcken
Louis Walters	Mary Weber	

Fusion Energy Advisory Committee (FESAC) - Agency Authority

Meetings: Quarterly

FESAC Members:

Troy Carter	Robert Cauble	Arati Desgupta
John Foster	Chuck Greenfield	Rich Groebner
Chris Hegna	Valerie Izzo	Stephen Knowlton
Kristina Lynch	Hutch Nielson	Getrude Patello
Juergen Rapp	Donald Rej	Linda Sugiyama
Brian Wirth		

High Energy Physics Advisory Panel (HEPAP) - Agency Authority

Meetings: Quarterly (or as needed)

HEPAP Members:

Karl van Bibber	James Buckley	Bruce Carlsten
John E. Carlstrom	Kyle Cranmer	Aaron Dominguez
Salman Habib	Eva Halkiadakis	Karsten Heeger
JoAnne Hewett	Joseph Incandela	Josh Klein
Kay Kinoshita	Andrew Lankford	David Larbalestier
Hitoshi Murayama	Stefano Profumo	Laura Reina
Thomas Roser	Gabriella Sciolla	Stefan Söldner-Rembold
Marie Spiropulu	Christopher Stubbs	Mark Trodden
Mayda Velasco	Risa Wechsler	James Wells
Geralyn Zeller		

Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) – Statutory Authority

Established by Energy Policy Act (EPACT) of 2005, section 807

Meetings: Quarterly

HTAC Members:

Kathy Ayers	Inês Azevedo	Kathryn Clay
Catherine Dunwoody	Anthony Eggert	Charles Freese
Anne Gobin	Maurice Kaya	Drew Kodjak
Harol (Hal) Koyama	Paul Leggett	Timothy Lipman
Morry Markowitz	Frank Novachek	Joan Ogden
Margo Oge	Joseph Powell	Adele Ratcliff
Janea Scott	Levi Thompson	

Methane Hydrate Advisory Committee (MHAC) – Statutory Authority

Established by Methane Hydrate Research and Development Act of 2000 and reauthorized by the Energy Policy Act (EPACT) of 2005

Meetings: Biennially

MHAC Members:

Thomas Blasingame	Richard Charter	Peter Flemings
Matthew Hornbach	Miriam Kastner	Carolyn Koh
Craig Shipp	Robert D. Kaminsky	Mark Myers
Michael Max	George Moridis	Joel E. Johnson
Robert L. Kleinberg	Evan A. Solomon	

National Coal Council (NCC) - Agency Authority

Meetings: Semiannually

NCC Members:

Robert O. Agbede	Nicholas K. Akins	Sy Ali	Barbara-Farmer Altizer
Richard L. Axelbaum	Richard Bajura	Shannon Maher Banaga	Janos M. Beer
Nina Bergan French	Robert A. Bibb	Jacqueline F. Bird	Rick Boyd
Lisa J. N. Bradley	F. William Brownell	Wanda I. Burget	Frank Burke
John Cassady	Donna Cerwonka	Henry J. Cialone	Kipp Coddington
Brad Crabtree	Joseph W. Craft, III	Michael D. Crotty	Jack Daly
Michael R. DeLallo	David L. Denton	Joseph S. Divoky	Edward (Ted) Doheny, II
George Duggan	Michael D. Durham	John W. Eaves	William R. Elliott
Amy Ericson	Ellen Ewart	Maohong Fan	Alex G. Fassbender
Paul J. Feldman	Robert J. Finley	John S. Fischer	David M. Flannery
Mark Forwerck	David A. Frederick	Thomas K. Gale	Paul Gatzemeier
Sheila Glesmann	Danny L. Gray	Clark D. Harrison	William Hoback
Clarence Joseph Hopf	Daniel R. Jack	Denise Johnson	Michael Jones
Brian Kalk	Casey J. Kaptur	Michael Karmis	John C. Kennedy
Michael Kennedy	Holly Krutka	David Lawson	John T. Long
Jason Makasi	Daniel T. Martin	Emmanuel R. Merle	Jeffrey Miller
Rafic Y. Minkara	Nancy Mohn	Betsy B. Monseu	Clark A. Moseley
Ram G. Narula	Kenneth J. Nemeth	Karen Obenshain	Mary Eileen O'Keefe
Jerry J. Oliver	Fredrick D. Palmer	Carlyl Pfeiffer	Carole Plowfield
Robert Puissant	Robert M. Purgert	Massood Ramezan	William Raney
Angila M. Retherfold	Daniel R. Roling	Todd Savage	Mark Schoenfield
John J. Siegel	Richard C. Smith	Sharon Sjostrom	Carolyn Slaughter
Deck S. Slone	Michael G. Sorensen	G. Scott Stallard	Mark Stemm
Vicky Sullivan	Scott Teel	John W. Thompson	Pamela Tomski
Sarah M. Wade	Daman S. Walia	Kathey Walker	Jeffrey L. Wallace
Kathy Walton	Richard M. Whiting	Jennifer Wilcox	Robert Williams
Kemal Williamson	Steven E. Winberg	Gregory A. Workman	Xiaoliang Yang

National Petroleum Council (NPC) - Agency Authority

Meetings: Annually or Semiannually

NPC Members:

Nicholas K. Akins	George A. Alcorn, Sr.	Robert Neal Anderson	Thurmon M. Andress
Robert H. Anthony	Alan S. Armstrong	Gregory L. Armstrong	Robert G. Armstrong
Greg A. Arnold	Philip K. Asherman	Edward H. Bastian	Riley P. Bechtel
Michael Bénézit	Sally M. Benson	Kevin D. Book	John F. Bookout
Lee K. Boothby	Jason E. Bordoff	Stuart J.B. Bradie	Mark S. Brownstein
Sharon E. Burke	Matthew D. Cabell	Kateri A. Callahan	Deborah H. Caplan
Robert B. Catell	John J. Christman, IV	Kim R. Cocklin	Linda Z. Cook
Brian C. Cothran	Richard D. Courtney	Christi L. Craddick	Martin S. Craighead
Helima L. Croft	Bruce Culpepper	William A. Custard	Charles D. Davison
Lisa Davis	Claiborne P. Deming	Leo P. Denault	Claudio Descalzi
John M. Deutch	Laurence M. Downes	David D. Dunlap	W. Byron Dunn
Bernard J. Duroc-Danner	Gregory L. Ebel	Kathleen M. Eisbrenner	John W. England
Ronald A. Erickson	Timothy C. Felt	Fereidun Fesharaki	William L. Fisher
James C. Flores	Paul L. Foster	Randy A. Foutch	Benjamin G.S. Fowke, III
Thomas A. Fry, III	Greg C. Garland	Robert W. Gee	Elliot F. Gerson
James A. Gibbs	Russell K. Girling	David C. Glendon	Richard K. Glenn
Paula R. Glover	Lawrence J. Goldstein	David L. Goldwyn	Joseph W. Gorder
John T. Gremp	James T. Hackett	Frederic C. Hamilton	Karen Alderman Harbert
John A. Harju	Marilu Hastings	John B. Hess	Jack D. Hightower
Stephen L. Hightower	Jeffery D. Hildebrand	Ralph A. Hill	John D. Hofmeister
Forrest E. Hoglund	Vicki A. Hollub	Martin J. Houston	Ray L. Hunt
Hillard G. Huntington	John R. Hurd	J. Jon Imaz	Terrence S. Jacobs
Amy Myers Jaffe	A. V. Jones, Jr.	James L. Jones	Jon Rex Jones
Fred C. Julander	Patricia Leonard Kampling	Andy Karsner	Paal Kibsgaard
Michael S. Kirschner	John Krenicki, Jr.	Vello A. Kuuskraa	Ryan M. Lance
Ralph A. LaRossa	Robert D. Lawler	Stephen D. Layton	Virginia B. Lazenby
Timothy C. Lieuwen	Michael C. Linn	Andrew N. Liveris	Mario Longhi
Amory B. Lovins	Terry D. McCallister	M. Kevin McEvoy	James T. McManus, II
Robert C. McNally	Rae McQuade	Ignacio Madridejos	Cary M. Maguire
Kenneth B. Medlock, III	Augustus C. Miller	David B. Miller	Mark K. Miller
Merrill A. Miller, Jr.	John C. Mingé	Al Monaco	David L. Murfin
Mark B. Murphy	Richard G. Newell	J. Larry Nichols	Patrick F. Noonan
John W. B. Northington	Pierce H. Norton II	Thomas B. Nusz	Javan D. Ottoson
C. R. Palmer	Michel J. Paque	Stephen Pastor	Donald L. Paul

Robert W. Perciasepe	Jeffrey M. Platt	David L. Porges	Allan G. Pulsipher
Rebecca E. Ranich	Lee R. Raymond	Debra L. Reed	Torgrim Reitan
June Ressler	Gary G. Rich	Corbin J. Robertson, Jr.	Paolo Rocca
Matthew C. Rogers	Marty Rutherford	Tisha Conoly Schuller	David T. Seaton
Peter A. Seligmann	Bobby S. Shackouls	Philip R. Sharp	Scott D. Sheffield
Bryan A. Shinn	Thomas E. Skains	Eric S. Slifka	Carl Michael Smith
Clark C. Smith	John W. Somerhalder, II	Jeffrey B. Spath	Terry K. Spencer
Charles B. Stanley	Bert Stedman	Lisa A. Stewart	David L. Stover
Douglas J. Suttles	Berry H. Tew, Jr.	William R. Thomas	Rex W. Tillerson
Lee M. Tillman	Scott W. Tinker	William Paschall Tosch	H. A. True, III
Robert B. Tudor, III	W. Bruce Valdez	Jamie L. Vazquez	Vaughn O. Vennerberg, II
Frank A. Verrastro	Bruce H. Vincent	John B. Walker	John W. Wallace
Cynthia J. Warner	Kelcy L. Warren	Michael D. Watford	John S. Watson
William J. Way	J. Robinson West	Craig E. White	William H. White
David W. Williams	Mary Jane Wilson	Stan Wise	Patrick H. Wood, III
Karen Buchwald Wright	George M. Yates	Daniel H. Yergin	John F. Young

Nuclear Energy Advisory Committee (NEAC) - Agency Authority

Meetings: Semiannually

NEAC Members:

Richard Meserve	Joy Rempe	Ashok Bhatnagar	Matthew Bunn
Dana Christensen	Margaret Chu	Don Hintz	Sue Ion
Thomas Isaacs	Raymond Juzaitis	Maria Korsnick	Warren F. (Pete) Miller
Carl Papericello	Burton Richter	Ray Rothrock	Mark Rudin
Regis Matzie	John Sackett	Alfred P. Sattelberger	Rachel Slaybaugh
Karen Vierow			

President's Council of Advisors on Science and Technology (PCAST) – Presidential Authority

Established by Executive Order 13539, as amended – President's Council of Advisors on Science and Technology

Meetings: Semimonthly

Working Group: Action Needed to Protect Against Biological Attack Working Group

PCAST Members:

John P. Holdren	Eric Lander	William Press	Maxine Savitz
Wanda M. Austin	Rosina Bierbaum	Christine Cassel	Christopher Chyba

S. James Gates, Jr.	Mark Gorenberg	Susan Graham	J. Michael McQuade
Chad Mirkin	Mario J. Molina	Craig Mundie	Ed Penhoet
Barbara Schaal	Eric Schmidt	Daniel Schrag	

Secretary of Energy Advisory Board (SEAB) - Agency authority

Meetings: Quarterly

SEAB Members:

John Deutch	Carol Browner	Michael Greenstone	Arunava Majumdar
Paula Hammond	Shirley Ann Jackson	Steven Koonin	Dan Reicher
Michael McQuade	Richard Meserve	Richard Mies	Ram Shenoy
Carmichael Roberts	Gary Samore	Martha Schlicher	Rafael Bras
Linda Stuntz	Ellen O'Kane Tauscher	Harold Varmus	

State Energy Advisory Board (STEAB) – Statutory Authority

Established by the State Energy Efficiency Programs Improvement Act of 1990

Meeting: Monthly

STEAB Members:

Susan Brown	Tom Carey	Molly Cripps	Diane Duva
Lauren Faber	Robert Jackson	Ashlie Lancaster	Louise Martinez
Andrew McAllister	Frank Murray	Geoff Wilcox	Malcom Woolf
David Springe			

Department of Energy's Boards, Councils, and Working Groups

Energy (External)

Electricity Subsector Coordinating Council (ESCC) – Presidential Authority

Established by Presidential Policy Directive 21 (PPD-21): Critical Infrastructure Security and Resilience and National Infrastructure Protection Plan (NIPP) 2013: Partnering for Critical Infrastructure Security and Resilience The ESCC is the principal coordination mechanism between leadership in the federal government and CEOs in the electric power sector, with the mission of coordinating efforts to prepare for national-level incidents or other threats to critical infrastructure.

Meeting: Three times a year

ESCC Members:

Southern Company	Arkansas Electric Cooperative	Lincoln Electric System	American Public Power Association
Canadian Electricity Association	Edison Electric Institute	Electric Power Supply Association	PJM
National Infrastructure Advisory Council	National Rural Electric Cooperative Association	North American Electric Reliability Corporation	Nuclear Energy Institute
ESCC Asset Owners: American Electric Power	AVANGRID	City Utilities of Springfield	Consolidated Edison
Dominion	Duke Energy	Edison International	ENMAX Corporation
Exelon Corporation	Georgia System Operations Corp.	Great River Energy	Hawaiian Electric Industries
MidAmerican Energy Co.	Norwich Public Electric Companies	Old Dominion Electric Cooperative	PG&E Corporation
PPL Corporation	Santee Cooper	Xcel Energy	

Energy Government Coordinating Council – Presidential Authority

Established by Presidential Policy Directive 21 (PPD-21): Critical Infrastructure Security and Resilience and National Infrastructure Protection Plan (NIPP) 2013: Partnering for Critical Infrastructure Security and Resilience.

The Energy GCC provides a forum for interagency Federal and state, local, territorial, and tribal (SLTT) partners to discuss security and resilience topics for the Nation's energy sector).

Meeting: Three times a year

Members:

Department of Homeland Security	Department of Defense	U.S. Coast Guard	Office of the Director of National Intelligence
Transportation Security Administration	Pipeline and Hazardous Materials Safety Administration	Federal Emergency Management Agency	Federal Aviation Administration
Federal Energy Regulatory Commission	Environmental Protection Agency	Department of State	Treasury Department
Department of Transportation	National Association of State Energy Officials	National Geospatial-Intelligence Agency	National Electrical Manufacturers Association
National Association of Regulatory Utility Commissioners			

Indian Country Energy and Infrastructure Working Group (ICEIWG) - Agency Authority

Established by Title V of the Energy Policy Act of 2005, Pub. L. No. 109-58, 119 Stat. 763 (2005) amended the Department of Energy Organization Act, Pub. L. No. 95-91, 91 Stat. 565 (1977) and the Energy Policy Act of 1992, Pub. L. 102-486, 106 Stat. 2776 (1992). The amended statutory provisions include establishment of the Office of Indian Energy Policy and Programs (Office) and duties of the Office's Director, providing authority specific to Indian energy matters. *See* 42 U.S.C. § 7144e (2015); 25 U.S.C. §§ 3501 note, 3502(b) (2015). Additionally, 42 U.S.C. § 7251 (2015) provides general authority for the Secretary, officers and employees of the Department to perform functions.

Meeting: Quarterly, The 2017 schedule will be published on the ICEIWG website: http://www.ncsl.org/research/energy/indian-country-energy-and-infrastructure-working-group-iceiwg.aspx#ICEIWG

ICEIWG Members:

Association of Village Council Presidents	Mississippi Band of Choctaw Indians	Blue Lake Rancheria	Osage Nation
Cherokee Nation	Seminole Tribe of Florida	Seneca Nation of Indians	Confederated Tribes of the Warm Springs Reservation of Oregon
Ewiiaapaayp Band of Kumeyaay Indians	Tanana Chiefs Conference	Gila River Indian Community	The Confederated Salish and Kootenai Tribes of the Flathead Nation
Ho-Chunk Nation	Mandan, Hidatsa & Arikara (MHA) Nation		

Oil and Natural Gas Coordinating Council (ONG - SCC) – Presidential Authority

Established by Presidential Policy Directive 21 (PPD-21): Critical Infrastructure Security and Resilience and National Infrastructure Protection Plan (NIPP) 2013: Partnering for Critical Infrastructure Security and Resilience.

The ONG SCC provides a private forum for effective coordination of oil and natural gas security strategies and activities, policy, and communication across the sector to support the nation's homeland security mission. The ONG SCC provides a venue for industry owners and operators to mutually plan, implement, and execute sufficient and appropriate sector-wide security programs, procedures and processes, exchange information, and assess accomplishments and progress toward continuous improvement in the protection of the sector's critical infrastructure.

Meeting: Three times a year

ONG - SCC Members:

National Grid	Devon Energy	Kinder Morgan	Aleyska-Pipeline
Phillips 66	NatFuel	Sempra Energy	Duke Energy
Anadarko Petroleum Corporation	British Petroleum	BHP Billiton Petroleum	Colonial Pipeline
AGA/Exelon	Marathon Petroleum Company	GPA Global	Trade Associations: American Exploration & Production Council
American Fuel & Petrochemical Manufacturers	American Gas Association	American Petroleum Institute	American Public Gas Association
Association of Oil Pipe Lines	Energy Security Council	Gas Processors Association	National Association of Convenience Stores
National Ocean Industries Association	National Propane Gas Association	Offshore Marine Service Association	Offshore Operators Committee
Petroleum Marketers Association of America	American Exploration & Production Council	Independent Petroleum Association of America	International Liquid Terminals Association
Interstate Natural Gas Association of America	Society of Independent Gas Marketers Association	Texas Oil & Gas Association	U.S. Oil & Gas Association
Western States Petroleum Association			

Energy (Internal)

Energy Council - Agency Authority

The Energy Council serves as a forum for Department-wide consideration of energy issues. The Council will provide advice to, and receive direction from, the Secretary and Deputy Secretary on issues of Department-wide applicability, including but not limited to:

- Strategic directions in energy policy
- Department-wide energy RDD&D portfolio
- Coordination of strategies to address issues that may have cross-Departmental implications, including development of energy markets and business models
- State, local, and tribal engagement and energy policy development
- Geopolitics of energy and the implications for the Department
- Energy infrastructure, security, and resilience

Meeting: Monthly

Council Members:

Secretary	Deputy Secretary	Under Secretary for Science and Energy	Under Secretary for Management and Performance
Assistant Secretary for Fossil Energy	Assistant Secretary for Nuclear Energy	Assistant Secretary for Energy Efficiency and Renewable Energy	Assistant Secretary for Electricity Delivery and Energy Reliability
Director, Office of Science	Assistant Secretary for International Affairs	Assistant Secretary for Congressional and Intergovernmental Affairs	Principal Deputy Assistant Secretary for Intergovernmental Affairs
Chief Financial Officer	Director of Advanced Research Projects Agency- Energy (ARPA-E)	Director, Office of Energy Policy and Systems Analysis*	Director, Office of Economic Impact and Diversity
Administrator, Energy Information Administration	Executive Director, Loan Programs Office	Advisors to the Secretary (Federal employees)	

Nuclear Policy Council - Agency Authority

The Nuclear Policy Council serves as a forum for Department-wide consideration of cross-cutting nuclear issues. The Council advises, and receives direction from, the Secretary and Deputy Secretary of Energy on key nuclear policy topics that transcend individual DOE program offices. The Council provides a means to address a range of cross-cutting nuclear issues, including nuclear energy, nuclear waste, nuclear proliferation or nuclear terrorism, that the

Secretary or Deputy Secretary have identified as priority matters requiring special attention or coordination.

Meeting: Quarterly

Council Members:

Secretary	Deputy Secretary	Under Secretary for Nuclear Security	Principal Deputy Administrator, NNSA
Under Secretary for Science and Energy	Under Secretary for Management and Performance	Chief of Staff	Associate Deputy Secretary
Senior Advisors	Deputy Under Secretary for Counterterrorism and Counter-proliferation	Deputy Administrator for Nuclear Nonproliferation	Deputy Administrator for Defense Programs
Deputy Administrator for NNSA's Office of Naval Reactors	Associate Administrator for the Office of Emergency Operations	Assistant Secretary for Nuclear Security	Assistant Secretary for International Affairs

Technology Transfer Policy Board - Agency Authority

The Technology Transfer Policy Board assists the Technology Transfer Coordinator and establishes an enduring framework for continuity and uniformity of technology transfer activities throughout the DOE complex. The Board is charged to develop policy recommendations for the Technology Transfer Coordinator and monitor the overall technology transfer activities of the DOE National Laboratories, single purpose research facilities, and other DOE facilities authorized to conduct technology transfer activities. It is noted that the activities of the Coordinator and the Board must comply with applicable provisions of the National Nuclear Security Administration Act.

Meeting: Monthly

Board Members:

Director, Office of Technology Transfer	Office of Science (two representatives)	Office of Energy Efficiency and Renewable Energy (four representatives)	National Nuclear Security Administration (two representatives)
General Counsel (two representatives)	Office of Management	Office of Energy Policy and International Affairs (vacant)	

Emergency Management

Emergency and Incident Management Council (EIMC) - Agency Authority

Established by the EIMC charter and DOE Order 151.1D, *Comprehensive Emergency Management System*, the EIMC provides senior leadership oversight of DOE's emergency management preparations, response, and recovery activities. The Council, chaired by the Deputy Secretary, serves as the primary strategic coordination mechanism for senior Department leadership during significant emergencies that require the coordinated efforts of several DOE sites and programs.

Meeting: Bimonthly

EIMC Members:

Deputy Secretary	Associate Deputy Secretary	S2 Chief of Staff	Senior Advisor to the Office of the Secretary
Under Secretary for Management and Performance	Under Secretary for Science and Energy	NNSA Administrator	Administrator, Energy Information Administration
Assistant Secretary for Congressional and Intergovernmental Affairs	Assistant Secretary for Electricity Delivery and Energy Reliability	Assistant Secretary for Environmental Management	Assistant Secretary for Fossil Energy
Associate Under Secretary for Environment, Health Safety and Security	Chief Information Officer	Chief Human Capital Officer	Director, Office of Intelligence and Counterintelligence
Director, Energy Policy and Systems Analysis	Director, Office of Management	Director, Office of Public Affairs	General Counsel

Emergency Support Function # 12 – Energy Support Agency Working Group – Presidential Authority

Established by Presidential Policy Directive 8, National Response Framework, Federal Interagency Operating Plans. Emergency Support Function (ESF) #12 – Energy is intended to facilitate the restoration of damaged energy systems and components when activated by the Secretary of Homeland Security for incidents requiring a coordinated Federal response. Under Department of Energy (DOE) leadership, ESF #12 is an integral part of the larger DOE responsibility of maintaining continuous and reliable energy supplies for the United States through preventive measures and restoration and recovery actions.

Meeting: Biannual

Working Group Members:

Department of Agriculture	Department of Commerce	Department of Defense	Department of Homeland Security
Department of the Interior	Department of Justice	Department of Labor	Department of State
Department of Transportation	Environmental Protection Agency	Nuclear Regulatory Commission	Power Marketing Administrations
Tennessee Valley Authority			

Human Resources

Executive Resources Board (ERB) – Statutory Authority

Each Federal agency is required by 5 U.S.C. § 3393(b) to establish one or more Executive Resources Boards. By statute, the ERB must conduct the merit staffing process for career entry into the Senior Executive Service (SES). Further, pursuant to 5 CFR 412.104(d), the ERB must approve the development plans for each candidate participating in the agency's SES Candidate Development Program (CDP) and the Presidential Management Fellows (PMF) Program, as well as review and revise the agency's Executive Development Plans (EDPs).

Meeting: Weekly

ERB Members:

Robert Gibbs	Kenneth Venuto	Joseph McBrearty	Dennis Miotla
Frank Lowery	Rebecca Martini	John Bremer	Alison Doone

Performance Review Board (PRB) – Statutory Authority

In accordance with 5 U.S.C. 4314(c), the DOE PRB must review initial performance ratings, performance bonuses, and annual pay increases for all career, non-career, limited term and limited emergency SES members. The purpose of the PRB is to fairly and impartially review the initial performance appraisals, summary ratings, and performance award recommendations. They provide a recommendation to the Deputy Secretary for final approval of the PRB results. Panel members are rotated annually.

Meeting: Annually

PRB Members:

Dennis Miotla	Cyndi Mays	Terri Lee	Kevin Smith
Berta Schreiber	Stan Kaplan	Roxanne Purucker	Peter O'Konski
Charles Durant	Teresa Robbins	Roger Snyder	Johnny Moore
Ken Picha	Amy Grose	Robert Dixon	Teresa Tyner
John Bremer			

Risk, Management and Operations

Credit Review Board- Agency Authority

The CRB ensures full consideration of credit management, debt collection, and policy issues by interested and affected persons inside and outside of DOE. The CRB makes recommendations to the Secretary prior to his granting final approval for any conditional commitment for a loan guarantee or loan, and participates in the oversight of the Loan Program's portfolio.

Meeting: Quarterly

CRB Members:

Deputy Secretary	Chief Financial Officer	Senior Advisor to the Secretary	Deputy Under Secretary for Management and Performance
Under Secretary for Science and Energy	Chief of Staff to the Secretary	Director, Office of Energy Policy and Systems Analysis	General Counsel
Senior Advisor	Loan Program Office		

Cyber Security Council - Agency Authority

DOE's Cyber Council is the principal forum for collaboration and coordination of the activities listed below across the DOE Enterprise, and for consideration of cyber-related issues requiring decision by the Council Chair.

- Implementing a diverse array of cyber measures (to include information and information technology) to support infom1ation sharing (mission enablement) and information safeguarding (mission assurance) across the extended DOE Enterprise, including government-owned, contractor-operated sites and facilities;
- Bolstering the U.S. Government's capabilities to address cyber threats;
- Improving cyber (information sharing and safeguarding) across the electric power subsector and the oil and natural gas subsector; and
- Ensuring a DOE Enterprise-wide coordinated response and reconstitution to malicious cyber activity.

Meeting: Bimonthly

Council Members:

Deputy Secretary	Office of the Chief of Staff	Associate Deputy Secretary	Under Secretary for Management and Performance

Under Secretary for Nuclear Security/ Administrator of the National Nuclear Security Administration	Under Secretary for Science and Energy	Assistant Secretary for Electricity Delivery and Energy Reliability	Chief Information Officer
Director of the Office of Intelligence and Counterintelligence	General Counsel	Director of the Office of Enterprise Assessments	Chief Financial Officer
Administrator from the Power Marketing Administrations (one representative)	Associate Under Secretary for Environment, Health, Safety, and Security, to include representation for the Senior Agency Official for Insider Threat	National Laboratories Directors Committee (NLDC) (one representative)	Laboratory and Production Site Representatives

Directives Review Board (DRB) - Agency Authority

The Directives Review Board advises, as well as concurs, on individual Departmental directives before receiving Operations Committee approval for release for DOE-wide comment and final issuance.

Meeting: Bimonthly

DRB Members:

Director, Office of Management	Office of the Under Secretary for Management and Performance	Office of the Under Secretary for Science and Energy	Office of the Under Secretary for Nuclear Security
Office of Environment, Health, Safety and Security	Office of Environmental Management	Office of General Counsel	Office of Science
Field Management Council (Advisory Member)	National Laboratory Directors Council (Advisory Member)		

DOE Operations Committee - Agency Authority

The DOE Operations Committee meets on a weekly basis to better enable the Department to provide cross-agency operational leadership. The Committee was established to: assure coordination of Department-wide management initiatives at the Deputy Under Secretary level; resolve issues in executive correspondence, Departmental directives, and other cross-departmental materials; and provide operational guidance and direction on other matters as assigned or otherwise required.

Meeting: Weekly

Committee Members:

Deputy Under Secretary for Management and Performance	Deputy Under Secretary for Science and Energy	Principal Deputy Administrator for NNSA	Chief Financial Officer
Chief of Staff Representatives from the Office of the Secretary			

Energy Systems Acquisition Advisory Board (ESAAB) – Agency Authority

Established in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets)* Advises the Secretary, Deputy Secretary as the Chief Executive for Project Management, and Departmental Project Management Executives on enterprise-wide project management policy and issues. Assists the Deputy Secretary on critical decision milestones for major system projects, those that cost $750 million or greater. Reviews all projects that cost $100 million or greater, with a specific focus on those struggling to meet their performance baselines.

Meeting: Quarterly, for all projects $100 million and greater; as needed, for critical decisions on major system projects (>$750 million)

ESAAB Members:

Deputy Secretary	Under Secretary for Management and Performance	Under Secretary for Science and Energy	Under Secretary for Nuclear Security
General Counsel	Chief Financial Officer	Chief Information Officer	Executive Director, Loan Program Office
Director, Office of Project Management Oversight and Assessments	Chair of the Project Management Risk Committee	Other Designations, made by the Secretary or Deputy Secretary	

Enterprise Risk Management Working Group - Agency Authority

The ERM Working Group advises DOE Leadership in the development and communication of a DOE ERM framework to identify and manage risks at the enterprise level across the DOE complex. The ERM Working Group supports the Department's new requirements detailed in OMB Circular A-123, Management's Responsibility for Enterprise Risk Management and Internal Control.

Meeting: Bimonthly

Working Group Members:

Associate Deputy Secretary	Office of the Under Secretary for Management and Performance	Office of the Under Secretary for Science and Energy	Office of the Chief Financial Officer
Office of the Under Secretary for Nuclear Security/National Nuclear Security Administration			

Field Management Council (FMC) - Agency Authority

The Field Management Council (FMC) council provides linkage between Program elements, facilitates communication and learning between organizations and operational elements, and acts as a conduit for headquarters decision makers to field leadership perspectives.

Meeting: Biannually

FMC Members:
The Field Management Council (FMC) is the full complement of Senior Executive Field Managers from all program offices with responsibility to execute the Department's mission.

Information Management Governance Board (IMGB) - Agency Authority

The DOE Information Management Governance Board (IMGB) serves as a forum for collaboration, development, coordination, and execution of efforts relating to DOE enterprise cyber activities and issues. The IMGB also promotes responsible information sharing and information safeguarding, in support of the DOE Cyber Council.

Meeting: Every three weeks

Council Members:

Office of the Chief Information Officer	Energy Information Administration	Office of Intelligence and Counterintelligence	Office of the Under Secretary for Nuclear Security/National Nuclear Security Administration (two representatives)

Office of the Under Secretary for Management and Performance (two representatives)	Office of the Under Secretary for Science and Energy (two representatives, including one from the Office of Electricity Delivery and Energy Reliability)	Power Marketing Administrations (one representative)	Policy Advisor, Office of the Secretary
Office of the General Counsel	Office of the Chief Financial Officer	Senior Procurement Executive	Office of Congressional and Intergovernmental Affairs
Office of Enterprise Assessments	Office of Energy Policy and Systems Analysis	Laboratory and Production Site Representatives (up to four, as identified by the National Laboratory CIOs and Production Site CIOs)	

Job Strategy Council - Agency Authority

The Department of Energy's Jobs Strategy Council is a crosscutting initiative that integrates the research, technology, and economic resources of the Department to respond to the economic and workforce development needs of the energy industry.

Meeting: Bimonthly

Council Members:

Under Secretary for Management and Performance	Under Secretary for Science and Energy	Under Secretary for Nuclear Security	Assistant Secretary for Congressional and Intergovernmental Affairs
Assistant Secretary for Electricity Delivery and Energy Reliability	Assistant Secretary for Energy Efficiency and Renewable Energy	Assistant Secretary for Fossil Energy	Assistant Secretary for Nuclear Energy
Director of the Office of Science	Administrator of the Energy Information Administration	Chief Human Capital Officer	Executive Director of the Loan Program Office

Director of the Office of Economic Impact and Diversity	Director of the Office of Energy Policy and Systems Analysis	Director of Indian Energy Policy and Programs	Director of the Office of Small and Disadvantaged Business Utilization
A representative from the National Laboratory Chief Operating Officers' Group	Representatives from National Renewable Energy Laboratory and Oak Ridge National Laboratory	Federal representatives from the Clean Energy Manufacturing Initiative and the National Network for Manufacturing Innovation	A representative from each of the Power Marketing Administrations
Deputy Secretary (as needed)	Chief of Staff (as needed)	Senior Advisors in the Office of the Secretary (as needed)	Any Departmental office identified by the Secretary (as needed)

Laboratory Operations Board (LOB) - Agency Authority

The objectives of the National Laboratory Operations Board are to strengthen and enhance the partnership between the Department and the National Laboratories, and to improve management and performance in order to more effectively and efficiently execute the missions of the Department and the National Laboratories.

Meeting: Monthly

LOB Members:

Under Secretary for Management and Performance	Director of the LOB	Deputy Under Secretary for Science and Energy	Chief Operating Officer (or as designated by the Administrator), National Nuclear Security Administration
Associate Administrator for Safety, Infrastructure, and Operations, National Nuclear Security Administration	Chief Operating Officer (or as designated by the Assistant Secretary), Office of Energy Efficiency and Renewable Energy	Chief Operating Officer (or as designated by the Assistant Secretary), Office of Environmental Management	Chief Operating Officer (or as designated by the Assistant Secretary for Fossil Energy), National Energy Technology Laboratory
Chief Operating Officer (or as	Chief Operating Officer (or as	Four representatives from the National	Associate Under Secretary (or as

designated by the Assistant Secretary), Office of Nuclear Energy	designated by the Director), Office of Science	Laboratories, comprised of two from the National Laboratory Chief Operating Officers (COO) group and two from the National Laboratory Chief Research Officer (CRO) group	designated by the Associate Under Secretary), Office of Environment, Health, Safety, and Security
Director, Office of Management	Chair of the Field Management Council	One contractor representative from a Management and Operating contractor	

National Laboratory Directors Council (NLDC) - Agency Authority

The National Laboratory Directors' Council (NLDC) advances the effectiveness of the Department of Energy (DOE) National Laboratory Complex in meeting the collective National missions and provides an interface to DOE organizations on issues and concerns of common interest, both strategic and operational. The Council also functions as a forum for information exchange, consensus building, and coordination of matters that affect the NLDC members. The primary NLDC relationship with the DOE shall be through the Secretary of Energy.

Meeting: Quarterly

NLDC Members:
The Council comprises the Laboratory Directors for each of the seventeen DOE's National Laboratories.

National Laboratory Policy Council (LPC) - Agency Authority

The Laboratory Policy Council (LPC) serves as a forum for the National Laboratories to provide strategic advice and assistm1ce to the Secretary in the Department's policy and program planning processes m1d for the Department to provide strategic guidance on National Laboratory activities in support of Departmental missions. The LPC provides leadership and enterprise-wide coordination, promotes the DOE National Laboratories as a system, and ensures that Laboratory stewardship responsibilities are founded on a trusting partnership between Federal and Laboratory leadership.

Meeting: Three times a year

LPC Members:

Secretary	Deputy Secretary	Under Secretary for Management and Performance	Under Secretary for Nuclear Security

Under Secretary for Science and Energy	Associate Deputy Secretary	Director, Office of Science	Assistant Secretary for Energy Efficiency and Renewable Energy
Assistant Secretary for Environmental Management	Assistant Secretary for Nuclear Energy	Assistant Secretary for Fossil Energy	Deputy Administrator for Defense Programs
Four National Laboratory Directors (chosen by the NLDC)	Senior Advisors in the Office of the Secretary (as appropriate)	Assistant Secretary for Electricity Delivery and Energy Reliability (as appropriate)	Director of the Office of Energy Policy and Systems Analysis (as appropriate)
Director of the Advances Research Projects Agency – Energy (as appropriate)	Chief Financial Officer (as appropriate)	General Counsel (as appropriate)	Assistant Secretary for Congressional and Intergovernmental Affairs (as appropriate)
Deputy Administrator for Defense Nuclear Nonproliferation (as appropriate)	Director of Intelligence and Counterintelligence (as appropriate)		

Nuclear Safety Committee - Agency Authority

The purpose of the Department of Energy's (DOE) Nuclear Safety Committee is to provide senior management leadership for the development of strategies to address complex-wide issues and policies to enhance the Department's nuclear safety and, as appropriate, provide advice and recommendations to the Secretary and Deputy Secretary on these strategies and policies.

Meeting: Monthly

Committee Members:

Associate Under Secretary for Environment, Health, Safety and Security	Central Technical Authority (CTA)/Chief Nuclear Safety (CNS), Office of Science	CTA/CNS, Office of Nuclear Energy	CTA/CNS, Office of Environmental Management
CTA/Chief of Defense Nuclear Safety, National Nuclear Security Administration	Program Office Manager Responsible for Nuclear Safety (EM, NNSA, NE, and SC)	Director, Office of Nuclear Safety	Director, Office of Health and Safety
Director, National Training Center	Director, Office of Environment, Safety	Director, Office of the Departmental Representative to the	Representative of the Office of General Counsel

	and Health Assessments	Defense Nuclear Facilities Safety Board	
Representative of the Field Managers Council			

Project Management Risk Committee (PMRC) – Agency Authority

Established in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets)* Provides enterprise-wide project management risk assessment and expert advice to the Secretary, Deputy Secretary as the Chief Executive for Project Management, other Departmental Project Management Executives, and the ESAAB. The PMRC provides advice on cost, schedule and technical issues, and associated risks regarding capital asset projects that are $100 million or greater.

Meeting: Biweekly

PMRC Members:

Associate Deputy Secretary	Director, Office of Project Management Oversight and Assessments	Director, Office of Project Assessments, Office of the Under Secretary for Management and Performance	Deputy Assistant Secretary for Acquisition and Project Management, Office of Environmental Management
Director, Office of Project Assessment, Office of Science	Deputy Director for Science Programs, Office of Science	Director, Office of Project Assessment, Office of the Under Secretary for Nuclear Security	Associate Administrator for Acquisition and Project Management, Office of the Under Secretary for Nuclear Security
Chief Operating Officer or Chief Engineer, Director of Technical and Project Management, Loan Program Office			

Risk and Portfolio Monitoring Committee (RPMC) - Agency Authority

The Risk and Portfolio Monitoring Committee (RPMC) plays a broad role in the oversight of portfolio management, together with the Loan Program Office Director of the Portfolio Management Division (DPMD), to ensure the Executive Director, the CRB, and the Secretary are appropriately informed regarding the portfolio assets as a whole, including significant or material actions or events affecting individual portfolio assets.

Meeting: Biweekly

Committee Members:

Director of Risk Management, Loan Program Office	Office of the Secretary	Office of the Chief Financial Officer	Office of General Counsel
Office of Energy Policy and Systems Analysis			

Safety Culture Improvement Panel (SCIP) - Agency Authority

The purpose of the Department of Energy's Safety Culture Improvement Panel (SCIP) is to:

- Establish a permanent, high-level organization devoted to promoting safety culture;
- Provide cross-organizational leadership focused on continuous safety culture improvement;
- Create an ongoing forum to exchange information and ideas that will establish, monitor, and sustain measures supporting a strong safety culture.

Meeting: Monthly

SCIP Members:

Matt Moury	Geoffrey Beausoleil	Michael Budney	Jennifer Appleton
James Hutton	Steven Davidson	Kelli Markham	Douglas Dearolph
Joseph McBrearty	Rock Aker	Jeffrey Edlund	James Guerry

Security Committee- Agency Authority

The Secretary of Energy established the Security Committee to identify corporate security strategies and guide security policy development. The Security Committee will develop recommendations regarding Department-wide security policies, facilitate active coordination of effective security strategies across the Department, and provide a forum for addressing cross-organizational issues and challenges.

Meeting: Quarterly

Committee Members:

Associate Deputy Secretary	Chief Security Officer, Nuclear Security	Chief Security Officer, Management and Performance	Chief Security Officer, Science and Energy

Associate Under Secretary for Office of Environment, Health, Safety and Security	Director of Intelligence and Counterintelligence	DOE General Counsel	DOE Chief Information Officer
Director, Office of Security	Chief Security and Continuity Officer, Bonneville Power Administration (as appropriate)	Chief Security and Emergency Management Officer, Western Area Power Administration (as appropriate)	Director, Enterprise Assessments (as appropriate)

2. Can you provide a complete list of ARPA-E's projects?

Response: Yes. Attached is a list showing approximately 550 projects. This includes all projects currently active (under contract), alumni (contract completed), and cancelled. Please note that public summaries for some projects are still under development.

Complete Listing of ARPA-E Projects

More information on ARPA-E programs and projects, searchable by lead institution, program, technology category, project status, and state can be found here: Search ARPA-E Projects

ADEPT Agile Delivery of Electrical Power Technology (14)

In today's increasingly electrified world, power conversion--the process of converting electricity between different currents, voltage levels, and frequencies--forms a vital link between the electronic devices we use every day and the sources of power required to run them. The projects that make up ARPA-E's ADEPT program, short for "Agile Delivery of Electrical Power Technology," are paving the way for more energy efficient power conversion and advancing the basic building blocks of power conversion: circuits, transistors, inductors, transformers, and capacitors.

Arkansas Power Electronics International, Inc.

Powerful, Efficient Electric Vehicle Chargers

Program: ADEPT

Project Term: 09/14/2010 to 03/31/2014

Project Status: ALUMNI

Project State: Arkansas

Technical Categories: Electrical Efficiency, Transportatio

Currently, charging the battery of an electric vehicle (EV) is a time-consuming process because chargers can only draw about as much power from the grid as a hair dryer. APEI is developing an EV charger that can draw as much power as a clothes dryer, which would drastically speed up charging time. APEI's charger uses silicon carbide (SiC)-based power transistors. These transistors control the electrical energy flowing through the charger's circuits more effectively and efficiently than traditional transistors made of straight silicon. The SiC-based transistors also require less cooling, enabling APEI to create EV chargers that are 10 times smaller than existing chargers.

Virginia Polytechnic Institute and State University

Integrated Power Adapter

Program: ADEPT

Project Term: 09/01/2010 to 11/30/2013

Project Status: ALUMNI

Project State: Virginia

Technical Categories: Electrical Efficiency

CPES at Virginia Tech is developing an extremely efficient power converter that could be used in power adapters for small, light-weight laptops and other types of mobile electronic devices. Power adapters convert electrical energy into usable power for an electronic device, and they currently waste a lot of energy when they are plugged into an outlet to power up. CPES at Virginia Tech is integrating high-density capacitors, new magnetic materials, high-frequency integrated circuits, and a constant-flux transformer to create its efficient power converter. The high-density capacitors enable the power adapter to store more energy. The new magnetic materials also increase energy storage, and they can be precisely dispensed using a low-cost ink-jet printer which keeps costs down. The high-frequency integrated circuits can handle more power, and they can handle it more efficiently. And, the constant-flux transformer processes a consistent flow of electrical current, which makes the converter more efficient.

Cree, Inc.

Utility-Scale Silicon Carbide Power Transistors

Program: ADEPT

Project Term: 09/01/2010 to 12/31/2014

Project Status: ALUMNI

Project State: North Carolina

Technical Categories: Electrical Efficiency, Grid

Cree is developing silicon carbide (SiC) power transistors that are 50% more energy efficient than traditional transistors. Transistors act like a switch, controlling the electrical energy that flows through an electrical circuit. Most power transistors today use silicon semiconductors to conduct electricity. However, transistors with SiC semiconductors operate at much higher temperatures, as well as higher voltage and power levels than their silicon counterparts. SiC-based transistors are also smaller and require less cooling than those made with traditional silicon power technology. Cree's SiC transistors will enable electrical circuits to handle higher power levels more efficiently, and they will result in much smaller and lighter electrical devices and power converters. Cree, an established leader in SiC technology, has already released a commercially available SiC transistor that can operate at up to 1,200 volts. The company has also demonstrated a utility-scale SiC transistor that operates at up to 15,000 volts.

Transphorm, Inc.

Transistors for Electric Motor Drives

Program: ADEPT

Project Term: 09/01/2010 to 05/28/2013

Project Status: ALUMNI

Project State: California

Technical Categories: Electrical Efficiency

Transphorm is developing transistors with gallium nitride (GaN) semiconductors that could be used to make cost-effective, high-performance power converters for a variety of applications, including electric motor drives which transmit power to a motor. A transistor acts like a switch, controlling the electrical energy that flows around an electrical circuit. Most transistors today use low-cost silicon semiconductors to conduct electrical energy, but silicon transistors don't operate efficiently at high speeds and voltage levels. Transphorm is using GaN as a semiconductor material in its transistors because GaN performs better at higher voltages and frequencies, and it is more energy efficient than straight silicon. However, Transphorm is using inexpensive silicon as a base to help keep costs low. The company is also packaging its transistors with other electrical components that can operate quickly and efficiently at high power levels--increasing the overall efficiency of both the transistor and the entire motor drive.

Case Western Reserve University

Titanium-Alloy Power Capacitor

Program: ADEPT

Project Term: 09/01/2010 to 11/30/2012

Project Status: ALUMNI

Project State: Ohio

Technical Categories: Electrical Efficiency

There is a constant demand for better performing, more compact, lighter-weight, and lower-cost electronic devices. Unfortunately, the materials traditionally used to make components for electronic devices have reached their limits. Case Western is developing capacitors made of new materials that could be used to produce the next generation of compact and efficient high-powered consumer electronics and electronic vehicles. A capacitor is an important component of an electronic device. It stores an electric charge and then discharges it into an electrical circuit in the device. Case Western is creating its capacitors from titanium, an abundant material extracted from ore which can be found in the U.S. Case Western's capacitors store electric charges on the surfaces of films, which are grown on a titanium alloy electrode that is formed as a spinal column with attached branches. The new material and spine design make the capacitor smaller and lighter than traditional capacitors, and they enable the component to store 300% more energy than capacitors of the same weight made of tantalum, the current industry standard. Case Western's titanium-alloy capacitors also spontaneously self-repair, which prolongs their life.

Georgia Tech Research Corporation

Utility-Scale Power Router

Program: ADEPT

Project Term: 09/01/2010 to 01/31/2013

Project Status: ALUMNI

Project State: Georgia

Technical Categories: Electrical Efficiency

Georgia Tech is developing a cost-effective, utility-scale power router that uses an enhanced transformer to more efficiently direct power on the grid. Existing power routing technologies are too expensive for widespread use, but the ability to route grid power to match real-time demand and power outages would significantly reduce energy costs for utilities, municipalities, and consumers. Georgia Tech is adding a power converter to an existing grid transformer to better control power flows at about 1/10th the cost of existing power routing solutions. Transformers convert the high-voltage electricity that is transmitted through the grid into the low-voltage electricity that is used by homes and businesses. The added converter uses fewer steps to convert some types of power and eliminates unnecessary power storage, among other improvements. The enhanced transformer is more efficient, and it would still work even if the converter fails, ensuring grid reliability.

Virginia Polytechnic Institute and State University

Voltage Regulator Chip

Program: ADEPT

Project Term: 09/01/2010 to 07/31/2014

Project Status: ALUMNI

Project State: Virginia

Technical Categories: Electrical Efficiency

CPES at Virginia Tech is finding ways to save real estate on a computer's motherboard that could be used for other critical functions. Every computer processor today contains a voltage regulator that automatically maintains a constant level of electricity entering the device. These regulators contain bulky components and take up about 30% of a computer's motherboard. CPES at Virginia Tech is developing a voltage regulator that uses semiconductors made of gallium nitride on silicon (GaN-on-Si) and high-frequency soft magnetic material. These materials are integrated on a small, 3D chip that can handle the same amount of power as traditional voltage regulators at 1/10 the size and with improved efficiency. The small size also frees up to 90% of the motherboard space occupied by current voltage regulators.

Teledyne Scientific & Imaging, LLC

Chip-Scale Power Conversion for LED Lighting

Program: ADEPT

Project Term: 10/01/2010 to 07/31/2013

Project Status: ALUMNI

Project State: California

Technical Categories: Electrical Efficiency

Teledyne is developing cost-effective power drivers for energy-efficient LED lights that fit on a compact chip. These power drivers are important because they transmit power throughout the LED device. Traditional LED driver components waste energy and don't last as long as the LED itself. They are also large and bulky, so they must be assembled onto a circuit board separately which increases the overall manufacturing cost of the LED light. Teledyne is shrinking the size and improving the efficiency of its LED driver components by using thin layers of an iron magnetic alloy and new gallium nitride on silicon devices. Smaller, more efficient components will enable the drivers to be integrated on a single chip, reducing costs. The new semiconductors in Teledyne's drivers can also handle higher levels of power and last longer without sacrificing efficiency. Initial applications for Teledyne's LED power drivers include refrigerated grocery display cases and retail lighting.

CUNY Energy Institute

Metacapacitors for LED Lighting

Program: ADEPT

Project Term: 09/02/2010 to 02/28/2014

Project Status: ALUMNI

Project State: New York

Technical Categories: Electrical Efficiency

CUNY Energy Institute is developing less expensive, more efficient, smaller, and longer-lasting power converters for energy-efficient LED lights. LEDs produce light more efficiently than incandescent lights and last significantly longer than compact fluorescent bulbs, but they require more sophisticated power converter technology, which increases their cost. LEDs need more sophisticated converters because they require a different type of power (low-voltage direct current, or DC) than what's generally supplied by power outlets. CUNY Energy Institute is developing sophisticated power converters for LEDs that contain capacitors made from new, nanoscale materials. Capacitors are electrical components that are used to store energy. CUNY Energy Institute's unique capacitors are configured with advanced power circuits to more efficiently control and convert power to the LED lighting source. They also eliminate the need for large magnetic components, instead relying on networks of capacitors that can be easily printed on plastic substrate. CUNY Energy Institute's prototype LED power converter already meets DOE's 2020 projections for the energy efficiency of LED power converters.

Massachusetts Institute of Technology

Advanced Power Electronics for LED Drivers

Program: ADEPT

Project Term: 09/01/2010 to 12/31/2013

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Electrical Efficiency

MIT is teaming with Georgia Institute of Technology, Dartmouth College, and the University of Pennsylvania to create more efficient power circuits for energy-efficient light-emitting diodes (LEDs) through advances in 3 related areas. First, the team is using semiconductors made of high-performing gallium nitride grown on a low-cost silicon base (GaN-on-Si). These GaN-on-Si semiconductors conduct electricity more efficiently than traditional silicon semiconductors. Second, the team is developing new magnetic materials and structures to reduce the size and increase the efficiency of an important LED power component, the inductor. This advancement is important because magnetics are the largest and most expensive part of a circuit. Finally, the team is creating an entirely new circuit design to optimize the performance of the new semiconductors and magnetic devices it is using.

HRL Laboratories, LLC

Compact, Interactive Electric Vehicle Charger

Program: ADEPT

Project Term: 10/01/2010 to 06/30/2014

Project Status: ALUMNI

Project State: California

Technical Categories: Electrical Efficiency

HRL Laboratories is using gallium nitride (GaN) semiconductors to create battery chargers for electric vehicles (EVs) that are more compact and efficient than traditional EV chargers. Reducing the size and weight of the battery charger is important because it would help improve the overall performance of the EV. GaN semiconductors process electricity faster than the silicon semiconductors used in most conventional EV battery chargers. These high-speed semiconductors can be paired with lighter-weight electrical circuit components, which helps decrease the overall weight of the EV battery charger. HRL Laboratories is combining the performance advantages of GaN semiconductors with an innovative, interactive battery-to-grid energy distribution design. This design would support 2-way power flow, enabling EV battery chargers to not only draw energy from the power grid, but also store and feed energy back into it.

GeneSiC Semiconductor

Utility-Scale Silicon Carbide Semiconductor

Program: ADEPT

Project Term: 09/01/2010 to 02/28/2013

Project Status: ALUMNI

Project State: Virginia

Technical Categories: Electrical Efficiency

GeneSiC is developing an advanced silicon-carbide (SiC)-based semiconductor called an anode-switched thyristor. This low-cost, compact SiC semiconductor conducts higher levels of electrical energy with better precision than traditional silicon semiconductors. This efficiency will enable a dramatic reduction in the size, weight, and volume of the power converters and the electronic devices they are used in. GeneSiC is developing its SiC-based semiconductor for utility-scale power converters. Traditional silicon semiconductors can't process the high voltages that utility-scale power distribution requires, and they must be stacked in complicated circuits that require bulky insulation and cooling hardware. GeneSiC's semiconductors are well suited for high-power applications like large-scale renewable wind and solar energy installations.

Georgia Tech Research Corporation

Compact, Low-Profile Power Converters

Program: ADEPT

Project Term: 09/01/2010 to 02/28/2014

Project Status: ALUMNI

Project State: Georgia

Technical Categories: Electrical Efficiency, Grid

Georgia Tech is creating compact, low-profile power adapters and power bricks using materials and tools adapted from other industries and from grid-scale power applications. Adapters and bricks convert electrical energy into usable power for many types of electronic devices, including laptop computers and mobile phones. These converters are often called wall warts because they are big, bulky, and sometimes cover up an adjacent wall socket that could be used to power another electronic device. The magnetic components traditionally used to make adapters and bricks have reached their limits; they can't be made any smaller without sacrificing performance. Georgia Tech is taking a cue from grid-scale power converters that use iron alloys as magnetic cores. These low-cost alloys can handle more power than other materials, but the iron must be stacked in insulated plates to maximize energy efficiency. In order to create compact, low-profile power adapters and bricks, these stacked iron plates must be extremely thin--only hundreds of nanometers in thickness, in fact. To make plates this thin, Georgia Tech is using manufacturing tools used in microelectromechanics and other small-scale industries.

General Electric

Scalable Thick-Film Magnetics

Program: ADEPT

Project Term: 01/01/2011 to 07/17/2012

Project Status: CANCELLED

Project State: Connecticut

Technical Categories: Electrical Efficiency

Magnetic components are typically the largest components in a power converter. To date, however, researchers haven't found an effective way to reduce their size without negatively impacting their performance. And, reducing the size of the converter's other components isn't usually an option because shrinking them can also diminish the effectiveness of the magnetic components. GE is developing smaller magnetic components for power converters that maintain high performance levels. The company is building smaller components with magnetic films. These films are created using the condensation of a vaporized form of the magnetic material. It's a purely physical process that involves no chemical reactions, so the film composition is uniform. This process makes it possible to create a millimeter-thick film deposition over a wide surface area fairly quickly, which would save on manufacturing costs. In fact, GE can produce 1-10 millimeter-thick films in hours. The magnetic components that GE is developing for this project could be used in a variety of applications, including solar inverters, electric vehicles, and lighting.

Fusion energy holds the promise of cheap, clean power production, but up to now scientists have been unable to successfully harness fusion as a power source due to complex scientific and technological challenges and the high cost of research. ARPA-E's ALPHA program seeks to create and demonstrate tools to aid in the development of new, lower-cost pathways to fusion power and to enable more rapid progress in fusion research and development.

Lawrence Berkeley National Laboratory

MEMS Based Drivers For Fusion

Program: ALPHA

Project Term: 08/01/2015 to 11/23/2017

Project Status: ACTIVE

Project State: California

Technical Categories: Centralized Generation

Lawrence Berkeley National Laboratory (LBNL), in coordination with Cornell University, will develop a driver for magneto-inertial fusion based on ion beam technology that can be manufactured with low-cost, scalable methods. Ion beams are commonly used in research laboratories and manufacturing, but currently available technology cannot deliver the required beam intensities at low enough cost to drive an economical fusion reactor. LBNL will take advantage of microelectromechanical (MEMS) technology to develop a design consisting of thousands of mini ion "beamlets" densely packed on silicon wafers - up to thousands of beamlets per 4 to 12 inch wafer. Ions will be accelerated using radio-frequency driven accelerators, resulting in extremely high current densities and high-intensity ion beams that can be focused on plasma targets to achieve fusion. The use of MEMS technology enables low-cost batch fabrication, which could reduce the overall cost of a fusion reactor, in addition to enabling drivers that are modular and scalable. If successful, this project will result in an economical and flexible ion beam driver technology for magneto-inertial fusion reactors.

Helion Energy Inc.

Compression of FRC Targets for Fusion

Program: ALPHA

Project Term: 09/30/2015 to 09/29/2018

Project Status: ACTIVE

Project State: Washington

Technical Categories: Centralized Generation

Helion Energy, Inc.'s team will develop a prototype device that will explore a potential low-cost path to fusion for a less expensive, simplified reactor design. In contrast to conventional designs, this prototype will be smaller than a semi-trailer - reducing cost and complexity. The smaller size is achieved by using new techniques to achieve the high temperatures and densities required for fusion. The research team will produce these conditions using field-reversed configuration (FRC) plasmas, a special form of plasma that may offer significant advantages for fusion research. FRC plasmas are movable - they can be produced at one location and then moved into the fusion chamber, which prevents the hot fusion products from damaging the FRC formation hardware. FRC plasmas also have an embedded magnetic field which helps them retain heat. Helion's reactor employs a pulsed heating technique that uses a series of magnetic coils to compress the plasma fuel to very high temperatures and densities. The reactor will also capture and reuse the magnetic energy used to heat and confine the plasma, further increasing efficiency. The smaller size and reduced complexity of the reactor's design will decrease research and development costs and speed up research progress in developing the efficiencies required for fusion power production.

University of Washington

Flow Z-Pinch for Fusion

Program: ALPHA

Project Term: 08/24/2015 to 08/23/2018

Project Status: ACTIVE

Project State: Washington

Technical Categories: Centralized Generation

The University of Washington (UW), along with its partner Lawrence Livermore National Laboratory, will work to mitigate instabilities in the plasma, and thus provide more time to heat and compress it while minimizing energy loss. The team will use the Z-Pinch approach for simultaneously heating, confining, and compressing plasma by applying an intense, pulsed electrical current which generates a magnetic field. While the simplicity of the Z-Pinch is attractive, it has been plagued by plasma instabilities. UW will investigate Z-pinch fusion using sheared-flow stabilized plasmas, meaning that adjacent layers of the plasma move parallel to each other at different speeds. These sheared axial flows have been shown to stabilize Z-pinch instabilities, and the team will investigate whether this will hold true under more extreme conditions using experimental and computational studies. If successful, UW's design would simplify the engineering required for an eventual reactor through its reduced number of components and efficiency. In addition, the design's avoidance of single-use components would enable fusion research to progress faster through more rapid experimentation.

Magneto-Inertial Fusion Technologies, Inc.,

Staged Z-Pinch Target For Fusion

Program: ALPHA

Project Term: 10/01/2015 to 09/30/2018

Project Status: ACTIVE

Project State: California

Technical Categories: Centralized Generation

Magneto-Inertial Fusion Technologies, Inc. (MIFTI) is developing a new version of the Staged Z-Pinch (SZP) fusion concept that reduces instabilities in the fusion plasma, allowing the plasma to persist for longer periods of time. The Z-Pinch is an approach for simultaneously heating, confining, and compressing plasma by applying an intense, pulsed electrical current which generates a magnetic field. While the simplicity of the Z-Pinch is attractive, it has been plagued by plasma instabilities. MIFTI's SZP plasma target consists of two components with different atomic numbers and is specifically configured to reduce instabilities. When the heavier component collapses around the lighter part, a shock front develops that travels faster than instabilities can grow, allowing the plasma to remain stable, long enough for fusion to occur. The approach also allows researchers to perform experiments in rapid succession, since it does not involve single-use components. MIFTI's design simplifies the engineering required for fusion through its efficiency and reduced number of components.

California Institute of Technology

Heating and Compression Mechanisms for Fusion

Program: ALPHA

Project Term: 10/01/2015 to 09/30/2017

Project Status: ACTIVE

Project State: California

Technical Categories: Centralized Generation

California Institute of Technology (Caltech), in coordination with Los Alamos National Laboratory (LANL), will investigate the scaling of adiabatic heating of plasma by propelling magnetized plasma jets into stationary heavy gases and/or metal walls. This is the reverse of the process that would occur in an actual fusion reactor - where a gas or metal liner would compress the plasma - but will provide experimental data to assess the magneto-inertial fusion approach. By using this alternative frame of reference, the researchers will be able to conduct experiments more frequently and at a lower cost because the experimental setup is non-destructive. The team will investigate the jet-target collision using many experiments with a wide range of parameters to determine the actual equation of state relating compression, change in magnetic field, and temperature increase. The experimental work will be supplemented with advanced 3D computer models. If successful, these results will show that compressional heating by a liner is a viable method for increasing temperatures to the levels required for magneto-inertial fusion. The study will also provide critical information on the interactions and limitations for a variety of possible driver and plasma target combinations being developed across the ALPHA program portfolio.

Sandia National Laboratory

Magnetization and Heating Tools for Low-Cost Fusion

Program: ALPHA

Project Term: 08/15/2015 to 11/24/2017

Project Status: ACTIVE

Project State: New Mexico

Technical Categories: Centralized Generation

Sandia National Laboratories will partner with the Laboratory for Laser Energetics at the University of Rochester to investigate the behavior of the magnetized plasma under fusion conditions, using a fusion concept known as Magnetized Liner Inertial Fusion (MagLIF). MagLIF uses lasers to pre-heat a magnetically insulated plasma in a metal liner and then compresses the liner to achieve fusion. The research team will conduct experiments at Sandia's large Z facility as well as Rochester's OMEGA facilities, and will collect key measurements of magnetized plasma fuel including temperature, density, and magnetic field over time. The results will help researchers improve compression and heating performance. By using the smaller OMEGA facility, researchers will be able to conduct experiments more rapidly, speeding the learning process and validating the MagLIF approach. Sandia's team will also use their experimental results to validate and expand a suite of simulation and numerical design tools to improve future fusion energy applications that employ magnetized inertial fusion concepts. This project will help accelerate the development of the MagLIF concept, and assist with the continued development of intermediate density approaches across the ALPHA program.

Los Alamos National Laboratory

Plasma Liners For Fusion

Program: ALPHA

Project Term: 08/12/2015 to 08/11/2018

Project Status: ACTIVE

Project State: New Mexico

Technical Categories: Centralized Generation

Los Alamos National Laboratory, along with HyperV Technologies and other partners, will design and build a new driver technology that is non-destructive, allowing for more rapid experimentation and progress toward economical fusion power. The team will use a spherical array of plasma guns to produce supersonic jets that merge to create an imploding plasma liner. Because the guns are located several meters away from the fusion burn region (i.e., they constitute a "standoff driver"), the reactor components should not be damaged by repeated experiments. This will allow the team to perform more rapid experimentation, allowing them to better understand the behavior of plasma liners as they implode. If successful, the project will demonstrate the validity of this driver design, optimize the precision and performance of the plasma guns, and obtain experimental data on ram-pressure scaling and liner uniformity critical to progress toward an economical fusion reactor.

NumerEx, LLC

Stabilized Liner Compressor For Low-Cost Fusion

Program: ALPHA

Project Term: 10/01/2015 to 09/30/2018

Project Status: ACTIVE

Project State: New Mexico

Technical Categories: Centralized Generation

NumerEx, LLC, teamed with the National High Magnetic Field Laboratory in Los Alamos, NM, will develop a Stabilized Liner Compressor (SLC) which uses a liquid metal liner for non-destructive experimentation and operation, meaning the liner implosion is quickly repeatable. The SLC uses a rotating chamber, in which liquid metal is formed into a hollow cylinder. The liquid is pushed by pistons driven by high-pressure gas, collapsing the inner surface around a target on the axis. The rotation of the liquid liner avoids instabilities that would otherwise occur during compression of the plasma. After each experiment, the liquid liner can flow back to its original position for subsequent implosion. In the NumerEx team's conceptual design for a power plant, the liquid liner acts as a blanket absorbing radiation from fusion reactions, reducing damage to the reactor hardware and creating fusion fuel for future reactor operation. Additionally, energy from the recoil of the liner and piston can be captured and reused, making the power plant design more efficient.

Swarthmore College

[Plasma Accelerator on the SSX]

Program: ALPHA

Project Term: 09/28/2015 to 09/27/2018

Project Status: ACTIVE

Project State: Pennsylvania

Technical Categories: Centralized Generation

Swarthmore College, along with its partner Bryn Mawr College, will investigate a new kind of plasma fusion target that may offer improved stability at low cost and relatively low energy input. The research team will design and develop new modules that accelerate and evolve plasmas to create elongated structures known as Taylor states, which have helical magnetic field lines resembling a rope. These Taylor state structures exhibit interesting and potentially very beneficial properties upon compression, and could be used as a fusion target if they are able to maintain their temperatures and stability long enough to be compressed to fusion conditions. The new plasma-forming modules will be tested using the team's existing Swarthmore Spheromak Experiment device (SSX), which has an advanced diagnostic suite and the capability to perform 100 experiments per day. This ability will enable rapid progress in understanding the behavior of these plasma plumes and illuminate their potential for use as new targets in the pursuit of fusion reactors.

AMPED Advanced Management and Protection of Energy Storage Devices (14)

The projects that comprise ARPA-E's AMPED Program, short for "Advanced Management and Protection of Energy Storage Devices," seek to develop advanced sensing, control, and power management technologies that redefine the way we think about battery management. Energy storage can significantly improve U.S. energy independence, efficiency, and security by enabling a new generation of electric vehicles. While rapid progress is being made in new battery materials and storage technologies, few innovations have emerged in the management of advanced battery systems. AMPED aims to unlock enormous untapped potential in the performance, safety, and lifetime of today's commercial battery systems exclusively through system-level innovations, and is thus distinct from existing efforts to enhance underlying battery materials and architectures.

Palo Alto Research Center

[Embedded Fiber Optic Sensing System for Battery Packs]

Program: AMPED

Project Term: 10/01/2012 to 03/06/2017

Project Status: ACTIVE

Project State: California

Technical Categories: Storage, Transportation Storage

PARC is developing new fiber optic sensors that would be embedded into batteries to monitor and measure key internal parameters during charge and discharge cycles. Two significant problems with today's best batteries are their lack of internal monitoring capabilities and their design oversizing. The lack of monitoring interferes with the ability to identify and manage performance or safety issues as they arise, which are presently managed by very conservative design oversizing and protection approaches that result in cost inefficiencies. PARC's design combines low-cost, embedded optical battery sensors and smart algorithms to overcome challenges faced by today's best battery management systems. These advanced fiber optic sensing technologies have the potential to dramatically improve the safety, performance, and life-time of energy storage systems.

Utah State University

[Dynamic Cell-Level Control for Battery Packs]

Program: AMPED

Project Term: 01/01/2013 to 03/06/2017

Project Status: ACTIVE

Project State: Utah

Technical Categories: Storage, Transportation Storage

USU is developing electronic hardware and control software to create an advanced battery management system that actively maximizes the performance of each cell in a battery pack. No two battery cells are alike--they differ over their life-times in terms of charge and discharge rates, capacity, and temperature characteristics, among other things. Traditionally, these issues have been managed by matching similarly performing cells at the factory level and conservative design and operation of battery packs, but this is an incomplete solution, leading to costly batching of cells and overdesign of battery packs. USU's flexible, modular, cost-effective design would represent a dramatic departure from today's systems, offering dynamic control at the cell-level to their physical limits and side stepping existing issues regarding the mismatch and uncertainty of battery cells throughout their useful life.

General Electric

[Thin-Film Temperature Sensors for Batteries]()

Program: AMPED

Project Term: 01/01/2013 to 12/31/2016

Project Status: ACTIVE

Project State: Connecticut

Technical Categories: Storage, Transportation Storage

GE is developing low-cost, thin-film sensors that enable real-time mapping of temperature and surface pressure for each cell within a battery pack, which could help predict how and when batteries begin to fail. The thermal sensors within today's best battery packs are thick, expensive, and incapable of precisely assessing important factors like temperature and pressure within their cells. In comparison to today's best systems, GE's design would provide temperature and pressure measurements using smaller, more affordable sensors than those used in today's measurement systems. Ultimately, GE's sensors could dramatically improve the thermal mapping and pressure measurement capabilities of battery management systems, allowing for better prediction of potential battery failures.

Robert Bosch, LLC

[Battery Management and Control Software]()

Program: AMPED

Project Term: 01/01/2013 to 03/06/2017

Project Status: ACTIVE

Project State: Michigan

Technical Categories: Storage, Transportation Storage

Bosch is developing battery monitoring and control software to improve the capacity, safety, and charge rate of electric vehicle batteries. Conventional methods for preventing premature aging and failures in electric vehicle batteries involve expensive and heavy overdesign of the battery and tend to result in inefficient use of available battery capacity. Bosch would increase usable capacity and enhance charging rates by improving the ability to estimate battery health in real-time, to predict and manage the impact of charge and discharge cycles on battery health, and to minimize battery degradation.

Southwest Research Institute

[Sensor Technology for Lithium-Ion Batteries]()

Program: AMPED

Project Term: 10/01/2012 to 02/15/2015

Project Status: ALUMNI

Project State: Texas

Technical Categories: Storage, Transportation Storage

SwRI is developing a battery management system to track the performance characteristics of lithium-ion batteries during charge and discharge cycles to help analyze battery capacity and health. No two battery cells are alike--they differ over their life-times in terms of charge and discharge rates, capacity, and temperature characteristics, among other things. In SwRI's design, a number of strain gauges would be strategically placed on the cells to monitor their state of charges and overall health during operation. This could help reduce the risk of batteries being over-charged and over-discharged. This novel sensing technique should allow the battery to operate within safe limits and prolong its cycle life. SwRI is working to develop complex algorithms and advanced circuitry to help demonstrate the potential of these sensing technologies at the battery-pack level.

Pennsylvania State University

Reconfigurable Battery Packs

Program: AMPED

Project Term: 01/01/2013 to 03/31/2016

Project Status: ALUMNI

Project State: Pennsylvania

Technical Categories: Storage, Transportation Storage

Penn State is developing an innovative, reconfigurable design for electric vehicle battery packs that can re-route power in real time between individual cells. Much like how most cars carry a spare tire in the event of a blowout, today's battery packs contain extra capacity to continue supplying power, managing current, and maintaining capacity as cells age and degrade. Some batteries carry more than 4 times the capacity needed to maintain operation, or the equivalent of mounting 16 tires on a vehicle in the event that one tire goes flat. This overdesign is expensive and inefficient. Penn State's design involves unique methods of electrical reconfigurability to enable the battery pack to switch out cells as they age and weaken. The system would also contain control hardware elements to monitor and manage power across cells, identify damaged cells, and signal the need to switch them out of the circuit.

Ford Motor Company

Ultra-Precise Battery Tester

Program: AMPED

Project Term: 01/01/2013 to 03/31/2016

Project Status: ALUMNI

Project State: Michigan

Technical Categories: Storage, Transportation Storage

Ford is developing a commercially viable battery tester with measurement precision that is significantly better than today's best battery testers. Improvements in the predictive ability of battery testers would enable significant reductions in the time and expense involved in electric vehicle technology validation. Unfortunately, the instrumental precision required to reliably predict performance of batteries after thousands of charge and discharge cycles does not exist in today's commercial systems. Ford's design would dramatically improve the precision of electric vehicle battery testing equipment, which would reduce the time and expense required in the research, development, and qualification testing of new automotive and stationary batteries.

Det Norske Veritas (U.S.A)

Gas-Based Battery Monitoring System

Program: AMPED

Project Term: 10/01/2012 to 04/01/2015

Project Status: ALUMNI

Project State: Texas

Technical Categories: Storage, Transportation Storage

DNV KEMA is testing a new gas monitoring system developed by NexTech Materials to provide early warning signals that a battery is operating under stressful conditions and at risk of premature failure. As batteries degrade, they emit low level quantities of gas that can be measured over the course of a battery's life-time. DNV KEMA is working with NexTech to develop technology to accurately measure these gas emissions. By taking accurate stock of gas emissions within the battery pack, the monitoring method could help battery management systems predict when a battery is likely to fail. Advanced prediction models could work alongside more traditional models to optimize the performance of electrical energy storage systems going forward. In the final phase of the project, DNV KEMA will build a demonstration in a community energy storage system with Beckett Energy Systems.

Battelle Memorial Institute

[Optical Fault Sensors for Lithium-Ion Batteries]

Program: AMPED

Project Term: 11/01/2012 to 09/30/2014

Project Status: ALUMNI

Project State: Ohio

Technical Categories: Storage, Transportation Storage

Battelle is developing an optical sensor to monitor the internal environment of lithium-ion (Li-Ion) batteries in real-time. Over time, crystalline structures known as dendrites can form within batteries and cause a short circuiting of the battery's electrodes. Because faults can originate in even the tiniest places within a battery, they are hard to detect with traditional sensors. Battelle is exploring a new, transformational method for continuous monitoring of operating Li-Ion batteries. Their optical sensors detect internal faults well before they can lead to battery failures or safety problems. The Battelle team will modify a conventional battery component to scan the cell's interior, watching for internal faults to develop and alerting the battery management system to take corrective action before a hazardous condition occurs.

Oak Ridge National Laboratory

[Temperature-Regulated Batteries]

Program: AMPED

Project Term: 10/01/2012 to 02/15/2015

Project Status: ALUMNI

Project State: Tennessee

Technical Categories: Storage, Transportation Storage

ORNL is developing an innovative battery design to more effectively regulate destructive isolated hot-spots that develop within a battery during use and eventually lead to degradation of the cells. Today's batteries are not fully equipped to monitor and regulate internal temperatures, which can negatively impact battery performance, life-time, and safety. ORNL's design would integrate efficient temperature control at each layer inside lithium ion (Li-Ion) battery cells. In addition to monitoring temperatures, the design would provide active cooling and temperature control deep within the cell, which would represent a dramatic improvement over today's systems, which tend to cool only the surface of the cells. The elimination of cell surface cooling and achievement of internal temperature regulation would have significant impact on battery performance, life-time, and safety.

University of Washington

[Optimal Battery Management System]

Program: AMPED

Project Term: 01/01/2013 to 06/30/2016

Project Status: ALUMNI

Project State: Washington

Technical Categories: Storage, Transportation Storage

University of Washington (UW) is developing a predictive battery management system that uses innovative modeling software to manage how batteries are charged and discharged, helping to optimize battery use. A significant problem with today's battery packs is their lack of internal monitoring capabilities, which interferes with our ability to identify and manage performance issues as they arise. UW's system would predict the physical states internal to batteries quickly and accurately enough for the data to be used in making decisions about how to control the battery to optimize its output and efficiency in real time. UW's models could be able to predict temperature, remaining energy capacity, and progress of unwanted reactions that reduce the battery lifetime.

Lawrence Livermore National Laboratory

Wireless Sensor System for Battery Packs

Program: AMPED

Project Term: 10/01/2012 to 09/30/2015

Project Status: ALUMNI

Project State: California

Technical Categories: Storage, Transportation Storage

LLNL is developing a wireless sensor system to improve the safety and reliability of lithium-ion (Li-Ion) battery systems by monitoring key operating parameters of Li-Ion cells and battery packs. This system can be used to control battery operation and provide early indicators of battery failure. LLNL's design will monitor every cell within a large Li-Ion battery pack without the need for large bundles of cables to carry sensor signals to the battery management system. This wireless sensor network will dramatically reduce system cost, improve operational performance, and detect battery pack failures in real time, enabling a path to cheaper, better, and safer large-scale batteries.

Eaton Corporation

Advanced Battery Management for Hybrid Vehicles

Program: AMPED

Project Term: 01/01/2013 to 03/31/2016

Project Status: ALUMNI

Project State: Ohio

Technical Categories: Storage, Transportation Storage

Eaton is developing advanced battery and vehicle systems models that will enable fast, accurate estimation of battery health and remaining life. The batteries used in hybrid vehicles are highly complex and require advanced management systems to maximize their performance. Eaton's battery models will be coupled with hybrid powertrain control and power management systems of the vehicle enabling a broader, more comprehensive vehicle management system for better optimization of battery life and fuel economy. Their design would reduce the sticker price of commercial hybrid vehicles, making them cost-competitive with non-hybrid vehicles.

Gayle Technologies, Inc.

Laser-Guided, Ultrasonic Battery Monitoring

Program: AMPED

Project Term: 10/01/2012 to 12/31/2014

Project Status: CANCELLED

Project State: Tennessee

Technical Categories: Storage, Transportation Storage

Gayle is developing a laser-guided, ultrasonic electric vehicle battery inspection system that would help gather precise diagnostic data on battery performance. The batteries used in hybrid vehicles are highly complex, requiring advanced management systems to maximize their performance. Gayle's laser-guided, ultrasonic system would allow for diagnosis of various aspects of the battery system, including inspection for defects during manufacturing and assembly, battery state-of-health, and flaws that develop from mechanical or chemical issues with the battery system during use. Because of its non-invasive nature, relatively low cost, and potential for yielding broad information content, this innovative technology could increase productivity in battery manufacturing and better monitor battery conditions during use or service.

ARID Advanced Research In Dry cooling (14)

ARPA-E's Advanced Research In Dry cooling (ARID) program comprises projects that are aimed at maintaining the efficiency of U.S. electric power generation, which otherwise could suffer due to regional water shortages. To achieve this objective, ARID project teams will create novel air-cooled heat exchangers, supplemental cooling systems, and/or cool-storage systems that can cost-effectively and efficiently dissipate, or reject, waste heat with no net water consumption. Project teams will design kilowatt-scale testing prototypes to ensure the technologies can scale up to the megawatt-cooling capacities of real systems without significant performance loss. If successful, these dry-cooling technologies will significantly reduce water use at power plants without sacrificing efficiency and with minimal additional costs.

University of Cincinnati

Air-Cooled Condenser and Storage System

Program: ARID

Project Term: 09/08/2015 to 09/07/2018

Project Status: ACTIVE

Project State: Ohio

Technical Categories: Resource Efficiency

University of Cincinnati (UC) researchers will develop a dry-cooling system, featuring an enhanced air-cooled condenser and a novel daytime peak-load shifting system (PLSS) that will enable dry cooling for power plants even during hot days. The team will transform a conventional air-cooled condenser by incorporating flow-modulating surfaces and modifying the tubular geometry of the system, both of which will reduce heat transfer resistance and increase the thermal surface area. Whenever the air temperature becomes too high for the air-cooled heat exchanger to be effective, the PLSS will cool the air inlet temperature back down to acceptable temperatures. This inlet air-cooler technology removes heat from the incoming air and stores it in a thermal energy storage (TES) system that incorporates phase-change materials, which can store and release heat over a range of temperatures. During periods when the ambient air is cooler, the TES will release the stored heat to the atmosphere. Together, the combined innovations could quadruple the condenser's coefficient of performance, while the system's compact design will result in a smaller footprint than other air-cooled designs.

Electric Power Research Institute, Inc. (EPRI)

Enhanced Air-Cooled Heat Exchanger

Program: ARID

Project Term: 08/19/2015 to 11/18/2018

Project Status: ACTIVE

Project State: California

Technical Categories: Resource Efficiency

The Electric Power Research Institute (EPRI) and its partners will design, fabricate, and demonstrate an indirect dry-cooling system that features a rotating mesh heat exchanger with encapsulated phase-change materials (PCMs) such as paraffin, which can absorb and reject heat efficiently. The novel system can be used downstream from a water-cooled steam surface condenser to cool water to a temperature near ambient air temperature, eliminating the need for a cooling tower. The team's design capitalizes on the high latent heat of the solid-to-liquid transition in the PCMs to provide an extremely effective way to lower the temperature of hot water exiting the condenser. The encapsulated PCMs are embedded in polymer tubes that form a porous, mesh-like structure. These modules are then mounted on a rotating system that continuously circulates the encapsulated PCMs from the hot water - where they absorb heat - into a dry section where ambient air passes by the encapsulated PCMs, causing the PCMs to solidify and reject heat to the atmosphere. The multidisciplinary team includes leading industry and academic partners that will provide technical and market assistance, and help build and test a 50 kWth prototype to demonstrate the technology's commercial viability.

University of Maryland

Advanced Absorption Cooling

Program: ARID

Project Term: 09/01/2015 to 08/31/2018

Project Status: ACTIVE

Project State: Maryland

Technical Categories: Resource Efficiency

The University of Maryland (UMD) and its partners will utilize a novel microemulsion absorbent, recently developed by UMD researchers, for use in an absorption cooling system that can provide supplemental dry cooling for power plants. These unique absorbents require much less heat to drive the process than conventional absorption materials. To remove heat and cool condenser water, microemulsion absorbents take in water vapor (refrigerant) and release the water as liquid during desorption without vaporization or boiling. UMD's technology will use waste heat from the power plant's flue gas to drive the cooling system, eliminating the need for an additional power source. The design will improve upon the efficiency of commercially available chillers by 300%, even though the cost and size of UMD's technology is smaller. The indirect, absorption cooling system will lower condenser water temperatures to below the ambient temperature, which will ensure the efficiency of power plant electricity production.

SRI International

Radiative Film for Supplemental Cooling

Program: ARID

Project Term: 08/05/2015 to 03/06/2017

Project Status: ACTIVE

Project State: California

Technical Categories: Resource Efficiency

SRI International (SRI) and PPG Industries, Inc. are integrating SRI's proprietary Spectrally Tuned All-Polymer Technology for Inducing Cooling (STATIC) technology into a novel structure for use as a radiative cooling system that can provide supplemental cooling for power plant water during the daytime or nighttime. The two-layer polymer structure covers a pool holding power plant condenser discharge water. The cover prevents sunlight from penetrating it and warming the water, while allowing thermal energy to radiate to the sky, even during the day. The STATIC structure provides an insulating air gap to prevent conductive and convective heating, and both layers work in concert to reject solar energy. Specifically, the bottom layer acts as an emitter at the water temperature and radiates heat to the sky, while the top layer and key component, produced using STATIC technology, enables transmittance of the thermal radiation. The cooling power can achieve greater than 100 W/m2 without evaporation. All materials are inexpensive and amenable to scalable manufacturing techniques, which could lower the cost of the system.

University of Wisconsin

Advanced Heat Exchangers

Program: ARID

Project Term: 10/01/2015 to 03/31/2017

Project Status: ACTIVE

Project State: Wisconsin

Technical Categories: Resource Efficiency

The University of Wisconsin and its partner Oak Ridge National Laboratory will develop enabling technologies for low-cost, high-performance air-cooled heat exchangers. The objective is to create an optimization algorithm in order to identify and design a novel heat exchanger topology with very high heat transfer performance. The team also plans to develop a high-thermal conductivity polymer composite filament that can be used in additive manufacturing (3D printing) to produce the high-performance heat exchanger design. Due to the design freedom enabled by additive manufacturing, the team plans to develop 3D heat exchanger geometries that optimize heat transfer and decrease the total footprint required for an air-cooled system. Both of these innovations could enhance air-side heat transfer and improve the efficiency and cost of heat exchangers.

University of Maryland

Advanced Heat Exchangers

Program: ARID

Project Term: 09/01/2015 to 08/31/2018
Project Status: ACTIVE
Project State: Maryland
Technical Categories: Resource Efficiency

The University of Maryland (UMD) and its partners will utilize UMD's expertise in additive manufacturing (3D printing) and thermal engineering to develop novel, polymer-based, air-cooled heat exchangers for use in indirect dry-cooling systems. The innovation leverages UMD's proprietary, cross media heat exchanger concept in which a low-cost, high-conductivity medium, such as aluminum, is encapsulated as a fiber in a polymeric material to facilitate more effective heat dissipation. To realize the innovative heat exchanger design, the team will develop an advanced, multi-head, composite 3D printer. The heat exchanger modules will be arranged in uniform rows with large spacing between the rows, which optimizes heat transfer while allowing for easier cleaning and maintenance. In addition to the system's advanced cooling capacities, the heat exchangers will also be low-cost, low-weight, and resistant to corrosion. Ideally, UMD's technology will be used in conjunction with a direct contact steam condenser in order to provide power plant cooling with performance comparable to evaporative, or wet-cooling, systems. UMD estimates that additive manufacturing could enable transformational heat exchanger designs with high performance at low cost, including the potential for onsite manufacturing of the heat exchanger, which could save additional transportation and installation costs.

Palo Alto Research Center

Radiative Film for Supplemental Cooling

Program: ARID
Project Term: 08/06/2015 to 03/06/2017
Project Status: ACTIVE
Project State: California
Technical Categories: Resource Efficiency

PARC, working with SPX Cooling Technologies, is developing a low-cost, passive radiative cooling panel for supplemental dry cooling at power plants. PARC's envisioned end product is a cooling module, consisting of multiple radiative cooling panels tiled over large, enclosed water channels that carry water from an initial cooling system, such as a dry-cooling tower. The cooling panel consists of a two-layer structure in which a reflective film sits atop a unique metamaterial-based emitter. In this architecture, the top layer completely reflects sunlight while the bottom layer effectively emits infrared radiation through a spectral window in the earth's atmosphere. This combination enables radiative cooling of the water even in full illumination by the sun. The cooling panel will be made using a lithography-free process compatible with roll-to-roll fabrication. In a large-scale system, the water temperature at the outlet of the cooling module is expected to be 8oC cooler than the temperature of the water at the inlet, which will result in a 3% efficiency gain for the power plant.

General Electric

Absorption Heat Pump

Program: ARID
Project Term: 09/01/2015 to 03/02/2017
Project Status: ACTIVE
Project State: Connecticut
Technical Categories: Resource Efficiency

GE will design, manufacture, and test an absorption heat pump that can be used for supplemental dry cooling at thermoelectric power plants. The team's project features a novel, absorbent-enabled regenerator that doubles the coefficient of performance of conventional absorption heat pumps. The new absorbents demonstrate greater hygroscopic potential, or the ability to prevent evaporation. To remove heat and cool condenser water, these absorbents take in water vapor (refrigerant) and release the water as liquid during desorption without vaporization or boiling. GE's technology will use waste heat from the power plant's flue gas to drive the cooling system, eliminating the need for an additional power source. GE estimates the system will cost half that of conventional absorption heat pumps.

University of Colorado, Boulder

[Radiative Cooling and Cold Storage]

Program: ARID

Project Term: 07/31/2015 to 07/30/2018

Project Status: ACTIVE

Project State: Colorado

Technical Categories: Resource Efficiency

Researchers from the University of Colorado at Boulder (CU-Boulder) will develop Radicold, a radiative cooling and cold water storage system to enable supplemental cooling for thermoelectric power plants. In the Radicold system, condenser water circulates through a series of pipes and passes under a number of cooling modules before it is sent to the central water storage unit. Each cooling module consists of a novel radiative-cooling surface integrated on top of a thermosiphon, thereby simultaneously cooling the water and eliminating the need for a pump to circulate it. The microstructured polymer film discharges heat from the water by radiating in the infrared through the Earth's atmosphere into the heat sink of cold, deep space. Below the film, a metal film reflects all incoming sunlight. This results in cooling with a heat flux of more than 100 W/m2 during both day and nighttime operation. CU-Boulder will use roll-to-roll manufacturing, a low-cost manufacturing technique that is capable of high-volume production, to fabricate the microstructured RadiCold film.

Advanced Cooling Technologies, Inc.

[Cool Storage for Supplemental Cooling]

Program: ARID

Project Term: 08/15/2015 to 08/14/2018

Project Status: ACTIVE

Project State: Pennsylvania

Technical Categories: Resource Efficiency

Advanced Cooling Technologies, Inc. (ACT) will work with Lehigh University, the University of Missouri, and Evapco, Inc. to design and build a novel cool storage system that will increase the efficiency of a plant's dry-cooling system. During the day, the system will transfer waste heat from the plant's heated condenser water via an array of heat pipes to a cool storage unit containing a phase-change material (PCM). The planned PCMs are salt hydrates that can be tailored to store and release large amounts of thermal energy, offering a way to store waste heat until it can be efficiently rejected. When temperatures are lower, such as at night, a novel system of self-agitated fins will be used to promote mixing and enhance heat transfer to air. The effectiveness of the fins will allow a reduction in the size of the storage media and the power required to operate it, both of which could lower costs for the system. Because the PCM materials are salts, their storage temperature can be tuned by changing the water content. Therefore, the storage system can potentially be customized to provide supplemental dry cooling for different climates, including regions with high ambient temperatures, such as the southwestern United States.

Colorado State University

[Ultra-Efficient Turbo-Compression Cooling]

Program: ARID

Project Term: 11/10/2015 to 11/09/2018

Project Status: ACTIVE

Project State: Colorado

Technical Categories: Resource Efficiency

Colorado State University (CSU) and its partners, Modine and Barber-Nichols, will develop a thermally powered supplemental cooling system for thermoelectric power plants that will enable dry cooling. The technology features a transformational turbo-compressor and low-cost, high-performance heat exchangers that are currently mass produced for the HVAC industry. To operate, low-grade waste heat from the power plant combustion exhaust gases, or flue gas, is captured and used to power a highly efficient turbo-compressor system. The compressor pressurizes vapor in a refrigeration cycle to remove up to 30% of the power plant cooling load. The cooling system utilizes proprietary technology to maximize the turbo compressor and total system efficiencies, enabling a low production cost and an overall smaller, less expensive dry-cooling system. As a result, the cooling system could allow thermoelectric power plants to maintain a high efficiency while eliminating the use of local water resources. Furthermore, due to its very high performance, the turbo-compression cooling system has potential applications in a range of other markets, including commercial HVAC systems, data center cooling, and distributed cooling industries.

Applied Research Associates, Inc. (ARA)

Cooling Using Thermochemical Cycle

Program: ARID

Project Term: 09/01/2015 to 08/31/2018

Project Status: ACTIVE

Project State: New Mexico

Technical Categories: Resource Efficiency

Applied Research Associates, Inc. (ARA) will design and fabricate a dry-cooling system that overcomes the inherent thermodynamic performance penalty of air-cooled systems, particularly under high ambient temperatures. ARA's ACTIVE cooling technology uses a polymerization thermochemical cycle to provide supplemental cooling and cool storage that can work as a standalone system or be synchronized with air-cooled units to cool power plant condenser water. The cool storage will be completed in two stages. During the day, the cool storage is maintained near the ambient temperature, and then at night the remainder of cooling can be done using the low temperature nighttime air. The cool storage unit is then ready for plant condenser reuse the next day. This technology will provide power plant condensers with return water at the necessary temperature levels to maintain power production at their optimum thermal efficiency.

Stony Brook University

Water Recovery for Cooling

Program: ARID

Project Term: 08/23/2015 to 08/22/2018

Project Status: ACTIVE

Project State: New York

Technical Categories: Resource Efficiency

Stony Brook University will work with Brookhaven National Laboratory, United Technologies Research Center, and the Gas Technology Institute to develop a thermosyphon system that condenses water vapor from power plant flue gas for evaporative cooling. The system could provide supplemental cooling for thermoelectric power plants in which the combustion process - burning fossil fuel to produce heat - results in a significant quantity of water vapor that is typically discharged to the atmosphere. In Stony Brook's system, an advanced loop thermosyphon will allow the liquid and vapor phases to flow in the same direction, and the working fluid (water) is actively managed with a fluid delivery system to create a thin film on the wall of the thermosyphon. This thin film will enable significantly higher heat transfer rates than traditional thermosyphon evaporators that use a pool of liquid. The cooled flue gas condensate is then stored and used for subsequent evaporative cooling when the ambient temperature exceeds acceptable operating limits, such as on a hot day when a dry-cooling system alone could not cool water sufficiently for reuse. In addition to creating a novel design and control architecture, the team will also design innovative, polymer-based components to minimize corrosion from the flue gas. The team estimates its system can capture 320,000 gallons of water per day for evaporative cooling, helping to eliminate the consumption of local water resources for evaporative cooling on high-temperature days.

TDA Research, Inc.

Water Recovery for Cooling

Program: ARID

Project Term: 08/06/2015 to 08/05/2016

Project Status: CANCELLED

Project State: Colorado

Technical Categories: Resource Efficiency

TDA Research (TDA) will develop a water recovery system that extracts and condenses 64% of the water vapor produced by the gas turbine in a natural gas combined cycle's (NGCC) power plant and stores this water for use in evaporative cooling. The system will provide supplemental cooling to NGCC power plants in which the combustion process - burning the natural gas to produce heat - produces a significant quantity of water vapor that is typically discharged to the atmosphere. First, a direct-contact condensation cycle will recover 27% of water vapor from the flue gas. To increase the amount of water recovered, a desiccant, which is a substance that attracts water, will be used to absorb an additional 37% of the water vapor. TDA's desiccant cycle utilizes the waste heat in the exhaust to regenerate the desiccant for reuse. This water recovery cycle would occur during cooler months when the water from combustion is easier to capture. Much of the water collected during this period will then be stored in an adjacent lake and saved for use during hotter summer months when evaporative cooling offers the maximum benefit to improve power plant efficiency. The project team estimates that its technology can reduce the performance penalty of a dry-cooling system by 30% compared to wet cooling. Moreover, the team is designing the system to use low-cost materials, which reduces capital costs.

BEEST Batteries for Electrical Energy Storage in Transportation (12)

The U.S. spends nearly a $1 billion per day to import petroleum, but we need dramatically better batteries for electric and plug-in hybrid vehicles (EV/PHEV) to truly compete with gasoline-powered cars. The projects in ARPA-E's BEEST program, short for "Batteries for Electrical Energy Storage in Transportation," could make that happen by developing a variety of rechargeable battery technologies that would enable EV/PHEVs to meet or beat the price and performance of gasoline-powered cars, and enable mass production of electric vehicles that people will be excited to drive.

Stanford University

The All-Electron Battery

Program: BEEST

Project Term: 07/01/2010 to 06/30/2012

Project Status: ALUMNI

Project State: California

Technical Categories: Transportation Storage

Stanford is developing an all-electron battery that would create a completely new class of energy storage devices for EVs. Stanford's all-electron battery stores energy by moving electrons rather than ions. Electrons are lighter and faster than the ion charge carriers in conventional Li-Ion batteries. Stanford's all-electron battery also uses an advanced structural design that separates critical battery functions, which increases both the life of the battery and the amount of energy it can store. The battery could be charged 1000s of times without showing a significant drop in performance.

PolyPlus Battery Company

Rechargeable Lithium-Air Batteries

Program: BEEST

Project Term: 07/01/2010 to 12/31/2012

Project Status: ALUMNI

Project State: California

Technical Categories: Transportation Storage

PolyPlus is developing the world's first commercially available rechargeable lithium-air (Li-Air) battery. Li-Air batteries are better than the Li-Ion batteries used in most EVs today because they breathe in air from the atmosphere for use as an active material in the battery, which greatly decreases its weight. Li-Air batteries also store nearly 700% as much energy as traditional Li-Ion batteries. A lighter battery would improve the range of EVs dramatically. PolyPlus is on track to making a critical breakthrough: the first manufacturable protective membrane between its lithium-based negative electrode and the reaction chamber where it reacts with oxygen from the air. This gives the battery the unique ability to recharge by moving lithium in and out of the battery's reaction chamber for storage until the battery needs to discharge once again. Until now, engineers had been unable to create the complex packaging and air-breathing components required to turn Li-Air batteries into rechargeable systems.

Recapping, Inc.

High Energy Density Capacitors

Program: BEEST

Project Term: 07/01/2010 to 12/31/2012

Project Status: ALUMNI

Project State: California

Technical Categories: Transportation Storage

Recapping is developing a capacitor that could rival the energy storage potential and price of today's best EV batteries. When power is needed, the capacitor rapidly releases its stored energy, similar to lightning being discharged from a cloud. Capacitors are an ideal substitute for batteries if their energy storage capacity can be improved. Recapping is addressing storage capacity by experimenting with the material that separates the positive and negative electrodes of its capacitors. These separators could significantly improve the energy density of electrochemical devices.

Xilectric, Inc.

Reinventing the Edison Battery

Program: BEEST

Project Term: 10/01/2012 to 09/30/2015

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Transportation Storage

Xilectric is developing a totally new class of low-cost rechargeable batteries with a chemistry analogous to the original nickel-iron Edison battery. At the turn of the 20th century, Thomas Edison experimented with low-cost, durable nickel-iron aqueous batteries for use in EVs. Given their inability to operate in cold weather and higher cost than lead-acid batteries, Edison's batteries were eventually dismissed for automotive applications. Xilectric is reviving and re-engineering the basic chemistry of the Edison battery, using domestically abundant, environmentally friendly, and low-cost metals, such as aluminum and magnesium, as its active components. Xilectric's design would be easy to manufacture and demonstrate longer life span than today's best Li-ion batteries, enabling more widespread use of EVs.

Applied Materials

New Electrode Manufacturing Process Equipment

Program: BEEST

Project Term: 07/01/2010 to 09/30/2013

Project Status: ALUMNI

Project State: California

Technical Categories: Transportation Storage

Applied Materials is developing new tools for manufacturing Li-Ion batteries that could dramatically increase their performance. Traditionally, the positive and negative terminals of Li-Ion batteries are mixed with glue-like materials called binders, pressed onto electrodes, and then physically kept apart by winding a polymer mesh material between them called a separator. With the Applied Materials system, many of these manually intensive processes will be replaced by next generation coating technology to apply each component. This process will improve product reliability and performance of the cells at a fraction of the current cost. These novel manufacturing techniques will also increase the energy density of the battery and reduce the size of several of the battery's components to free up more space within the cell for storage.

Sila Nanotechnologies, Inc.

Double Energy Density Anodes for Lithium-Ion Batteries

Program: BEEST

Project Term: 10/01/2012 to 03/31/2016

Project Status: ALUMNI

Project State: California

Technical Categories: Transportation Storage

Sila is developing a high-throughput technology for scalable synthesis of high-capacity nanostructured materials for Li-Ion EV batteries. The successful implementation of this technology will allow improvements in energy storage capacity of today's best batteries at half the cost. In contrast to other high-capacity material synthesis technologies, Sila's materials show minimal volume changes during the battery operation, which is a key challenge of next-generation battery anode materials. In addition, Sila's technology may allow for the dramatic enhancements of the batteries' cycle life, structural stability, safety, and charging rate. The low-cost, drop-in compatibility with existing cell manufacturing technologies, and environmental friendliness of both the material synthesis and electrode fabrication will assist in the rapid adoption of Sila's technology. Coupling increased battery capacity with substantial cost reduction could alleviate the driving range anxiety and price problems associated with today's EVs. Increasing the capacity of battery electrodes is critical to lowering the cost of Li-Ion batteries and making EVs cost-competitive with gasoline-based vehicles.

24M Technologies

Semi-Solid Flowable Battery Electrodes

Program: BEEST

Project Term: 09/01/2010 to 02/28/2014

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Transportation Storage

Scientists at 24M are crossing a Li-Ion battery with a fuel cell to develop a semi-solid flow battery. This system relies on some of the same basic chemistry as a standard Li-Ion battery, but in a flow battery the energy storage material is held in external tanks, so storage capacity is not limited by the size of the battery itself. The design makes it easier to add storage capacity by simply increasing the size of the tanks and adding more paste. In addition, 24M's design also is able to extract more energy from the semi-solid paste than conventional Li-Ion batteries. This creates a cost-effective, energy-dense battery that can improve the driving range of EVs or be used to store energy on the electric grid.

Pellion Technologies

Rechargeable Magnesium Batteries

Program: BEEST

Project Term: 09/01/2010 to 12/31/2012

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Transportation Storage

Pellion Technologies is developing rechargeable magnesium batteries that would enable an EV to travel 3 times farther than it could using Li-ion batteries. Prototype magnesium batteries demonstrate excellent electrochemical behavior, delivering thousands of charge cycles with very little fade. Nevertheless, these prototypes have always stored too little energy to be commercially viable. Pellion Technologies is working to overcome this challenge by rapidly screening potential storage materials using proprietary, high-throughput computer models. To date, 12,000 materials have been identified and analyzed. The resulting best materials have been electrochemically tested, yielding several very promising candidates.

Sion Power Company

Lithium-Sulfur Batteries

Program: BEEST

Project Term: 10/01/2010 to 09/30/2013

Project Status: ALUMNI

Project State: Arizona

Technical Categories: Transportation Storage

Sion Power is developing a lithium-sulfur (Li-S) battery, a potentially cost-effective alternative to the Li-Ion battery that could store 400% more energy per pound. All batteries have 3 key parts--a positive and negative electrode and an electrolyte--that exchange ions to store and release electricity. Using different materials for these components changes a battery's chemistry and its ability to power a vehicle. Traditional Li-S batteries experience adverse reactions between the electrolyte and lithium-based negative electrode that ultimately limit the battery to less than 50 charge cycles. Sion Power will sandwich the lithium- and sulfur-based electrode films around a separator that protects the negative electrode and increases the number of charges the battery can complete in its lifetime. The design could eventually allow for a battery with 400% greater storage capacity per pound than Li-Ion batteries and the ability to complete more than 500 recharge cycles.

Planar Energy Devices, Inc.

Solid State Lithium Batteries

Program: BEEST

Project Term: 07/01/2010 to 04/10/2012

Project Status: CANCELLED

Project State: Florida

Technical Categories: Transportation Storage

Planar Energy is developing a new production process where lithium-ion batteries would be printed as a thin film onto sheets of metal or plastic. Thin-film printing methods could revolutionize battery manufacturing, allowing for smaller, lighter, and cheaper EV batteries. Typically, a battery's electrolyte--the material that actually stores energy within the cell--is a liquid or semi-liquid; this makes them unsuitable for use in thin-film printing. Planar is working with a ceramic-based gel electrolyte that is better suited for printing. The electrolyte would be printed onto large reels of metal or plastic along with other battery components. Once printed, these reels can be cut up into individual cells and wired together to make battery packs. By reducing packaging materials with this unique production process, Planar's efficient Li-Ion battery design would allow more space for storing energy--at a far lower cost--than today's best Li-Ion battery designs.

Missouri University of Science and Technology

Lithium-Air Battery

Program: BEEST

Project Term: 08/01/2010 to 01/16/2013

Project Status: CANCELLED

Project State: Missouri

Technical Categories: Transportation Storage

Researchers at Missouri S&T are developing an affordable lithium-air (Li-Air) battery that could enable an EV to travel up to 350 miles on a single charge. Today's EVs run on Li-Ion batteries, which are expensive and suffer from low energy density compared with gasoline. This new Li-Air battery could perform as well as gasoline and store 3 times more energy than current Li-Ion batteries. A Li-Air battery uses an air cathode to breathe oxygen into the battery from the surrounding air, like a human lung. The oxygen and lithium react in the battery to produce electricity. Current Li-Air batteries are limited by the rate at which they can draw oxygen from the air. The team is designing a battery using hierarchical electrode structures to enhance air breathing and effective catalysts to accelerate electricity production.

Revolt Technology, LLC

Rechargeable Zinc-Air Batteries

Program: BEEST

Project Term: 10/01/2010 to 06/30/2012

Project Status: CANCELLED

Project State: Oregon

Technical Categories: Transportation Storage

ReVolt is developing a rechargeable zinc-air battery that could offer 300-500% more storage capacity than today's Li-Ion batteries at half their cost. Zinc-air batteries could be much more inexpensive, lightweight, and energy dense than Li-Ion batteries because air--one of the battery's main reactants--does not need to be housed inside the battery. This frees up more space for storage. Zinc-air batteries have not been commercially viable for use in EVs because they typically cannot be recharged, complicating vehicle "refueling". ReVolt has designed a system whereby the battery's zinc-based negative electrode is suspended in liquid and passed through a tube that functions as the battery's positive electrode. This allows the device to charge and discharge just like a regular battery.

BEETIT Building Energy Efficiency Through Innovative Thermodevices (17)

The projects that comprise ARPA-E's BEETIT program, short for "Building Energy Efficiency Through Innovative Thermodevices," are developing new approaches and technologies for building cooling equipment and air conditioners. These projects aim to drastically improve building energy efficiency and reduce greenhouse gas emissions such as carbon dioxide (CO2) at a cost comparable to current technologies.

INFINIA TECHNOLOGY CORPORATION

High-Efficiency Air Conditioner

Program: BEETIT

Project Term: 05/20/2014 to 09/08/2018

Project Status: ACTIVE

Project State: Washington

Technical Categories: Building Efficiency

ITC is developing a freezer that does not rely on harmful refrigerants and is more energy efficient than conventional systems. Many freezers are based on vapor compression, in which a liquid refrigerant circulates within the freezer, absorbs heat, and then pumps it out into the external environment. Unfortunately, these systems can be expensive and inefficient. ITC's freezer uses helium gas as its refrigerant, representing a safe, affordable, and environmentally friendly approach to cooling. ITC's improvements to the Stirling cycle system could enable the cost-effective mass production of high-efficiency freezers without the use of polluting refrigerants. ITC received a separate award of up to $1,766,702 from the Department of the Navy to help decrease military fuel use.

University of Maryland

Elastic Metal Alloy Refrigerants

Program: BEETIT

Project Term: 10/01/2010 to 12/31/2016

Project Status: ACTIVE

Project State: Maryland

Technical Categories: Building Efficiency

UMD is developing an energy-efficient cooling system that eliminates the need for synthetic refrigerants that harm the environment. More than 90% of the cooling and refrigeration systems in the U.S. today use vapor compression systems which rely on liquid to vapor phase transformation of synthetic refrigerants to absorb or release heat. Thermoelastic cooling systems, however, use a solid-state material--an elastic shape memory metal alloy--as a refrigerant and a solid to solid phase transformation to absorb or release heat. UMD is developing and testing shape memory alloys and a cooling device that alternately absorbs or creates heat in much the same way as a vapor compression system, but with significantly less energy and a smaller operational footprint.

University of California, Los Angeles

Compact Solid State Cooling Systems

Program: BEETIT

Project Term: 10/01/2010 to 09/30/2012

Project Status: ALUMNI

Project State: California

Technical Categories: Building Efficiency

UCLA is developing a novel solid state cooling technology to translate a recent scientific discovery of the so-called giant electrocaloric effect into commercially viable compact cooling systems. Traditional air conditioners use noisy, vapor compression systems that include a polluting liquid refrigerant to circulate within the air conditioner, absorb heat, and pump the heat out into the environment. Electrocaloric materials achieve the same result by heating up when placed within an electric field and cooling down when removed--effectively pumping heat out from a cooler to warmer environment. This electrocaloric-based solid state cooling system is quiet and does not use liquid refrigerants. The innovation includes developing nano-structured materials and reliable interfaces for heat exchange. With these innovations and advances in micro/nano-scale manufacturing technologies pioneered by semiconductor companies, UCLA is aiming to extend the performance/reliability of the cooling module.

University of Notre Dame

Carbon Dioxide and Ionic Liquid Refrigerants

Program: BEETIT

Project Term: 10/01/2010 to 09/30/2013

Project Status: ALUMNI

Project State: Indiana

Technical Categories: Building Efficiency

Notre Dame is developing an air-conditioning system with a new ionic liquid and CO2 as the working fluid. Synthetic refrigerants used in air conditioning and refrigeration systems are potent GHGs and can trap 1,000 times more heat in the atmosphere than CO2 alone--making CO2 an attractive alternative for synthetic refrigerants in cooling systems. However, operating cooling systems with pure CO2requires prohibitively high pressures and expensive hardware. Notre Dame is creating a new fluid made of CO2and ionic liquid that enables the use of CO2at low pressures and requires minimal changes to existing hardware and production lines. This new fluid also produces no harmful emissions and can improve the efficiency of air conditioning systems--enabling new use of CO2as a refrigerant in cooling systems.

United Technologies Research Center

Liquid Desiccant in Air Conditioners

Program: BEETIT

Project Term: 09/02/2010 to 08/31/2014

Project Status: ALUMNI

Project State: Connecticut

Technical Categories: Building Efficiency

UTRC is developing an air conditioning system that is optimized for use in warm and humid climates. UTRC's air conditioning system integrates a liquid drying agent or desiccant and a traditional vapor compression system found in 90% of air conditioners. The drying agent reduces the humidity in the air before it is cooled, using less energy. The technology uses a membrane as a barrier between the air and the liquid salt stream allowing only water vapor to pass through and not the salt molecules. This solves an inherent problem with traditional liquid desiccant systems--carryover of the liquid drying agent into the conditioned air stream--which eliminates corrosion and health issues.

Battelle Memorial Institute

Cascade Reverse Osmosis Air Conditioning System

Program: BEETIT

Project Term: 09/01/2010 to 12/30/2011

Project Status: ALUMNI

Project State: Ohio

Technical Categories: Building Efficiency

Battelle is developing a new air conditioning system that uses a cascade reverse osmosis-based absorption cycle. Analyses show that this new cycle can be as much as 60% more efficient than vapor compression, which is used in 90% of air conditioners. Traditional vapor-compression systems use polluting liquids for a cooling effect. Absorption cycles use benign refrigerants such as water, which is absorbed in a salt solution and pumped as liquid--replacing compression of vapor. The refrigerant is subsequently separated from absorbing salt using heat for re-use in the cooling cycle. Battelle is replacing thermal separation of refrigerant with a more efficient reverse osmosis process. Research has shown that the cycle is possible, but further investment will be needed to reduce the number of cascade reverse osmosis stages and therefore cost.

Architectural Applications

[Energy Efficient Building Ventilation Systems]

Program: BEETIT

Project Term: 10/15/2010 to 10/14/2011

Project Status: ALUMNI

Project State: Oregon

Technical Categories: Building Efficiency

A2 is developing a building moisture and heat exchange technology that leverages a new material and design to create healthy buildings with lower energy use. Commercial building owners/operators are demanding buildings with greater energy efficiency and healthier indoor environments. A2 is developing a membrane-based heat and moisture exchanger that controls humidity by transferring the water vapor in the incoming fresh air to the drier air leaving the building. Unlike conventional systems, A2 locates the heat and moisture exchanger within the depths of the building's wall to slow down the air flow and increase the surface area that captures humidity, but with less fan power. The system's integration into the wall reduces the size and demand on the air conditioning equipment and increases liable floor area flexibility.

Pennsylvania State University

[Helium-Based Soundwave Chiller]

Program: BEETIT

Project Term: 09/01/2010 to 07/31/2014

Project Status: ALUMNI

Project State: Pennsylvania

Technical Categories: Building Efficiency

Penn State is designing a freezer that substitutes the use of sound waves and environmentally benign refrigerant for synthetic refrigerants found in conventional freezers. Called a thermoacoustic chiller, the technology is based on the fact that the pressure oscillations in a sound wave result in temperature changes. Areas of higher pressure raise temperatures and areas of low pressure decrease temperatures. By carefully arranging a series of heat exchangers in a sound field, the chiller is able to isolate the hot and cold regions of the sound waves. Penn State's chiller uses helium gas to replace synthetic refrigerants. Because helium does not burn, explode or combine with other chemicals, it is an environmentally-friendly alternative to other polluting refrigerants. Penn State is working to apply this technology on a large scale.

Georgia Tech Research Corporation

[Innovative Miniaturized Heat Pumps for Buildings]

Program: BEETIT

Project Term: 09/01/2010 to 06/30/2014

Project Status: ALUMNI

Project State: Georgia

Technical Categories: Building Efficiency

Georgia Tech is using innovative components and system design to develop a new type of absorption heat pump. Georgia Tech's new heat pumps are energy efficient, use refrigerants that do not emit greenhouse gases, and can run on energy from combustion, waste heat, or solar energy. Georgia Tech is leveraging enhancements to heat and mass transfer technology possible in micro-scale passages and removing hurdles to the use of heat-activated heat pumps that have existed for more than a century. Use of micro-scale passages allows for miniaturization of systems that can be packed as monolithic full-system packages or discrete, distributed components enabling integration into a variety of residential and commercial buildings. Compared to conventional heat pumps, Georgia Tech's design innovations will create an absorption heat pump that is much smaller, has higher energy efficiency, and can also be mass produced at a lower cost and assembly time. Georgia Tech received a separate award of up to $2,315,845 from the Department of the Navy to help decrease military fuel use.

ADMA Products, Inc.

Membrane Dehumidifier

Program: BEETIT

Project Term: 09/01/2010 to 07/31/2014

Project Status: ALUMNI

Project State: Ohio

Technical Categories: Building Efficiency

ADMA Products is developing a foil-like membrane for air conditioners that efficiently removes moisture from humid air. ADMA Products' metal foil-like membrane consists of a paper-thin, porous metal sheet coated with a layer of water-loving molecules. This new membrane allows water vapor to permeate across the membrane at high fluxes, at the same time blocking air penetration and resulting in high selectivity. The high selectivity of the membrane translates to less energy use, while the high permeation fluxes result in a more compact device. The new materials and the flat foil-like nature of the membrane facilitate the mass production of a low-cost compact dehumidification device. ADMA received a separate award of up to $466,176 from the Department of the Navy to help decrease military fuel use.

Sheetak, Inc.

High-Efficiency Solid State Cooling Technologies

Program: BEETIT

Project Term: 09/01/2010 to 06/30/2015

Project Status: ALUMNI

Project State: Texas

Technical Categories: Building Efficiency

Sheetak is developing a thermoelectric-based solid state cooling system that is more efficient, more reliable, and more affordable than today's best systems. Many air conditioners are based on vapor compression, in which a liquid refrigerant circulates within the air conditioner, absorbs heat, and then pumps it out into the external environment. Sheetak's system, by contrast, relies on an electrical current passing through the junction of two different conducting materials to change temperature. Sheetak's design uses proprietary thermoelectric materials to achieve significant energy efficiency and, unlike vapor compression systems, contains no noisy moving parts or polluting refrigerants. Additionally, Sheetak's air conditioner would be made with some of the same manufacturing processes used to produce semiconductor chips, which could lead to less material use and facilitate more affordable production.

University of Florida

Membrane-Based Absorption Refrigeration Systems

Program: BEETIT

Project Term: 09/01/2010 to 08/31/2015

Project Status: ALUMNI

Project State: Florida

Technical Categories: Building Efficiency

The University of Florida is improving a refrigeration system that uses low-quality heat to provide the energy needed to drive cooling. This system, known as absorption refrigeration system (ARS), typically consists of large coils that transfer heat. Unfortunately, these large heat exchanger coils are responsible for bulkiness and high cost of ARS. The University of Florida is using new materials as well as system design innovations to develop nanoengineered membranes to allow for enhanced heat exchange that reduces bulkiness. This design allows for compact, cheaper, and more reliable use of ARS that use solar or waste heat.

Astronautics Corporation of America

Air Conditioning with Magnetic Refrigeration

Program: BEETIT

Project Term: 09/01/2010 to 04/30/2014

Project Status: ALUMNI

Project State: Wisconsin

Technical Categories: Building Efficiency

Astronautics is developing an air conditioning system that relies on magnetic fields. Typical air conditioners use vapor compression to cool air. Vapor compression uses a liquid refrigerant to circulate within the air conditioner, absorb the heat, and pump the heat out into the external environment. Astronautics' design uses a novel property of certain materials, called "magnetocaloric materials", to achieve the same result as liquid refrigerants. These magnetocaloric materials essentially heat up when placed within a magnetic field and cool down when removed, effectively pumping heat out from a cooler to warmer environment. In addition, magnetic refrigeration uses no ozone-depleting gases and is safer to use than conventional air conditioners, which are prone to leaks.

Dais Analytic Corporation

Dehumidifying Air for Cooling & Refrigeration

Program: BEETIT

Project Term: 10/01/2010 to 02/29/2012

Project Status: ALUMNI

Project State: Florida

Technical Categories: Building Efficiency

Dais is developing a product called NanoAir which dehumidifies the air entering a building to make air conditioning more energy efficient. The system uses a polymer membrane that allows moisture but not air to pass through it. A vacuum behind the membrane pulls water vapor from the air, and a second set of membranes releases the water vapor outside. The membrane's high selectivity translates into reduced energy consumption for dehumidification. Dais' design goals for NanoAir are the use of proprietary materials and processes and industry-standard installation techniques. NanoAir is also complementary to many other energy saving strategies, including energy recovery. Dais received a separate award of up to $800,000 from the Department of the Navy to help decrease military fuel use.

Pacific Northwest National Laboratory

High-Efficiency Adsorption Chillers

Program: BEETIT

Project Term: 09/15/2010 to 07/31/2015

Project Status: ALUMNI

Project State: Washington

Technical Categories: Building Efficiency

PNNL is designing more efficient adsorption chillers by incorporating significant improvements in materials that adsorb liquids or gases. An adsorption chiller is a type of air conditioner that is powered by heat, solar or waste heat, or combustion of natural gas. Unlike typical chillers, an adsorption chiller has few moving parts and uses almost no electricity to operate. PNNL is designing adsorbent materials at the molecular level that have at least 3 times higher refrigerant capacity and up to 20 times faster kinetics than adsorbents used in current chillers. By using the new adsorbent, PNNL is able to create a chiller that is significantly smaller, has twice the energy efficiency, and lower material and assembly costs compared to conventional adsorption chillers. PNNL received a separate award of up to $2,190,343 from the Department of the Navy to help decrease military fuel use.

United Technologies Research Center

Water-Based Refrigerants

Program: BEETIT

Project Term: 09/02/2010 to 03/16/2012

Project Status: CANCELLED

Project State: Connecticut

Technical Categories: Building Efficiency

UTRC is developing an efficient air conditioning compressor that will use water as the refrigerant. Most conventional air conditioning systems use hydrofluorocarbons to cool the air, which are highly potent GHGs. Because water is natural and non-toxic, it is an attractive refrigerant. However, low vapor density of water requires higher compression ratios, typically resulting in large and inefficient multi-stage compression. UTRC's design utilizes a novel type of supersonic compression that enables high-compression ratios in a single stage, thus enabling more compact and cost-effective technology than existing designs. UTRC's water-based air conditioner system could reduce the use of synthetic refrigerants while also increasing energy efficiency.

Material Methods, LLC

Sound Wave Refrigerants

Program: BEETIT

Project Term: 09/15/2010 to 09/21/2011

Project Status: CANCELLED

Project State: California

Technical Categories: Building Efficiency

Material Methods is developing a heat pump technology that substitutes the use of sound waves and an environmentally benign refrigerant for synthetic refrigerants found in conventional heat pumps. Called a thermoacoustic heat pump, the technology is based on the fact that the pressure oscillations in a sound wave result in temperature changes. Areas of higher pressure raise temperatures and areas of low pressure decrease temperatures. By carefully arranging a series of heat exchangers in a sound field, the heat pump is able to isolate the hot and cold regions of the sound waves. This technology is environmentally safe, and the simplicity of the mechanical system creates efficiencies that make the system cost competitive with traditional refrigerant-based systems.

CHARGES Cycling Hardware to Analyze and Ready Grid-Scale Electricity Storage (2)

Methods for storing electricity for the electric power system (i.e. the grid) are developing rapidly, but widespread adoption of these technologies requires real-world data about their performance, economic benefit, and long-term reliability. The CHARGES program, short for "Cycling Hardware to Analyze and Ready Grid-Scale Electricity Storage," establishes two sites where ARPA-E-funded battery technologies will be tested under conditions designed to represent not just today's applications, but also the demands of tomorrow's electric power system. The program will establish realistic duty cycles for storage devices on a microgrid, and test them in both a controlled environment and under realistic microgrid operating conditions. The objective of the CHARGES program is to accelerate the commercialization of electrochemical energy storage systems developed in current and past ARPA-E-funded research efforts. The program aims to help ARPA-E-funded battery development teams improve their storage technologies to deliver substantial economic benefit under real-world conditions, both now and in the future.

Det Norske Veritas (U.S.A)

Grid Energy Storage Valuation

Program: CHARGES

Project Term: 04/27/2015 to 04/26/2019

Project Status: ACTIVE

Project State: Texas

Technical Categories: Distributed Generation, Storage

DNV GL and Group NIRE will provide a unique combination of third-party testing facilities, testing and analysis methodologies, and expert oversight to the evaluation of ARPA-E-funded energy storage systems. The project will leverage DNV GL's deep expertise in economic analysis of energy storage technologies, and will implement economically optimized duty cycles into the testing and validation protocol. DNV GL plans to test ARPA-E storage technologies at its state-of-the-art battery testing facility in partnership with the New York Battery and Energy Storage Technology Consortium. Those batteries that pass the rigorous evaluation process will be adapted for testing under real world conditions on Group NIRE's multi-megawatt, wind-integrated microgrid in Texas. Testing will show how well the ARPA-E storage technologies can serve critical applications and will assist ARPA-E-funded battery developers in identifying any issues with performance and durability. This testing will also deliver performance data that buyers of grid storage need, enabling informed choices about commercial adoption of grid storage technologies.

University of California, San Diego

Grid Energy Storage Valuation

Program: CHARGES

Project Term: 02/09/2015 to 02/08/2019

Project Status: ACTIVE

Project State: California

Technical Categories: Distributed Generation, Storage

The University of California, San Diego (UCSD) will conduct testing of existing ARPA-E energy storage technologies in both laboratory and grid-connected conditions. Home to one of the country's largest microgrids, UCSD will apply its advanced understanding of microgrid operation in the California market to select and value applications for storage, in grid-connected and islanded conditions, and to develop duty cycles for energy storage in order to serve individual and stacked applications. UCSD plans to test cells and modules from ARPA-E-funded battery developers in its battery laboratories, and UCSD experts will assist ARPA-E battery developers in resolving issues and enhancing performance. Those batteries that perform well in laboratory testing using the selected duty cycles will then be deployed for extended testing on UCSD's microgrid. This approach will allow UCSD to achieve test results that represent a wide spectrum of applications, determine system performance under a variety of conditions, and eventually generate initial performance data that can be shared with electric utilities and other potential grid storage buyers to inform them of the promise of early-stage storage technologies.

DELTA Delivering Efficient Local Thermal Amenities (11)

The projects in ARPA-E's DELTA Program, short for "Delivering Efficient Local Thermal Amenities," aim to reduce the costs for heating and cooling buildings by developing Localized Thermal Management Systems (LTMS). LTMS modify the physical space around the human body rather than the entire building, with significant energy savings for both new and old buildings. Such technologies range from on-body wearable devices to off-body installed systems and provide more options for maintaining occupant comfort within buildings. ARPA-E's DELTA projects include a broad range of LTMS approaches that potentially enable energy savings of upwards of 2% of the total domestic energy supply and similar reductions in greenhouse gas emissions.

SRI International

Wearable Electroactive Textile

Program: DELTA

Project Term: 05/01/2015 to 04/30/2018

Project Status: ACTIVE

Project State: California

Technical Categories: Building Efficiency

SRI International will develop a highly efficient, wearable thermal regulation system that leverages the human body's natural thermal regulation areas such as the palms of the hands, soles of feet, and upper facial area. This innovative "active textile" technology is enabled by a novel combination of low-cost electroactive and passive polymer materials and structures to efficiently manage heat transfer while being quiet and comfortable. SRI's electronically controllable active textile technology is versatile - allowing the wearer to continue to use their existing wardrobe. We believe that these features will allow for products that augment wearable technologies and thus achieve the widespread adoption needed to save energy on a large scale.

Stanford University

Photonic Structure Textiles

Program: DELTA

Project Term: 04/30/2015 to 04/29/2018

Project Status: ACTIVE

Project State: California

Technical Categories: Building Efficiency

Stanford University will develop transformative methods for integrating photonic, or radiant energy structures into textiles. Controlling the thermal photonic properties of textiles can significantly influence the heat dissipation rate of the human body, which loses a significant amount of heat through thermal radiation. To achieve heating, the team utilizes metallic nanowire embedded in textiles to enhance reflection of body heat. To achieve cooling, the team utilizes visibly opaque yet infrared transmissivity (IR) transparent textile. These techniques for heating and cooling have not yet been achieved to date. The team will leverage advances in photonic structures to build textiles with varying amounts of infrared transparency and reflectivity to enable a wearer to achieve comfort in a wider temperature range, and therefore generate a substantial reduction of energy consumption for both heating and cooling.

University of California, Berkeley

Wirelessly Powered Heating and Cooling Devices

Program: DELTA

Project Term: 05/14/2015 to 05/13/2018

Project Status: ACTIVE

Project State: California

Technical Categories: Building Efficiency

Until now, local comfort devices have had little market traction because they had to be tethered by a cord to a power source. The University of California at Berkeley will team with WiTricity to develop and integrate highly resonant wireless power transfer technology to deliver efficient local thermal amenities to the feet, hands, face, and trunk of occupants in workstations. Until now, local comfort devices have had little market traction because they had to be tethered by a cord to a power source. The team will leverage on-going developments in wireless charging systems for consumer electronics to integrate high-efficiency power transmitting devices with local comfort devices such as heated shoe insoles and cooled and heated office chairs. The team will develop four types of local comfort devices to deliver heating and cooling most effectively. The devices will draw very little electrical power and enable potential HVAC energy savings of at least 30%.

University of Maryland

Robotic Personal Conditioning Device

Program: DELTA

Project Term: 04/15/2015 to 05/12/2018

Project Status: ACTIVE

Project State: Maryland

Technical Categories: Building Efficiency

Heating, Ventilation, and Air Conditioning (HVAC) account for 13% of energy consumed in the U.S. and about 40% of the energy used in a typical U.S. residence, making it the largest energy expense for most homes. Even though more energy-efficient HVAC technologies are being adopted in both the commercial and residential sectors, these technologies focus on efficiently heating or cooling large areas and dealing with how the building's net occupancy changes during a day, a week and across seasons. Building operators have to tightly manage temperature for an average occupancy comfort level; but the occupants only occupy a small fraction of the building's interior. There is a critical need for technologies that create localization of thermal management to relax the temperature settings in buildings, reduce the load on HVAC systems and enhance occupant comfort. This is achieved by tailoring the thermal environment around the individual, thus saving energy by not over-heating or over-cooling areas within the building where the occupants do not reside.

University of California - Irvine

Thermocomfort Cloth

Program: DELTA

Project Term: 04/20/2015 to 04/19/2018

Project Status: ACTIVE

Project State: California

Technical Categories: Building Efficiency

The University of California at Irvine will develop a dynamically adjustable thermoregulatory fabric. This fabric leverages established heat-managing capabilities of space blankets and color-changing polymers inspired by squid skin that will provide wearers with the unique ability to adaptively harness their own individual radiant heat production. This technology holds the potential to establish an entirely new line of personal apparel and localized thermal management products that could significantly reduce the energy required to heat and cool buildings.

University of Maryland

[Meta-Cooling Textile]

Program: DELTA

Project Term: 05/01/2015 to 04/30/2018

Project Status: ACTIVE

Project State: Maryland

Technical Categories: Building Efficiency

Led by Dr. YuHuang Wang, the "Meta Cooling Textile (MCT)" project team is developing a thermally responsive clothing fabric that extends the skin's thermoregulation ability to maintain comfort in hotter or cooler office settings. Commercial wearable localized thermal management systems are bulky, heavy, and costly. MCT marks a potentially disruptive departure from current technologies by providing clothing with active control over the primary channels for energy exchange between the body and the environment. In hotter surroundings, the fabric's pores open up to increase ventilation while changes in the microstructure of the fabric increase the amount of energy transmitted through the fabric from the wearer. In cooler conditions, these effects are reversed to increase the garment's ability to insulate the wearer. The added bidirectional regulation capacity will enable the wearer to expand their thermal comfort range and thus relax the temperature settings in building.

Otherlab, Inc.

[Passive Thermo-Adaptive Textiles]

Program: DELTA

Project Term: 05/08/2015 to 05/07/2017

Project Status: ACTIVE

Project State: California

Technical Categories: Building Efficiency

Otherlab will develop thermally adaptive materials that change their thickness in response to temperature changes, allowing the creation of garments that passively respond to variations in temperature. In contrast to existing garments that have a constant insulation value whether conditions are hot or cold, thermally adaptive materials change shape as temperature changes, leading to a change in insulation. The material change is a physical response, passively operating and requiring no input from the wearer or any control system. Garments made from thermally adaptive fabrics will enable the wearing of fewer layers of clothing for comfort over a broader temperature range, effectively lowering the heating and cooling requirements for buildings. Beyond apparel, this advanced insulation may find applications in drapery and bedding.

Stony Brook University

[Electroactive Smart Air-Conditioner VEnt Registers (eSAVER)]

Program: DELTA

Project Term: 05/05/2015 to 05/04/2018

Project Status: ACTIVE

Project State: New York

Technical Categories: Building Efficiency

The State University of New York (SUNY) at Stony Brook will develop eSAVER, an active air conditioning vent capable of modulating airflow distribution, velocity, and temperature to promote localized thermal envelopes around building occupants. SUNY Stony Brook's smart vent modulates the airflow using an array of electro-active polymer tubes that are individually controlled to create a localized curtain of air to suit the occupant's heating or cooling needs. The eSAVER can immediately be implemented by simply replacing an existing HVAC register with the new unit or can be installed in new constructions for significant reduction in HVAC system size,construction cost,and further improvement in energy efficiency.The project team estimates this will result in upwards of 30% energy savings through directed localization of existing building heating/cooling output.

Syracuse University

[Micro-Environmental Control System]

Program: DELTA

Project Term: 05/01/2015 to 04/30/2018

Project Status: ACTIVE

Project State: New York

Technical Categories: Building Efficiency

Syracuse University will develop a near-range micro-environmental control system transforming the way office buildings are thermally conditioned to improve occupant comfort. The system leverages a high-performance micro-scroll compressor coupled to a phase-change material, which is a substance with a high latent heat of fusion and the capability to store and release large amounts of heat at a constant temperature. This material will store the cooling produced by the compression system at night, releasing it as a cool breeze of air to make occupants more comfortable during the day. When heating is needed, the system will operate as an efficient heat pump, drawing heat from the phase-change material and delivering warm air to the occupant. The micro-scroll compressor is smaller than any of its type, minimizing the amount of power needed. The use of this micro-environmental control system, along with expanding the set-point range could save more than 15% of the energy used for heating and cooling, while maintaining occupant comfort.

University of California, San Diego

[Adaptive Textiles Technology]

Program: DELTA

Project Term: 05/07/2015 to 05/06/2018

Project Status: ACTIVE

Project State: California

Technical Categories: Building Efficiency

University of California at San Diego will develop smart responsive garments that enable building occupants to adjust their personal temperature settings and promote thermal comfort to reduce or eliminate the need for building-level air conditioning. The essence of building energy savings in UCSD's approach is based on the significant energy consumption reduction from the traditional global cooling/heating of the whole room space. This is done via localized cooling and heating only in the wearable structure in the very limited space near a person's skin. This smart textile will thermally regulate the garment's heat transport through changes in thickness and pore architecture by shrinking the textile when hot and expanding it when cold.

Cornell University

[Thermoregulatory Clothing System]

Program: DELTA

Project Term: 04/27/2015 to 04/26/2018

Project Status: ACTIVE

Project State: New York

Technical Categories: Building Efficiency

Cornell University will develop thermoregulatory apparel that enables the expansion of the comfortable temperature range in buildings by more than 4°F in both heating and cooling seasons. Cornell's thermoregulatory apparel integrates advanced textile technologies and state-of-the-art wearable electronics into a functional apparel design without compromising comfort, wearability, washability, appearance, or safety. The thermoregulatory clothing system senses the wearer's skin temperature and activates a heated or cooled airflow around the individual, reducing the energy required to heat or cool the building itself by satisfying the comfort requirements of the individual.

ARPA-E's Electrofuels program is using microorganisms to create liquid transportation fuels in a new and different way that could be up to 10 times more energy efficient than current biofuel production methods. ARPA-E is the only U.S. government agency currently funding research on electrofuels.

North Carolina State University

Liquid Fuel from Heat-Loving Microorganisms

Program: Electrofuels

Project Term: 07/01/2010 to 12/31/2014

Project Status: ALUMNI

Project State: North Carolina

Technical Categories: Transportation Fuels

NC State is working with the University of Georgia to create electrofuels from primitive organisms called extremophiles that evolved before photosynthetic organisms and live in extreme, hot water environments with temperatures ranging from 167-212 degrees Fahrenheit. The team is genetically engineering these microorganisms so they can use hydrogen to turn carbon dioxide directly into alcohol-based fuels. High temperatures are required to distill the biofuels from the water where the organisms live, but the heat-tolerant organisms will continue to thrive even as the biofuels are being distilled--making the fuel-production process more efficient. The microorganisms don't require light, so they can be grown anywhere--inside a dark reactor or even in an underground facility.

Ginkgo Bioworks

Biofuels from E. Coli

Program: Electrofuels

Project Term: 07/16/2010 to 01/15/2014

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Transportation Fuels

Ginkgo Bioworks is bypassing photosynthesis and engineering E. coli to directly use carbon dioxide (CO2) to produce biofuels. E. coli doesn't naturally metabolize CO2, but Ginkgo Bioworks is manipulating and incorporating the genes responsible for CO2 metabolism into the microorganism. By genetically modifying E. coli, Ginkgo Bioworks will enhance its rate of CO2consumption and liquid fuel production. Ginkgo Bioworks is delivering CO2 to E. coli as formic acid, a simple industrial chemical that provides energy and CO2 to the bacterial system.

Medical University of South Carolina

Liquid Fuel from Microbial Communities

Program: Electrofuels

Project Term: 07/09/2010 to 02/15/2015

Project Status: ALUMNI

Project State: South Carolina

Technical Categories: Transportation Fuels

MUSC is developing an engineered system to create liquid fuels from communities of interdependent microorganisms. MUSC is first pumping carbon dioxide (CO2) and renewable sources of electricity into a battery-like cell. A community of microorganisms uses the electricity to convert the CO2 into hydrogen. That hydrogen is then consumed by another community of microorganisms living in the same system. These new microorganisms convert the hydrogen into acetate, which in turn feed yet another community of microorganisms. This last community of microorganisms uses the acetate to produce a liquid biofuel called butanol. Similar interdependent microbial communities can be found in some natural environments, but they've never been coupled together in an engineered cell to produce liquid fuels. MUSC is working to triple the amount of butanol that can be produced in its system and to reduce the overall cost of the process.

Massachusetts Institute of Technology

Liquid Fuel from Bacteria

Program: Electrofuels

Project Term: 07/15/2010 to 10/01/2013

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Transportation Fuels

MIT is using solar-derived hydrogen and common soil bacteria called Ralstonia eutropha to turn carbon dioxide (CO_2) directly into biofuel. This bacteria already has the natural ability to use hydrogen and $CO_2$for growth. MIT is engineering the bacteria to use hydrogen to convert CO_2 directly into liquid transportation fuels. Hydrogen is a flammable gas, so the MIT team is building an innovative reactor system that will safely house the bacteria and gas mixture during the fuel-creation process. The system will pump in precise mixtures of hydrogen, oxygen, and CO_2, and the online fuel-recovery system will continuously capture and remove the biofuel product.

Columbia University

Biofuels from Bacteria, Electricity, and CO2

Program: Electrofuels

Project Term: 07/01/2010 to 06/30/2014

Project Status: ALUMNI

Project State: New York

Technical Categories: Transportation Fuels

Columbia University is using carbon dioxide (CO_2) from ambient air, ammonia--an abundant and affordable chemical--and a bacteria called N. europaea to produce liquid fuel. The Columbia University team is feeding the ammonia and CO_2 into an engineered tank where the bacteria live. The bacteria capture the energy from ammonia and then use that energy to convert CO_2 into a liquid fuel. When the bacteria use up all the ammonia, renewable electricity can regenerate it and pump it back into the system--creating a continuous fuel-creation cycle. In addition, Columbia University is also working with the bacteria A. ferrooxidans to capture and use energy from ferrous iron to produce liquid fuels from CO_2.

University of California, Los Angeles

Liquid Fuel from Renewable Electricity and Bacteria

Program: Electrofuels

Project Term: 07/15/2010 to 04/30/2014

Project Status: ALUMNI

Project State: California

Technical Categories: Transportation Fuels

UCLA is utilizing renewable electricity to power direct liquid fuel production in genetically engineered Ralstonia eutropha bacteria. UCLA is using renewable electricity to convert carbon dioxide into formic acid, a liquid soluble compound that delivers both carbon and energy to the bacteria. The bacteria are genetically engineered to convert the formic acid into liquid fuel--in this case alcohols such as butanol. The electricity required for the process can be generated from sunlight, wind, or other renewable energy sources. In fact, UCLA's electricity-to-fuel system could be a more efficient way to utilize these renewable energy sources considering the energy density of liquid fuel is much higher than the energy density of other renewable energy storage options, such as batteries.

OPX Biotechnologies, Inc.

Engineering Bacteria for Efficient Fuel Production

Program: Electrofuels

Project Term: 07/12/2010 to 03/31/2014

Project Status: ALUMNI

Project State: Colorado

Technical Categories: Transportation Fuels

OPX Biotechnologies is engineering a microorganism currently used in industrial biotechnology to directly produce a liquid fuel from hydrogen and carbon dioxide (CO2). The microorganism has the natural ability to use hydrogen and CO2 for growth. OPX Biotechnologies is modifying the microorganism to divert energy and carbon away from growth and towards the production of liquid fuels in larger, commercially viable quantities. The microbial system will produce a fuel precursor that can be chemically upgraded to various hydrocarbon fuels.

Pennsylvania State University

Genetically Modified Bacteria for Fuel Production

Program: Electrofuels

Project Term: 07/01/2010 to 06/30/2014

Project Status: ALUMNI

Project State: Pennsylvania

Technical Categories: Transportation Fuels

Penn State is genetically engineering bacteria called Rhodobacter to use electricity or electrically generated hydrogen to convert carbon dioxide into liquid fuels. In collaboration with the University of Kentucky, Penn State is taking genes from oil-producing algae called Botryococcus braunii and putting them into Rhodobacter to produce hydrocarbon molecules, which closely resemble gasoline. Penn State is developing engineered tanks to support microbial fuel production and determining the most economical way to feed the electricity or hydrogen to the bacteria, including using renewable sources of power like solar energy.

Harvard University

Fuel from Bacteria, CO2, Water, and Solar Energy

Program: Electrofuels

Project Term: 07/01/2010 to 09/30/2013

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Transportation Fuels

Harvard is engineering a self-contained, scalable electrofuels production system that can directly generate liquid fuels from bacteria, carbon dioxide (CO2), water, and sunlight. Harvard is genetically engineering bacteria called Shewanella, so the bacteria can sit directly on electrical conductors and absorb electrical current. This current, which is powered by solar panels, gives the bacteria the energy they need to process CO2 into liquid fuels. The Harvard team pumps this CO2 into the system, in addition to water and other nutrients needed to grow the bacteria. Harvard is also engineering the bacteria to produce fuel molecules that have properties similar to gasoline or diesel fuel--making them easier to incorporate into the existing fuel infrastructure. These molecules are designed to spontaneously separate from the water-based culture that the bacteria live in and to be used directly as fuel without further chemical processing once they're pumped out of the tank.

University of Massachusetts, Amherst

Biofuels from Solar Energy and Bacteria

Program: Electrofuels

Project Term: 07/01/2010 to 06/30/2014

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Transportation Fuels

UMass Amherst is feeding renewable electricity to bacteria to provide the microorganisms with the energy they need to turn carbon dioxide (CO2) directly into liquid fuels. UMass Amherst's energy-to-fuels conversion process is anticipated to be more efficient than current biofuels approaches in part because this process will leverage the high efficiency of photovoltaics to convert solar energy into electricity. UMass Amherst is using bacteria already known to produce biofuel from electric current and CO2and working to increase the amount of electric current those microorganisms will accept and use for biofuels production. In collaboration with scientists at University of California, San Diego, the UMass Amherst team is also investigating the use of hydrogen sulfide as a source of energy to power biofuel production.

Lawrence Berkeley National Laboratory

Turning Bacteria into Biofuel

Program: Electrofuels

Project Term: 07/16/2010 to 12/31/2014

Project Status: ALUMNI

Project State: California

Technical Categories: Transportation Fuels

LBNL is improving the natural ability of a common soil bacteria called Ralstonia eutropha to use hydrogen and carbon dioxide for biofuel production. First, LBNL is genetically modifying the bacteria to produce biofuel at higher concentrations. Then, LBNL is using renewable electricity obtained from solar, wind, or wave power to produce high amounts of hydrogen in the presence of the bacteria--increasing the organism's access to its energy source and improving the efficiency of the biofuel-creation process. Finally, LBNL is tethering electrocatalysts to the bacteria's surface which will further accelerate the rate at which the organism creates biofuel. LBNL is also developing a chemical method to transform the biofuel that the bacteria produce into ready-to-use jet fuel.

Ohio State University

Fuel From Bacteria

Program: Electrofuels

Project Term: 07/01/2010 to 06/30/2014

Project Status: ALUMNI

Project State: Ohio

Technical Categories: Transportation Fuels

Ohio State is genetically modifying bacteria to efficiently convert carbon dioxide directly into butanol, an alcohol that can be used directly as a fuel blend or converted to a hydrocarbon, which closely resembles gasoline. Bacteria are typically capable of producing a certain amount of butanol before it becomes too toxic for the bacteria to survive. Ohio State is engineering a new strain of the bacteria that could produce up to 50% more butanol before it becomes too toxic for the bacteria to survive. Finding a way to produce more butanol more efficiently would significantly cut down on biofuel production costs and help make butanol cost competitive with gasoline. Ohio State is also engineering large tanks, or bioreactors, to grow the biofuel-producing bacteria in, and they are developing ways to efficiently recover biofuel from the tanks.

Massachusetts Institute of Technology

Natural Oil Production from Microorganisms

Program: Electrofuels

Project Term: 07/15/2010 to 03/31/2014

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Transportation Fuels

MIT is using carbon dioxide (CO_2) and hydrogen generated from electricity to produce natural oils that can be upgraded to hydrocarbon fuels. MIT has designed a 2-stage biofuel production system. In the first stage, hydrogen and CO_2 are fed to a microorganism capable of converting these feedstocks to a 2-carbon compound called acetate. In the second stage, acetate is delivered to a different microorganism that can use the acetate to grow and produce oil. The oil can be removed from the reactor tank and chemically converted to various hydrocarbons. The electricity for the process could be supplied from novel means currently in development, or more proven methods such as the combustion of municipal waste, which would also generate the required CO_2 and enhance the overall efficiency of MIT's biofuel-production system.

FOCUS Full-Spectrum Optimized Conversion and Utilization of Sunlight (13)

High utilization of renewable energy is a vital component of our energy portfolio. Solar energy systems can provide secure energy with predictable future costs--largely unaffected by geopolitics and climate--because sunshine is widely available and free. The projects that comprise ARPA-E's FOCUS program, short for "Full-Spectrum Optimized Conversion and Utilization of Sunlight," could pave the way for cost-competitive hybrid solar energy systems that combine the advantages of existing photovoltaic (PV) and concentrated solar power (CSP) technologies.

University of Tulsa

[Liquid Filter with Plasmonic Nanoparticles]

Program: FOCUS

Project Term: 05/15/2014 to 02/14/2017

Project Status: ACTIVE

Project State: Oklahoma

Technical Categories: Distributed Generation

The University of Tulsa is developing a hybrid solar converter that captures ultraviolet and infrared wavelengths of light in a thermal fluid while directing visible wavelengths of light to a photovoltaic (PV) cell to produce electricity. The PV cells can be kept at moderate temperatures while high-quality heat is captured in the thermal fluid for storage and conversion into electricity when needed. The thermal fluid will flow behind the PV cell to capture waste heat and then flow in front of the PV cell, where it heats further and also act as a filter, passing only the portions of sunlight that the PV cell converts most efficiently while absorbing the rest. This light absorption control will be accomplished by including nanoparticles of different materials, shapes, and sizes in the fluid that are tailored to absorb different portions of sunlight. The heat captured in the fluid can be stored to provide dispatchable solar energy during non-daylight hours. Together, the PV cells and thermal energy provide instantaneous as well as storable power for dispatch when most needed.

Yale University

[High-Temperature Dual-Junction Topping Cells]

Program: FOCUS

Project Term: 07/15/2014 to 07/31/2017

Project Status: ACTIVE

Project State: Connecticut

Technical Categories: Distributed Generation

Yale University is developing a dual-junction solar cell that can operate efficiently at temperatures above 400 °C, unlike today's solar cells, which lose efficiency rapidly above 100°C and are likely to fail at high temperatures over time. Yale's specialized dual-junction design will allow the cell to extract significantly more energy from the sun at high temperature than today's cells, enabling the next generation of hybrid solar converters to deliver much higher quantities of electricity and highly useful dispatchable heat. Heat rejected from the cells at high temperature can be stored and used to generate electricity with a heat engine much more effectively than cells producing heat at lower temperatures. Therefore, electricity can be produced at higher overall efficiency for use even when the sun is not shining.

Tulane University

[Hybrid Solar Converter]

Program: FOCUS

Project Term: 08/01/2014 to 07/31/2017

Project Status: ACTIVE

Project State: Louisiana

Technical Categories: Distributed Generation

Tulane University is developing a hybrid solar energy system capable of capturing, storing, and dispatching solar energy. The system will collect sunlight using mass-manufactured, pneumatically-driven mirrors (heliostats) that track the sun's movement. This contrasts with today's mechanically-driven heliostats that are bulky and costly. The heliostats concentrate sunlight onto high-efficiency solar cells that generate electricity for immediate use from a portion of the light while the remaining light directly heats a tank filled with hot fluid up to 600 °C. The tank stores energy for use by a heat engine when needed most. Tulane University's system will enable efficient use of the full solar spectrum while storing a large component of sunlight as heat for conversion into electricity at any time of day.

Massachusetts Institute of Technology

Stacked Hybrid Solar Converter

Program: FOCUS

Project Term: 06/17/2014 to 06/16/2017

Project Status: ACTIVE

Project State: Massachusetts

Technical Categories: Distributed Generation

MIT is developing a hybrid solar converter that integrates a thermal absorber and solar cells into a layered stack, allowing some portions of sunlight to be converted directly to electricity and the rest to be stored as heat for conversion when needed most. MIT's design focuses concentrated sunlight onto metal fins coated with layers that reflect a portion of the sunlight while absorbing the rest. The absorbed light is converted to heat and stored in a thermal fluid for conversion to mechanical energy by a heat engine. The reflected light is directed to solar cells and converted directly into electricity. This way, each portion of the solar spectrum is directed to the conversion system where it can be most effectively used. The sunlight passes through a transparent microporous gel that also insulates each of the components so that the maximum energy can be extracted from both the heat-collecting metal fins and the solar cells. This unique stack design could utilize the full solar spectrum efficiently and enable the dispatch of electricity at any time of the day.

Arizona State University

High-Temperature Topping Cells from LED Materials

Program: FOCUS

Project Term: 05/30/2014 to 05/29/2017

Project Status: ACTIVE

Project State: Arizona

Technical Categories: Distributed Generation

ASU is developing a solar cell that can maintain efficient operation at temperatures above 400°C. Like many other electronics, solar panels work best in cooler environments. As the temperature of traditional solar cells increases beyond 100°C, the energy output decreases markedly and components are more prone to failure. ASU's technology adapts semiconducting materials used in today's light-emitting diode (LED) industry to enable efficient, long-term high-temperature operation. These materials could allow the cells to maintain operation at much higher temperatures than today's solar cells, so they can be integrated as the sunlight-absorbing surface of a thermal receiver in the next generation of hybrid solar collectors. The solar cell would provide electricity using a portion of the incoming sunlight, while the receiver collects usable heat at high temperature that can be stored and dispatched to generate electricity as needed.

Gas Technology Institute

Double-Reflector Hybrid Solar Energy System

Program: FOCUS

Project Term: 05/13/2014 to 08/31/2017

Project Status: ACTIVE

Project State: Illinois

Technical Categories: Distributed Generation

GTI is developing a hybrid solar converter that focuses sunlight onto solar cells with a reflective backside mirror. These solar cells convert most visible wavelengths of sunlight to electricity while reflecting the unused wavelengths to heat a stream of flowing particles. The particles are used to store the heat for use immediately or at a later time to drive a turbine and produce electricity. GTI's design integrates the parabolic trough mirrors, commonly used in CSP plants, into a dual-mirror system that captures the full solar spectrum while storing heat to dispatch electricity when the sun does not shine. Current solar cell technologies capture limited portions of the solar spectrum to generate electricity that must be used immediately. By using back-reflecting gallium arsenide (GaAs) cells, this hybrid converter is able to generate both electricity from specific solar wavelengths and capture the unused light as heat in the flowing particles. The particle-based heat storage system is a departure from standard fluid-based heat storage approaches and could enable much more efficient and higher energy density heat storage. GTI's converter could be used to provide solar electricity whether or not the sun is shining.

Sharp Laboratories of America

Partially Transmitting Mirror

Program: FOCUS

Project Term: 06/01/2014 to 05/31/2017

Project Status: ACTIVE

Project State: Washington

Technical Categories: Distributed Generation

Sharp Labs is developing a hybrid solar converter that splits the light spectrum, sending a band of the solar spectrum to solar cells to generate electricity and the rest to a thermal fluid to be stored as heat. The team's converter builds off the CSP trough concentrator design, integrating a partially transmitting mirror near the focus to reflect visible wavelengths of light onto high-efficiency solar cells while passing ultraviolet and most infrared light to heat a thermal fluid. The visible light is concentrated further before reaching the solar cells to maximize their power output. A thermal management system built into the solar cells allows them to be maintained at an optimal operating temperature and could be used to recover useful waste heat. Hot thermal fluid generated by the converter can be stored and used when needed to drive a turbine to produce electricity. The converter leverages the advantages of both PV and CSP to use each portion of the solar spectrum most effectively. This could enable utilities to provide dispatchable, on-demand, solar electricity at low cost even when the sun does not shine.

General Electric

Electrochemical Energy Storage with a Supercritical CO2 Cycle

Program: FOCUS

Project Term: 08/01/2014 to 07/31/2017

Project Status: ACTIVE

Project State: Connecticut

Technical Categories: Distributed Generation

GE is designing and testing components of a turbine system driven by high-temperature, high-pressure carbon dioxide (CO_2) to develop a more durable and efficient energy conversion system. Current solar energy system components break down at high temperatures, shortening the system's cycle life. GE's energy storage system stores heat from the sun in molten salt at moderate temperature and uses surplus electricity from the grid to create a phase change heat sink, which helps manage the temperature of the system. Initially, the CO_2 remains at a low temperature and low pressure to enable more efficient energy storage. Then, the temperature and pressure of the $CO_2$is increased and expanded through a turbine to generate dispatchable electricity. The dramatic change in temperature and pressure is enabled by an innovative system design that prevents thermal losses across the turbine and increases its cycle life. This grid-scale energy storage system could be coupled to a hybrid solar converter to deliver solar electricity on demand.

Arizona State University

Solar-Concentrating Photovoltaic Mirror

Program: FOCUS

Project Term: 06/01/2014 to 05/31/2017

Project Status: ACTIVE

Project State: Arizona

Technical Categories: Distributed Generation

ASU is developing a hybrid solar energy system that modifies a CSP trough design, replacing the curved mirror with solar cells that collect both direct and diffuse rays of a portion of sunlight while reflecting the rest of the direct sunlight to a thermal absorber to generate heat. Electricity from the solar cells can be used immediately while the heat can be stored for later use. Today's CSP systems offer low overall efficiency because they collect only direct sunlight, or the light that comes in a straight beam from the sun. ASU's technology could increase the amount of light that can be converted to electricity by collecting diffuse sunlight, or light that has been scattered by the atmosphere, clouds, and off the earth. By integrating curved solar cells into a hybrid trough system, ASU will effectively split the solar spectrum and use each portion of the spectrum in the most efficient way possible. Diffuse and some direct sunlight are converted into electricity in the solar cells, while the unused portion of the direct sunlight is reflected for conversion to heat.

Massachusetts Institute of Technology

Low-Cost Hetero-Epitaxial Solar Cell for Hybrid Converter

Program: FOCUS

Project Term: 05/15/2014 to 07/31/2015

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Distributed Generation

MIT is developing a high-efficiency solar cell grown on a low-cost silicon wafer, which incorporates a micro-scale heat management system. The team will employ a novel fabrication process to ensure compatibility between the indium gallium phosphide (InGaP) solar cell and an inexpensive silicon wafer template, which will reduce cell costs. MIT will also develop a color-selective filter, designed to split incoming concentrated sunlight into two components. One component will be sent to the solar cells and immediately converted into electricity and the other will be sent to a thermal receiver to be captured as heat. This will allow the simultaneous availability of electricity and heat. By leveraging the InGaP system, MIT's solar cells will be more tolerant to high temperature operation than today's PV cells and allow recovery of more useful higher temperature waste heat through the micro-scale heat management system. The solar cell and heat recovery system will enable more efficient use of the entire solar spectrum to produce dispatchable renewable electricity.

Cogenra Solar, Inc.

Hybrid Solar Converter with Light-Filtering Mirror

Program: FOCUS

Project Term: 07/10/2014 to 07/09/2016

Project Status: ALUMNI

Project State: California

Technical Categories: Distributed Generation

Cogenra Solar is developing a hybrid solar converter with a specialized light-filtering mirror that splits sunlight by wavelength, allowing part of the sunlight spectrum to be converted directly to electricity with photovoltaics (PV), while the rest is captured and stored as heat. By integrating a light-filtering mirror that passes the visible part of the spectrum to a PV cell, the system captures and converts as much as possible of the photons into high-value electricity and concentrates the remaining light onto a thermal fluid, which can be stored and be used as needed. Cogenra's hybrid solar energy system also captures waste heat from the solar cells, providing an additional source of low-temperature heat. This hybrid converter could make more efficient use of the full solar spectrum and can provide inexpensive solar power on demand.

Northrop Grumman Aerospace Systems

Thermo-Acoustic Hybrid Solar Energy System

Program: FOCUS

Project Term: 06/15/2014 to 10/15/2016

Project Status: CANCELLED

Project State: California

Technical Categories: Distributed Generation

Northrop Grumman is developing a dish-shaped sunlight-concentrating hybrid solar converter that integrates high-efficiency solar cells and a thermo-acoustic engine that generates electricity directly from heat. Current solar cells lose significant amounts of energy as heat, because they do not have heat storage capability. By integrating a high-temperature solar cell and thermo-acoustic engine into a single system, thermal energy losses are minimized. The thermo-acoustic unit, which was originally designed for space missions, converts waste heat from the solar cell into sound waves to generate electricity using as few moving parts as possible. The engine and solar cell are connected to a molten salt thermal storage unit to store heat when the sun shines and to release the heat and make electricity when the sun is not shining. Northrop Grumman's system could efficiently generate electricity more cheaply than existing solar power plants and lead to inexpensive, on-demand electricity from solar energy.

MicroLink Devices

Dual-Junction Photovoltaic Topping Device for High-Temp Operation

Program: FOCUS

Project Term: 06/11/2014 to 08/04/2016

Project Status: CANCELLED

Project State: Illinois

Technical Categories: Distributed Generation

MicroLink is developing a high-efficiency solar cell that can maintain efficient operation at high temperatures and leverage reusable cell templates to reduce overall cell cost. MicroLink's cell will be able to operate at temperatures above 400°C, unlike today's solar cells, which lose efficiency rapidly above 100°C and are likely to fail at high temperatures over time. MicroLink's specialized dual-junction design will allow the cell to extract significantly more energy from the sun at high temperature than today's cells, enabling the next generation of hybrid solar converters to deliver much higher quantities of electricity and useful dispatchable heat. When integrated into hybrid solar converters, heat rejected from the cells at high temperature can be stored and used to generate electricity when the sun is not shining.

GENI Green Electricity Network Integration (15)

The projects in ARPA-E's GENI program, short for "Green Electricity Network Integration," aim to modernize the way electricity is transmitted in the U.S. through advances in hardware and software for the electric grid. These advances will improve the efficiency and reliability of electricity transmission, increase the amount of renewable energy the grid can utilize, and provide energy suppliers and consumers with greater control over their power flows in order to better manage peak power demand and cost.

Oak Ridge National Laboratory

Magnetic Amplifier for Power Flow Control

Program: GENI

Project Term: 02/24/2012 to 12/31/2016

Project Status: ACTIVE

Project State: Tennessee

Technical Categories: Grid

ORNL is developing an electromagnet-based, amplifier-like device that will allow for complete control over the flow of power within the electric grid. To date, complete control of power flow within the grid has been prohibitively expensive. ORNL's controller could provide a reliable, cost-effective solution to this problem. The team is combining two types of pre-existing technologies to assist in flow control, culminating in a prototype iron-based magnetic amplifier. Ordinarily, such a device would require expensive superconductive wire, but the magnetic iron core of ORNL's device could serve as a low-cost alternative that is equally adept at regulating power flow.

Texas Engineering Experiment Station

Automated Grid Disruption Response System

Program: GENI

Project Term: 03/01/2012 to 06/30/2015

Project Status: ALUMNI

Project State: Texas

Technical Categories: Grid

The RATC research team is using topology control as a mechanism to improve system operations and manage disruptions within the electric grid. The grid is subject to interruption from cascading faults caused by extreme operating conditions, malicious external attacks, and intermittent electricity generation from renewable energy sources. The RATC system is capable of detecting, classifying, and responding to grid disturbances by reconfiguring the grid in order to maintain economically efficient operations while guaranteeing reliability. The RATC system would help prevent future power outages, which account for roughly $80 billion in losses for businesses and consumers each year. Minimizing the time it takes for the grid to respond to expensive interruptions will also make it easier to integrate intermittent renewable energy sources into the grid.

Varentec, Inc.

Dynamic Power Flow Controller

Program: GENI

Project Term: 01/03/2012 to 05/31/2016

Project Status: ALUMNI

Project State: California

Technical Categories: Grid

Varentec is developing compact, low-cost transmission power controllers with fractional power rating for controlling power flow on transmission networks. The technology will enhance grid operations through improved use of current assets and by dramatically reducing the number of transmission lines that have to be built to meet increasing contributions of renewable energy sources like wind and solar. The proposed transmission controllers would allow for the dynamic control of voltage and power flow, improving the grid's ability to dispatch power in real time to the places where it is most needed. The controllers would work as fail-safe devices whereby the grid would be restored to its present operating state in the event of a controller malfunction instead of failing outright. The ability to affordably and dynamically control power flow with adequate fail-safe switchgear could open up new competitive energy markets which are not possible under the current regulatory structure and technology base.

Boston University

Decision-Support Software for Grid Operators

Program: GENI

Project Term: 04/19/2013 to 03/31/2016

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Grid

The BU team is developing control technology to help grid operators more actively manage power flows and integrate renewables by optimally turning entire power lines on and off in coordination with traditional control of generation and load resources. The control technology being developed would provide grid operators with tools to help manage transmission congestion by identifying the facilities whose on/off status must change to lower generation costs, increase utilization of renewable resources and improve system reliability. The technology is based on fast optimization algorithms for the near to real-time change in the on/off status of transmission facilities and their software implementation.

Smart Wire Grid, Inc.

Distributed Power Flow Control

Program: GENI

Project Term: 04/23/2012 to 09/30/2014

Project Status: ALUMNI

Project State: California

Technical Categories: Grid

Smart Wire Grid is developing a solution for controlling power flow within the electric grid to better manage unused and overall transmission capacity. The 300,000 miles of high-voltage transmission line in the U.S. today are congested and inefficient, with only around 50% of all transmission capacity utilized at any given time. Increased consumer demand should be met in part with a more efficient and economical power flow. Smart Wire Grid's devices clamp onto existing transmission lines and control the flow of power within--much like how internet routers help allocate bandwidth throughout the web. Smart wires could support greater use of renewable energy by providing more consistent control over how that energy is routed within the grid on a real-time basis. This would lessen the concerns surrounding the grid's inability to effectively store intermittent energy from renewables for later use.

Georgia Tech Research Corporation

Autonomous, Decentralized Grid Architecture

Program: GENI

Project Term: 01/11/2012 to 02/15/2015

Project Status: ALUMNI

Project State: Georgia

Technical Categories: Grid

Georgia Tech is developing a decentralized, autonomous, internet-like control architecture and control software system for the electric power grid. Georgia Tech's new architecture is based on the emerging concept of electricity prosumers--economically motivated actors that can produce, consume, or store electricity. Under Georgia Tech's architecture, all of the actors in an energy system are empowered to offer associated energy services based on their capabilities. The actors achieve their sustainability, efficiency, reliability, and economic objectives, while contributing to system-wide reliability and efficiency goals. This is in marked contrast to the current one-way, centralized control paradigm.

AutoGrid, Inc.

Integration of Renewables via Demand Management

Program: GENI

Project Term: 01/11/2012 to 03/31/2014

Project Status: ALUMNI

Project State: California

Technical Categories: Grid

AutoGrid, in conjunction with Lawrence Berkeley National Laboratory and Columbia University, will design and demonstrate automated control software that helps manage real-time demand for energy across the electric grid. Known as the Demand Response Optimization and Management System - Real-Time (DROMS-RT), the software will enable personalized price signals to be sent to millions of customers in extremely short timeframes--incentivizing them to alter their electricity use in response to grid conditions. This will help grid operators better manage unpredictable demand and supply fluctuations in short time-scales--making the power generation process more efficient and cost effective for both suppliers and consumers. DROMS-RT is expected to provide a 90% reduction in the cost of operating demand response and dynamic pricing programs in the U.S.

California Institute of Technology

Scalable Distributed Automation System

Program: GENI

Project Term: 03/01/2012 to 06/01/2015

Project Status: ALUMNI

Project State: California

Technical Categories: Grid

Caltech is developing a distributed automation system that allows distributed generators--solar panels, wind farms, thermal co-generation systems--to effectively manage their own power. To date, the main stumbling block for distributed automation systems has been the inability to develop software that can handle more than 100,000 distributed generators and be implemented in real time. Caltech's software could allow millions of generators to self-manage through local sensing, computation, and communication. Taken together, localized algorithms can support certain global objectives, such as maintaining the balance of energy supply and demand, regulating voltage and frequency, and minimizing cost. An automated, grid-wide power control system would ease the integration of renewable energy sources like solar power into the grid by quickly transmitting power when it is created, eliminating the energy loss associated with the lack of renewable energy storage capacity of the grid.

University of Washington

Renewable Energy Positioning System

Program: GENI

Project Term: 03/01/2012 to 10/14/2015

Project Status: ALUMNI

Project State: Washington

Technical Categories: Grid

The University of Washington and the University of Michigan are developing an integrated system to match well-positioned energy storage facilities with precise control technologies so the electric grid can more easily include energy from renewable power sources like wind and solar. Because renewable energy sources provide intermittent power, it is difficult for the grid to efficiently allocate those resources without developing solutions to store their energy for later use. The two universities are working with utilities, regulators, and the private sector to position renewable energy storage facilities in locations that optimize their ability to provide and transmit electricity where and when it is needed most. Expanding the network of transmission lines is prohibitively expensive, so combining well-placed storage facilities with robust control systems to efficiently route their power will save consumers money and enable the widespread use of safe, renewable sources of power.

Sandia National Laboratory

Probability-Based Software for Grid Optimization

Program: GENI

Project Term: 04/01/2012 to 01/16/2015

Project Status: ALUMNI

Project State: New Mexico

Technical Categories: Grid

Sandia National Laboratories is working with several commercial and university partners to develop software for market management systems (MMSs) that enable greater use of renewable energy sources throughout the grid. MMSs are used to securely and optimally determine which energy resources should be used to service energy demand across the country. Contributions of electricity to the grid from renewable energy sources such as wind and solar are intermittent, introducing complications for MMSs, which have trouble accommodating the multiple sources of price and supply uncertainties associated with bringing these new types of energy into the grid. Sandia's software will bring a new, probability-based formulation to account for these uncertainties. By factoring in various probability scenarios for electricity production from renewable energy sources in real time, Sandia's formula can reduce the risk of inefficient electricity transmission, save ratepayers money, conserve power, and support the future use of renewable energy.

General Electric

Cost-Effective Cable Insulation

Program: GENI

Project Term: 02/24/2012 to 05/31/2014

Project Status: ALUMNI

Project State: Connecticut

Technical Categories: Grid

GE is developing new, low-cost insulation for high-voltage direct current (HVDC) electricity transmission cables. The current material used to insulate HVDC transmission cables is very expensive and can account for as much as 1/3 of the total cost of a high-voltage transmission system. GE is embedding nanomaterials into specialty rubber to create its insulation. Not only are these materials less expensive than those used in conventional HVDC insulation, but also they will help suppress excess charge accumulation. The excess charge left behind on a cable poses a major challenge for high-voltage insulation--if it is not kept to a low level, it could ultimately lead the insulation to fail. GE's low-cost insulation is compatible with existing U.S. cable manufacturing processes, further enhancing its cost effectiveness.

General Atomics

Low-Insertion HVDC Circuit Breaker

Program: GENI

Project Term: 01/09/2012 to 07/31/2013

Project Status: ALUMNI

Project State: California

Technical Categories: Grid

General Atomics is developing a direct current (DC) circuit breaker that could protect the grid from faults 100 times faster than its alternating current (AC) counterparts. Circuit breakers are critical elements in any electrical system. At the grid level, their main function is to isolate parts of the grid where a fault has occurred--such as a downed power line or a transformer explosion--from the rest of the system. DC circuit breakers must interrupt the system during a fault much faster than AC circuit breakers to prevent possible damage to cables, converters and other grid-level components. General Atomics' high-voltage DC circuit breaker would react in less than 1/1,000th of a second to interrupt current during a fault, preventing potential hazards to people and equipment.

Michigan State University

Power Flow Controller for Renewables

Program: GENI

Project Term: 02/08/2012 to 11/15/2015

Project Status: ALUMNI

Project State: Michigan

Technical Categories: Grid

MSU is developing a power flow controller to improve the routing of electricity from renewable sources through existing power lines. The fast, innovative, and lightweight circuitry that MSU is incorporating into its controller will eliminate the need for a separate heavy and expensive transformer, as well as the construction of new transmission lines. MSU's controller is better suited to control power flows from distributed and intermittent wind and solar power systems than traditional transformer-based controllers are, so it will help to integrate more renewable energy into the grid. MSU's power flow controller can be installed anywhere in the existing grid to optimize energy transmission and help reduce transmission congestion.

General Electric

Connecting Renewables Directly to the Grid

Program: GENI

Project Term: 01/23/2012 to 01/22/2015

Project Status: ALUMNI

Project State: Connecticut

Technical Categories: Grid

GE is developing electricity transmission hardware that could connect distributed renewable energy sources, like wind farms, directly to the grid--eliminating the need to feed the energy generated through intermediate power conversion stations before they enter the grid. GE is using the advanced semiconductor material silicon carbide (SiC) to conduct electricity through its transmission hardware because SiC can operate at higher voltage levels than semiconductors made out of other materials. This high-voltage capability is important because electricity must be converted to high-voltage levels before it can be sent along the grid's network of transmission lines. Power companies do this because less electricity is lost along the lines when the voltage is high.

Cornell University

Cloud Computing for the Grid

Program: GENI

Project Term: 02/08/2012 to 08/07/2015

Project Status: ALUMNI

Project State: New York

Technical Categories: Grid

Cornell is creating a new software platform for grid operators called GridControl that will utilize cloud computing to more efficiently control the grid. In a cloud computing system, there are minimal hardware and software demands on users. The user can tap into a network of computers that is housed elsewhere (the cloud) and the network runs computer applications for the user. The user only needs interface software to access all of the cloud's data resources, which can be as simple as a web browser. Cloud computing can reduce costs, facilitate innovation through sharing, empower users, and improve the overall reliability of a dispersed system. Cornell's GridControl will focus on 4 elements: delivering the state of the grid to users quickly and reliably; building networked, scalable grid-control software; tailoring services to emerging smart grid uses; and simulating smart grid behavior under various conditions.

GENSETS Generators for Small Electrical and Thermal Systems (14)

The GENSETS program aims to develop transformative generator technologies to enable widespread deployment of residential combined heat and power (CHP) systems. These small, natural gas-fueled systems can fulfill most of a US household's electricity and hot water needs, and if widely used could increase the overall efficiency of power generation in the US, and reduce greenhouse gas emissions.

Metis Design Corporation

Advanced Microturbine Engine for Residential CHP

Program: GENSETS

Project Term: 10/22/2015 to 10/21/2017

Project Status: ACTIVE

Project State: Massachusetts

Technical Categories: Distributed Generation

Metis Design Corporation (MDC) with Lawrence Berkley National Laboratory will develop a Brayton cycle engine for residential use to produce heat and electricity. To begin the cycle, air is drawn into the system where it is compressed and pressurized. This compressed air is then heated in a recuperator and introduced in to the combustion chamber. Fuel is injected in to the combustion chamber and subsequently the air-fuel mixture is ignited. The high temperature exhaust gases then expand through a turbine, providing some of the work that drives the original compressor and the remainder produces electricity in a generator. Other innovations include adding a rotating vaneless diffuser to the compression process to reduce viscous losses that would normally reduce the efficiency of small compressors. The design also includes a high-efficiency recuperator to capture waste heat from the turbine exhaust and a low swirl burner to reduce emissions.

West Virginia University Research Corporation

Oscillating Linear Engine and Alternator

Program: GENSETS

Project Term: 11/03/2015 to 11/02/2018

Project Status: ACTIVE

Project State: West Virginia

Technical Categories: Distributed Generation

West Virginia University, along with its partners at ANSYS, Inc., Sustainable Engineering, Wilson Works, and Stryke Industries, will develop a CHP generator for residential use based on a two-stroke, spark-ignited free-piston internal combustion engine (ICE). Traditional internal combustion engines use the force generated by the combustion of a fuel (natural gas in this case) to move a piston, transferring chemical energy to mechanical energy, which when used in conjunction with a generator produces electricity. This free-piston design differs from traditional slider-crank ICE models by eliminating the crankshaft and using a spring to increase frequency and stabilize operation. The resulting design is compact with few moving parts and has reduced frictional losses. In place of a traditional alternator, this engine drives a permanent magnet linear electric generator.

Air Squared Inc.

High Efficiency Generator System

Program: GENSETS

Project Term: 05/01/2016 to 04/30/2019

Project Status: ACTIVE

Project State: Colorado

Technical Categories: Distributed Generation

Air Squared Inc., with partners at Argonne National Laboratory, Purdue University, and Mississippi State University, will develop an advanced internal combustion engine (ICE) integrated with an organic Rankine cycle (ORC) for waste heat recovery. The ICE will use spark-assisted compression ignition (SACI) combustion, a turbulent jet ignition (TJI) fueling system, a high compression ratio, and aggressive exhaust gas recirculation to deliver a higher thermal efficiency with low emissions. Traditional internal combustion engines use the force generated by the combustion of a fuel (e.g. natural gas) to move a piston, transferring chemical energy to mechanical energy. This can then be used in conjunction with a generator to create electricity. SACI is an advanced combustion technique that uses a homogeneous mixture of fuel and air with spark assist to enable higher thermal efficiencies and lower emissions. The TJI combustion system further increases thermal efficiency by enabling reliable SACI combustion even with ultra-lean mixtures (i.e. high air to fuel ratio). The ORC design uses mostly the same components of a traditional Rankine cycle, but uses an ammonia/water mixture instead of steam, combined with a novel oil-free scroll expander.

Temple University

Advanced Stirling Power Generation System for CHP

Program: GENSETS

Project Term: 10/26/2015 to 10/25/2018

Project Status: ACTIVE

Project State: Pennsylvania

Technical Categories: Distributed Generation

Temple University and their partner, Infinia Technology Corporation, propose to demonstrate an advanced Stirling power generation system for residential CHP applications. A Stirling engine uses a working gas housed in a sealed environment, in this case the working gas is helium. When heated by the natural gas-fueled burner, the helium expands causing a piston to move and interact with a linear alternator to produce electricity. As the gas cools and contracts, the process resets before repeating again. Advanced Stirling engines endeavor to carefully manage heat inside the system to make the most efficient use of the natural gas energy. This project makes extensive use of additive manufacturing i.e. constructing components one layer at a time - similar to 3D printing. They propose using additive manufacturing because building the system as one piece minimizes interfacial heat losses and improves heat transfer, leading to increased efficiency.

Aerodyne Research, Inc.

Single-Cylinder Two-Stroke Free-Piston Internal Combustion Generator

Program: GENSETS

Project Term: 11/01/2015 to 10/31/2018

Project Status: ACTIVE

Project State: Massachusetts

Technical Categories: Distributed Generation

Aerodyne Research, Inc. with partners from Stony Brook University, Precision Combustion, Inc., and C-K Engineering, Inc. will design and build a CHP generator based on a small single-cylinder, two-stroke free-piston internal combustion engine. Similar to an automotive internal combustion engine, the proposed system follows the same process: the combustion of natural gas fuel creates a force that moves a piston, transferring chemical energy to mechanical energy used in conjunction with a linear alternator to create electricity. The free-piston configuration used here, instead of a traditional slider-crank mechanism, has the potential to achieve high electrical conversion efficiency. Their design also includes a double-helix spring that replaces the crankshaft flywheel in conventional engines and can store 5-10 times the work output of the engine cycle and operates at high frequency, which is key to high energy density, compact size, low weight, and low cost. The system will also incorporate low temperature, glow plug-assisted homogeneous charge compression ignition (HCCI) combustion, which reduces heat loss from the engine and further increases efficiency.

INFINIA TECHNOLOGY CORPORATION

Sustainable Economic mCHP Stirling (SEmS) Generator

Program: GENSETS

Project Term: 11/30/2015 to 11/29/2018

Project Status: ACTIVE

Project State: Washington

Technical Categories: Distributed Generation

Infinia Technology Corporation (ITC) in collaboration with team members Qnergy, Alcoa Howmet, Gas Technology Institute (GTI), MicroCogen Partners, and A.O. Smith Corporation will develop a Free-Piston Stirling engine (FPSE) powered by an ultra-low-emissions natural gas burner for micro-CHP applications. A Stirling engine uses a working gas housed in a sealed environment, in this case the working gas is helium. When heated by the natural gas-fueled burner, the gas expands causing a piston to move and interact with a linear alternator to produce electricity. As the gas cools and contracts, the process resets before repeating again. Advanced Stirling engines endeavor to carefully manage heat inside the system to make the most efficient use of the natural gas energy. The ITC design features free-piston architecture using flexure bearings thus eliminating rubbing parts and allowing for long system life under continuous use. The team will also develop novel materials that enable high-temperature engine operation, further increasing the efficiency of the system.

Sunpower, Inc.

Free Piston Stirling Engine Based 1kW Generator

Program: GENSETS

Project Term: 12/01/2015 to 05/31/2018

Project Status: ACTIVE

Project State: Ohio

Technical Categories: Distributed Generation

Sunpower, Inc., in partnership with Aerojet Rocketdyne and Precision Combustion Inc. (PCI), proposes a high-frequency, high efficiency 1 kW free-piston Stirling engine (FPSE). A Stirling engine uses a working gas such as helium, which is housed in a sealed environment. When heated by the natural gas-fueled burner, the gas expands causing a piston to move and interact with a linear alternator to produce electricity. As the gas cools and contracts, the process resets before repeating again. Advanced Stirling engines endeavor to carefully manage heat inside the system to make the most efficient use of the natural gas energy. New innovations from this team include the highly efficient and high frequency design which reduces size and cost and can be wall mounted. The heater-head assembly acts as the heat exchanger between the burner and the enclosed working gas, and the higher temperature allows for greater efficiency. Aerojet Rocketdyne will assist this effort by developing high temperature materials to use in this process, while PCI will add a novel catalytically-assisted, two-stage, burner to maximize heat transfer to the heater-head.

Tour Engine, Inc.

High Efficiency Split-Cycle Engine for Residential Generators

Program: GENSETS

Project Term: 11/24/2015 to 05/23/2017

Project Status: ACTIVE

Project State: California

Technical Categories: Distributed Generation

Tour Engine, Inc. in collaboration with Wisconsin Engine Research Consultants (WERC) will develop a miniature internal combustion engine (ICE) based on Tour's existing split-cycle engine technology. Traditional ICEs use the force generated by the combustion of a fuel (e.g. natural gas (NG)) to move a piston, transferring chemical energy to mechanical energy. This can then be used in conjunction with a generator to create electricity. Unlike a normal combustion engine, a split-cycle engine divides the process into a cold cylinder (intake and compression) and a hot cylinder (expansion and exhaust). This allows for independent optimization of the compression and expansion ratios, leading to increased thermal efficiency. A novel Spool Shuttle Crossover Valve (SSCV) is the key enabler for the Tour engine, as it transfers the fuel/air charge from the cold to hot cylinder.

Wisconsin Engine Research Consultants, LLC

Spark-Assisted HCCI Residential Generator

Program: GENSETS

Project Term: 12/17/2015 to 12/16/2018

Project Status: ACTIVE

Project State: Wisconsin

Technical Categories: Distributed Generation

Wisconsin Engine Research Consultants (WERC), LLC and its partners Adiabatics, Inc., Briggs and Stratton, and the University of Wisconsin-Madison will develop a generator using an internal combustion engine (ICE) that incorporates an advanced spark-assisted homogeneous charge compression ignition (SA-HCCI) system. Traditional internal combustion engines use the force generated by the combustion of a fuel (e.g. natural gas) to move a piston, transferring chemical energy to mechanical energy. This can then be used in conjunction with a generator to create electricity. SA-HCCI systems achieve combustion by compressing their fuel/air mix to the point of ignition, with a spark helping to initiate the process. These systems run very fuel lean and achieve high efficiency and waste less heat compared to conventional ICEs. In addition, the WERC team will further increase efficiency by incorporating thermal barrier coatings, an advanced boost system, and an optimized low-friction combustion chamber.

Brayton Energy

1kW Recuperated Brayton-Cycle Engine

Program: GENSETS

Project Term: 11/09/2015 to 11/08/2018

Project Status: ACTIVE

Project State: New Hampshire

Technical Categories: Distributed Generation

Brayton Energy, LLC will develop a 1 kW recuperated Brayton cycle engine to produce heat and electricity for residential use. To begin the cycle, compressed air is preheated in a recuperator before adding fuel, then the air-fuel mix is ignited in a combustion chamber. The high temperature exhaust gases then expand through the turbine, providing some of the work that drives the compressor and also produces electricity in a generator. Major project innovations include the use of a rotary screw-type compressor and expander that operate in a sub-atmospheric Brayton cycle i.e. below atmospheric pressure. In addition, Brayton will also use their innovative patented recuperator that is currently in production, and an ultra-low emission combustor.

Sencera Energy, Inc.

Hybrid Engine Generator for Residential CHP

Program: GENSETS

Project Term: 02/01/2016 to 01/31/2018

Project Status: ACTIVE

Project State: North Carolina

Technical Categories: Distributed Generation

Sencera Energy, Inc., and Ohio University will develop a novel kinematic Stirling-Brayton hybrid engine using flexure based volume displacement in lieu of a conventional piston-cylinder Stirling engine. A Stirling engine uses a working gas housed in a sealed environment, in this case the working gas is helium. When heated by the natural gas-fueled burner, the gas expands causing a piston to move and interact with an alternator to produce electricity. As the gas cools and contracts, the process resets before repeating again. Advanced Stirling engines endeavor to carefully manage heat inside the system to make the most efficient use of the natural gas energy. The flexure-based design achieves the same function as a piston-cylinder set by simply changing the volume of the working spaces, as opposed to sliding a piston along the interior of a cylinder. The removal of pistons from the design eliminates the need for sliding seals such as piston rings or air/gas bearings, resulting in lower engine friction, less fluid flow loss and fewer dead volumes. It also lowers the potential fabrication cost compared to other heat engines. The proposed kinematic engine design provides easy coupling to existing rotary alternator designs, which allows the use of robust, mature, and cost-effective off-the-shelf alternator technologies and controllers.

MAHLE Powertrain

Advanced Lean Burn Micro-CHP Genset

Program: GENSETS

Project Term: 11/01/2015 to 11/23/2018

Project Status: ACTIVE

Project State: Michigan

Technical Categories: Distributed Generation

Mahle Powertrain with partners at Oak Ridge National Laboratory, Louthan Engineering, Kohler Company, and Intellichoice Energy will design and develop a CHP generator that uses an internal combustion engine with a turbulent jet ignition (TJI) combustion system. Similar to an automotive internal combustion engine, the proposed system follows the same process: the combustion of natural gas fuel creates a force that moves a piston, transferring chemical energy to mechanical energy used in conjunction with a generator to create electricity. The TJI combustion system incorporates a pre-chamber combustor, enabling the engine to operate in ultra-lean conditions (i.e. high air to fuel mixture), which results in significant improvement in engine thermal efficiency. The team will further increase the system's efficiency by using low friction engine components, while a low-temperature after-treatment system will reduce exhaust emissions.

NanoConversion Technologies, Inc.

High-Efficiency Thermoelectric CHP

Program: GENSETS

Project Term: 11/16/2015 to 11/15/2017

Project Status: ACTIVE

Project State: California

Technical Categories: Distributed Generation

NanoConversion Technologies, Inc. along with researchers from Gas Technologies Institute (GTI), will develop a high-efficiency thermoelectric CHP system. This is a solid-state device that uses heat to create electricity and contains no moving parts, thus creating no noise or vibrations. Instead, this thermoelectric CHP engine uses a novel concentration mode-thermoelectric converter (C-TEC) to harness the heat of the natural gas combustor to vaporize and ionize sodium, creating positive sodium ions and electrons that carry electric current. The C-TEC uses this sodium expansion cycle to produce electricity using an array of electrochemical cells. The superadiabatic combustor technology from GTI provides a low emission external combustion heat source with 95% fuel-to-heat efficiency and a stable temperature compatible with the C-TEC units.

Mohawk Innovative Technology, Inc.

High-Speed Microturbine with Air Foil Bearings for Residential CHP

Program: GENSETS

Project Term: 03/15/2016 to 06/09/2016

Project Status: CANCELLED

Project State: New York

Technical Categories: Distributed Generation

Mohawk Innovative Technology, Inc. (MiTi) and its partners at the University of Texas at Austin and Mitis SA will develop a 1 kW microturbine generator for residential CHP based on MiTi's hyperlaminar flow engine (HFE) design. Key innovations of the design include highly miniaturized components operating at ultra-high speeds and a viscous shear mechanism to compress air that is mixed with natural gas and undergoes a flameless combustion process that minimizes emissions. The hot combustion gas drives the turbine and generator to produce electricity and heat water for household use. Besides using the viscous shear-driven compressor and turbine impellers and flameless combustion, the turbogenerator uses permanent magnet generator elements and air foil bearings with very low power loss, all of which are combined into a highly efficient, low emission, and oil-free turbomachine for residential combined heat and power that requires little or no maintenance.

GRID DATA Generating Realistic Information for the Development of Distribution and Transmission Algorithms (7)

The Generating Realistic Information for the Development of Distribution and Transmission Algorithms (GRID DATA) program will fund the development of large-scale, realistic, validated, and open-access power system network models. These models will have the detail required to allow the successful development and testing of transformational power system optimization and control algorithms, including new Optimal Power Flow (OPF) algorithms. Project teams will take one of two tracks to develop models. The first option is to partner with a utility to collect and then anonymize real data as the basis for a model that can be released publically. The second approach is to construct purely synthetic power system models. The program will also fund the creation of an open-access, self-sustaining repository for the storage, annotation, and curation of these power systems models, as well as others generated by the community.

GridBright, Inc.

Power Systems Model Repository

Program: GRID DATA

Project Term: 05/25/2016 to 05/24/2019

Project Status: ACTIVE

Project State: California

Technical Categories: Grid

GridBright, Inc. and Utility Integration Solutions, LLC. (UISOL, a GE Company) will develop a power systems model repository based on state-of-the-art open-source software. The models in this repository will be used to facilitate testing and adoption of new grid optimization and control algorithms. The repository will use field-proven open-source software and will be made publicly available in the first year of the project. Key features of the repository include an advanced search capability to support search and extraction of models based on key research characteristics, faster model upload and download times, and the ability to support thousands of users. The team will establish a long-term strategy for managing the repository that will allow its operation to continue after its project term with ARPA-E ends.

University of Wisconsin

EPIGRIDS Transmission System Models

Program: GRID DATA

Project Term: 08/10/2016 to 08/10/2018

Project Status: ACTIVE

Project State: Wisconsin

Technical Categories: Grid

The University of Wisconsin-Madison and its partners will develop realistic transmission system models and scenarios that will serve as test cases to reduce barriers to the development and adoption of new technologies in grid optimization and control. The EPIGRIDS project aims to construct realistic grid models by using software to emulate the transmission and generation expansion decision processes used by utility planners. This synthetic model development will utilize Geographic Information Systems (GIS) data on population density, industrial and commercial energy consumption patterns, and land use, over sizes ranging from the city-level to continental-scale. In order to test the robustness of the system's solutions, it will allow users to tailor specific data sets and scenarios to challenge particular aspects of optimization and control algorithm development. Flexible methodologies for data set construction and connecting features of these data sets to geographically described energy use and land use constraints will enable collaborative development of new models, far beyond those directly delivered by this project.

National Renewable Energy Laboratory

[SMARTDATA Grid Models]

Program: GRID DATA

Project Term: 04/01/2016 to 08/31/2018

Project Status: ACTIVE

Project State: Colorado

Technical Categories: Grid

The National Renewable Energy Laboratory (NREL), with partner MIT-Comillas-IIT, will develop combined distribution-transmission power grid models. The team will create distribution models using a version of Comillas' Reference Network Model (RNM) that will be adapted to U.S. utilities and based on real data from a broad range of utility partners. The models will be complemented by the development of customizable scenarios that can be used for accurate algorithm comparisons. These scenarios will take into account unknown factors that affect the grid, such as future power generation technologies, increasing distributed energy resources, varying electrical load, disruptions due to weather events, and repeatable contingency sequences. These enhanced datasets and associated data building tools are intended to provide large-scale test cases that realistically describe potential future grid systems and enable the nation's research community to more accurately test advanced algorithms and control architectures. MIT-Comillas-IIT will assist NREL with the distribution model creation. Alstom Grid will assist in validating the distribution models.

Pacific Northwest National Laboratory

[Sustainable Data Evolution Technology]

Program: GRID DATA

Project Term: 07/19/2016 to 07/18/2019

Project Status: ACTIVE

Project State: Washington

Technical Categories: Grid

The Pacific Northwest National Laboratory (PNNL), along with the National Rural Electric Cooperative Association, PJM, Avista, and CAISO, will develop a sustainable data evolution technology (SDET) to create open-access transmission and distribution power grid datasets as well as data creation tools that the grid community can use to create new datasets based on user requirements and changing grid complexity. The SDET approach will derive features and metrics from many private datasets provided by PNNL's industry partners. For transmission systems, PNNL will develop advanced, graph-theory based techniques and statistical approaches to reproduce the derived features and metrics in synthetic power systems models. For distribution systems, the team will use anonymization and obfuscation techniques and apply them to datasets from utility partners.

University of Illinois, Urbana Champaign

[Synthetic Data for Power Grid R&D]

Program: GRID DATA

Project Term: 06/20/2016 to 06/19/2018

Project Status: ACTIVE

Project State: Illinois

Technical Categories: Grid

The University of Illinois at Urbana-Champaign, with partners from Cornell University, Virginia Commonwealth University, and Arizona State University will develop a set of entirely synthetic electric transmission system models. Their 10 open-source system models and associated scenarios will match the complexity of the actual power grid. By utilizing statistics derived from real data, the team's models will have coordinates based on North American geography with network structure, characteristics, and consumer demand that mimics real grid profiles. Smaller models will be based on smaller areas, such as part of a U.S. state, while the large models will cover much of the continent. All models and their scenarios will be validated using security-constrained optimal power flows, with parameters tuned to emulate the statistical characteristics of actual transmission system models.

University of Michigan

Transmission System Data Set

Program: GRID DATA

Project Term: 05/27/2016 to 05/26/2018

Project Status: ACTIVE

Project State: Michigan

Technical Categories: Grid

The University of Michigan, with partners from Los Alamos National Laboratory, the California Institute of Technology, and Columbia University, will develop a transmission system data set with greater reliability, size, and scope compared to current models. The project combines existing power systems data with advanced obfuscation techniques to anonymize the data while still creating realistic models. In addition, the project delivers year-long test cases that capture grid network behavior over time, enabling the analysis of optimization algorithms over different time scales. These realistic datasets will be used to develop synthetic test cases to examine the scalability and robustness of optimization algorithms. The team is also developing a new format for capturing power system model data using JavaScript Object Notation and will provide open-source tools for data quality control and validation, format translation, synthetic test case generation, and obfuscation. Finally, the project aims at developing an infrastructure for ensuring replicable research and easing experimentation, using the concept of virtual machines to enable comparison of algorithms as hardware and software evolve over time.

Pacific Northwest National Laboratory

Data Repository for Power System Models

Program: GRID DATA

Project Term: 07/01/2016 to 06/30/2020

Project Status: ACTIVE

Project State: Washington

Technical Categories: Grid

The Pacific Northwest National Laboratory (PNNL) has partnered with the National Rural Electric Cooperative Association (NRECA) to build a power system model repository, which will maintain and develop open-access power grid models and data sets. The DR POWER approach will review, annotate, and verify submitted datasets while establishing a repository and a web portal to distribute open-access models and scenarios. Through the portal, users can explore the curated data, create suitable datasets (which may include time variation), review and critique models, and download datasets in a specified format. Key features include the ability to collaboratively build, refine, and review a range of large-scale realistic power system models. For researchers, this represents a significant improvement over the current open availability of only small-scale, static models that do not properly represent the challenging environments encountered by present and future power grids. The repository and the web portal will be hosted in PNNL's Electricity Infrastructure Operations Center with access to petabytes of computing storage and load-balancing across multiple computing resources.

GRIDS Grid-Scale Rampable Intermittent Dispatchable Storage (16)

The projects that comprise ARPA-E's GRIDS program, short for "Grid-Scale Rampable Intermittent Dispatchable Storage," are developing storage technologies that can store renewable energy for use at any location on the grid at an investment cost less than $100 per kilowatt hour. Flexible, large-scale storage would create a stronger and more robust electric grid by enabling renewables to contribute to reliable power generation.

Energy Storage Systems, Inc.

Iron Flow Battery

Program: GRIDS

Project Term: 10/01/2012 to 08/30/2017

Project Status: ACTIVE

Project State: Oregon

Technical Categories: Storage

ESS is developing a cost-effective, reliable, and environmentally friendly all-iron hybrid flow battery. A flow battery is an easily rechargeable system that stores its electrolyte--the material that provides energy--as liquid in external tanks. Currently, flow batteries account for less than 1% of the grid-scale energy storage market because of their high system costs. The ESS flow battery technology is distinguished by its cost-effective electrolytes, based on earth-abundant iron, and its innovative battery hardware design that dramatically increases power density and enables a smaller and less costly battery. Creating a high-performing and low-cost storage system would enable broad adoption of distributed energy storage systems and help bring more renewable energy technologies--such as wind and solar--onto the grid.

United Technologies Research Center

Breakthrough Flow Battery Cell Stack

Program: GRIDS

Project Term: 09/09/2010 to 09/30/2013

Project Status: ALUMNI

Project State: Connecticut

Technical Categories: Storage

UTRC is developing a flow battery with a unique design that provides significantly more power than today's flow battery systems. A flow battery is a cross between a traditional battery and a fuel cell. Flow batteries store their energy in external tanks instead of inside the cell itself. Flow batteries have traditionally been expensive because the battery cell stack, where the chemical reaction takes place, is costly. In this project, UTRC is developing a new stack design that achieves 10 times higher power than today's flow batteries. This high power output means the size of the cell stack can be smaller, reducing the amount of expensive materials that are needed. UTRC's flow battery will reduce the cost of storing electricity for the electric grid, making widespread use feasible.

CUNY Energy Institute

Flow-Assisted Alkaline Battery

Program: GRIDS

Project Term: 09/15/2010 to 03/31/2015

Project Status: ALUMNI

Project State: New York

Technical Categories: Storage

CUNY Energy Institute is working to tame dendrite formation and to enhance the lifetime of Manganese in order to create a long-lasting, fully rechargeable battery for grid-scale energy storage. Traditional consumer-grade disposable batteries are made of Zinc and Manganese, two inexpensive, abundant, and non-toxic metals, but these disposable batteries can only be used once. If they are recharged, the Zinc in the battery develops filaments called dendrites that grow haphazardly and disrupt battery performance, while the Manganese quickly loses its ability to store energy. CUNY Energy Institute is also working to reduce dendrite formation by pumping fluid through the battery, enabling researchers to fix the dendrites as they form. The team has already tested its Zinc battery through 3,000 recharge cycles (and counting). CUNY Energy Institute aims to demonstrate a better cycle life than lithium-ion batteries, which can be up to 20 times more expensive than Zinc-based batteries.

Proton Energy Systems

Regenerative Fuel Cells

Program: GRIDS

Project Term: 09/01/2010 to 03/31/2014

Project Status: ALUMNI

Project State: Connecticut

Technical Categories: Storage

Proton Energy Systems is developing an energy storage device that converts water to hydrogen fuel when excess electricity is available, and then uses hydrogen to generate electricity when energy is needed. The system includes an electrolyzer, which generates and separates hydrogen and oxygen for storage, and a fuel cell which converts the hydrogen and oxygen back to electricity. Traditional systems use acidic membranes, and require expensive materials including platinum and titanium for key parts of the system. In contrast, Proton Energy Systems' new technology will use an inexpensive alkaline membrane and will contain only inexpensive metals such as nickel and stainless steel. If successful, Proton Energy Systems' design will have similar performance to today's regenerative fuel cell systems at a fraction of the cost, and can be used to store electricity on the electric grid.

University of Southern California

Iron-Air Rechargeable Battery

Program: GRIDS

Project Term: 10/01/2010 to 09/30/2013

Project Status: ALUMNI

Project State: California

Technical Categories: Storage

USC is developing an iron-air rechargeable battery for large-scale energy storage that could help integrate renewable energy sources into the electric grid. Iron-air batteries have the potential to store large amounts of energy at low cost--iron is inexpensive and abundant, while oxygen is freely obtained from the air we breathe. However, current iron-air battery technologies have suffered from low efficiency and short life spans. USC is working to dramatically increase the efficiency of the battery by placing chemical additives on the battery's iron-based electrode and restructuring the catalysts at the molecular level on the battery's air-based electrode. This can help the battery resist degradation and increase life span. The goal of the project is to develop a prototype iron-air battery at significantly cost lower than today's best commercial batteries.

ITN Energy Systems, Inc.

Advanced Vanadium Redox Flow Battery

Program: GRIDS

Project Term: 10/01/2012 to 06/30/2015

Project Status: ALUMNI

Project State: Colorado

Technical Categories: Storage

ITN is developing a vanadium redox flow battery for residential and small-scale commercial energy storage that would be more efficient and affordable than today's best energy storage systems. In a redox flow battery, chemical reactions occur that allow the battery to absorb or deliver electricity. Unlike conventional batteries, flow batteries use a liquid (also known as an electrolyte) to store energy; the more electrolyte that is used, the longer the battery can operate. Vanadium electrolyte-based redox flow battery systems are a technology for today's market, but they require expensive ion-exchange membranes. In the past, prices of vanadium have fluctuated, increasing the cost of the electrolyte and posing a major obstacle to more widespread adoption of vanadium redox flow batteries. ITN's design combines a low-cost ion-exchange membrane and a low-cost electrolyte solution to reduce overall system cost, ultimately making a vanadium redox flow battery cost-competitive with more traditional lead-acid batteries.

The Boeing Company

Advanced Flywheel Composite Rotors

Program: GRIDS

Project Term: 10/01/2010 to 09/30/2013

Project Status: ALUMNI

Project State: Illinois

Technical Categories: Storage

Boeing is developing a new material for use in the rotor of a low-cost, high-energy flywheel storage technology. Flywheels store energy by increasing the speed of an internal rotor--slowing the rotor releases the energy back to the grid when needed. The faster the rotor spins, the more energy it can store. Boeing's new material could drastically improve the energy stored in the rotor. The team will work to improve the storage capacity of their flywheels and increase the duration over which they store energy. The ultimate goal of this project is to create a flywheel system that can be scaled up for use by electric utility companies and produce power for a full hour at a cost of $100 per kilowatt hour.

General Compression

[Fuel-Free Compressed-Air Energy Storage]

Program: GRIDS

Project Term: 09/13/2010 to 04/01/2011

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Storage

General Compression has developed a transformative, near-isothermal compressed air energy storage system (GCAES) that prevents air from heating up during compression and cooling down during expansion. When integrated with renewable generation, such as a wind farm, intermittent energy can be stored in compressed air in salt caverns or pressurized tanks. When electricity is needed, the process is reversed and the compressed air is expanded to produce electricity. Unlike conventional compressed air energy storage (CAES) projects, no gas is burned to convert the stored high-pressure air back into electricity. The result of this breakthrough is an ultra-efficient, fully shapeable, 100% renewable and carbon-free power product. The GCAES system can provide high quality electricity and ancillary services by effectively integrating renewables onto the grid at a cost that is competitive with gas, coal, and nuclear generation.

General Atomics

[Soluble Lead Flow Battery]

Program: GRIDS

Project Term: 09/01/2010 to 08/28/2013

Project Status: ALUMNI

Project State: California

Technical Categories: Storage

General Atomics is developing a flow battery technology based on chemistry similar to that used in the traditional lead-acid battery found in nearly every car on the road today. Flow batteries store energy in chemicals that are held in tanks outside the battery. When the energy is needed, the chemicals are pumped through the battery. Using the same basic chemistry as a traditional battery but storing its energy outside of the cell allows for the use of very low-cost materials. The goal is to develop a system that is far more durable than today's lead-acid batteries, can be scaled to deliver megawatts of power, and which lowers the cost of energy storage below $100 per kilowatt hour.

Primus Power

[Advanced Flow Battery Electrodes]

Program: GRIDS

Project Term: 09/01/2010 to 12/31/2012

Project Status: ALUMNI

Project State: California

Technical Categories: Storage

Primus Power is developing zinc-based, rechargeable liquid flow batteries that could produce substantially more energy at lower cost than conventional batteries. A flow battery is similar to a conventional battery, except instead of storing its energy inside the cell it stores that energy for future use in chemicals that are kept in tanks that sit outside the cell. One of the most costly components in a flow battery is the electrode, where the electrochemical reactions actually occur. Primus Power is investigating and developing mixed-metal materials for their electrodes that could ultimately reduce the lifetime cost of flow batteries because they are more durable and long-lasting than electrodes found in traditional batteries. Using these electrodes, Primus Power's flow batteries can be grouped together into robust, containerized storage pods for use by utilities, renewable energy developers, businesses, and campuses.

ABB, Inc.

Magnetic Energy Storage System

Program: GRIDS

Project Term: 10/01/2010 to 06/30/2014

Project Status: ALUMNI

Project State: North Carolina

Technical Categories: Storage

ABB is developing an advanced energy storage system using superconducting magnets that could store significantly more energy than today's best magnetic storage technologies at a fraction of the cost. This system could provide enough storage capacity to encourage more widespread use of renewable power like wind and solar. Superconducting magnetic energy storage systems have been in development for almost 3 decades; however, past devices were designed to supply power only for short durations--generally less than a few minutes. ABB's system would deliver the stored energy at very low cost, making it ideal for eventual use in the electricity grid as a cost-effective competitor to batteries and other energy storage technologies. The device could potentially cost even less, on a per kilowatt basis, than traditional lead-acid batteries.

Fluidic, Inc.

High-Power Zinc-Air Energy Storage

Program: GRIDS

Project Term: 10/01/2010 to 03/31/2013

Project Status: ALUMNI

Project State: Arizona

Technical Categories: Storage

Fluidic is developing a low-cost, rechargeable, high-power module for Zinc-air batteries that will be used to store renewable energy. Zinc-air batteries are traditionally found in small, non-rechargeable devices like hearing aids because they are well-suited to delivering low levels of power for long periods of time. Historically, Zinc-air batteries have not been as useful for applications which require periodic bursts of power, like on the electrical grid. Fluidic hopes to fill this need by combining the high energy, low cost, and long run-time of a Zinc-air battery with new chemistry providing high power, high efficiency, and fast response. The battery module could allow large grid-storage batteries to provide much more power on very short demand--the most costly kind of power for utilities--and with much more versatile performance.

TVN Systems, Inc.

Hydrogen Bromine Battery

Program: GRIDS

Project Term: 10/01/2012 to 06/30/2015

Project Status: ALUMNI

Project State: Kansas

Technical Categories: Storage

TVN is developing an advanced hydrogen-bromine flow battery that incorporates a low-cost membrane and durable catalyst materials. A flow battery's membrane separates its active materials and keeps them from mixing, while the catalyst serves to speed up the chemical reactions that generate electricity. Today's hydrogen-bromine batteries use very expensive membrane material and catalysts that can degrade as the battery is used. TVN is exploring new catalysts that will last longer than today's catalysts, and developing new membranes at a fraction of the cost of today's membranes. Demonstrating long-lasting, cost-competitive storage systems could enable deployment of renewable energy technologies throughout the grid.

Lawrence Berkeley National Laboratory

Hydrogen-Bromine Flow Battery

Program: GRIDS

Project Term: 10/01/2010 to 09/30/2013
Project Status: ALUMNI
Project State: California
Technical Categories: Storage

LBNL is designing a flow battery for grid storage that relies on a hydrogen-bromine chemistry which could be more efficient, last longer, and cost less than today's lead-acid batteries. Flow batteries are fundamentally different from traditional lead-acid batteries because the chemical reactants that provide their energy are stored in external tanks instead of inside the battery. A flow battery can provide more energy because all that is required to increase its storage capacity is to increase the size of the external tanks. The hydrogen-bromine reactants used by LBNL in its flow battery are inexpensive, long lasting, and provide power quickly. The cost of the design could be well below $100 per kilowatt hour, which would rival conventional grid-scale battery technologies.

Materials & Systems Research, Inc.

Advanced Sodium Battery

Program: GRIDS
Project Term: 10/01/2012 to 06/30/2016
Project Status: CANCELLED
Project State: Utah
Technical Categories: Storage

MSRI is developing a high-strength, low-cost solid-state electrolyte membrane structure for use in advanced grid-scale sodium batteries. The electrolyte, a separator between the positive and negative electrodes, carries charged materials called ions. In the solid electrolyte sodium batteries, sodium ions move through the solid-state ceramic electrolyte. This electrolyte is normally brittle, expensive, and difficult to produce because it is formed over the course of hours in high-temperature furnaces. With MSRI's design, this ceramic electrolyte will be produced cheaply within minutes by single-step coating technologies onto high-strength support materials. The high-strength support material provides excellent structural integrity, much superior to the conventional cell design, which depends solely on the brittle ceramic material for its strength. The resulting stronger, cheaper sodium battery design will enable a new generation of low-cost, safe, and reliable batteries for grid-scale energy storage applications.

Beacon Power, LLC

Next-Generation Flywheel Energy Storage

Program: GRIDS
Project Term: 03/06/2012 to 10/31/2015
Project Status: CANCELLED
Project State: Massachusetts
Technical Categories: Storage

Beacon Power is developing a flywheel energy storage system that costs substantially less than existing flywheel technologies. Flywheels store the energy created by turning an internal rotor at high speeds--slowing the rotor releases the energy back to the grid when needed. Beacon Power is redesigning the heart of the flywheel, eliminating the cumbersome hub and shaft typically found at its center. The improved design resembles a flying ring that relies on new magnetic bearings to levitate, freeing it to rotate faster and deliver 400% as much energy as today's flywheels. Beacon Power's flywheels can be linked together to provide storage capacity for balancing the approximately 10% of U.S. electricity that comes from renewable sources each year.

HEATS High Energy Advanced Thermal Storage (15)

The projects that make up ARPA-E's HEATS program, short for "High Energy Advanced Thermal Storage," seek to develop revolutionary, cost-effective ways to store thermal energy. HEATS focuses on 3 specific areas: 1) developing high-temperature solar thermal energy storage capable of cost-effectively delivering electricity around the clock and thermal energy storage for nuclear power plants capable of cost-effectively meeting peak demand, 2) creating synthetic fuel efficiently from sunlight by converting sunlight into heat, and 3) using thermal energy storage to improve the driving range of electric vehicles (EVs) and also enable thermal management of internal combustion engine vehicles.

Massachusetts Institute of Technology

Advanced Thermo-Adsorptive Battery

Program: HEATS

Project Term: 12/13/2011 to 09/30/2016

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Storage

MIT is developing a low-cost, compact, high-capacity, advanced thermo-adsorptive battery (ATB) for effective climate control of EVs. The ATB provides both heating and cooling by taking advantage of the materials' ability to adsorb a significant amount of water. This efficient battery system design could offer up as much as a 30% increase in driving range compared to current EV climate control technology. The ATB provides high-capacity thermal storage with little-to-no electrical power consumption. MIT is also looking to explore the possibility of shifting peak electricity loads for cooling and heating in a variety of other applications, including commercial and residential buildings, data centers, and telecom facilities.

Massachusetts Institute of Technology

Solar Thermal Energy Storage Device

Program: HEATS

Project Term: 01/09/2012 to 01/08/2015

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Storage, Transportation Storage

MIT is developing a thermal energy storage device that captures energy from the sun; this energy can be stored and released at a later time when it is needed most. Within the device, the absorption of sunlight causes the solar thermal fuel's photoactive molecules to change shape, which allows energy to be stored within their chemical bonds. A trigger is applied to release the stored energy as heat, where it can be converted into electricity or used directly as heat. The molecules would then revert to their original shape, and can be recharged using sunlight to begin the process anew. MIT's technology would be 100% renewable, rechargeable like a battery, and emissions-free. Devices using these solar thermal fuels--called HybriSol--can also be used without a grid infrastructure for applications such as de-icing, heating, cooking, and water purification.

University of Minnesota

Solar Thermochemical Fuels Production

Program: HEATS

Project Term: 12/19/2011 to 06/18/2015

Project Status: ALUMNI

Project State: Minnesota

Technical Categories: Storage

The University of Minnesota is developing a solar thermochemical reactor that will efficiently produce fuel from sunlight, using solar energy to produce heat to break chemical bonds. The University of Minnesota envisions producing the fuel by using partial redox cycles and ceria-based reactive materials. The team will achieve unprecedented solar-to-fuel conversion efficiencies of more than 10% (where current state-of-the-art efficiency is 1%) by combined efforts and innovations in material development, and reactor design with effective heat recovery mechanisms and demonstration. This new technology will allow for the effective use of vast domestic solar resources to produce precursors to synthetic fuels that could replace gasoline.

University of Utah

[Advanced Metal-Hydrides-Based Thermal Battery]

Program: HEATS

Project Term: 12/01/2011 to 02/28/2015

Project Status: ALUMNI

Project State: Utah

Technical Categories: Transportation Storage

The University of Utah is developing a compact hot-and-cold thermal battery using advanced metal hydrides that could offer efficient climate control system for EVs. The team's innovative designs of heating and cooling systems for EVs with high energy density, low-cost thermal batteries could significantly reduce the weight and eliminate the space constraint in automobiles. The thermal battery can be charged by plugging it into an electrical outlet while charging the electric battery and it produces heat and cold through a heat exchanger when discharging. The ultimate goal of the project is a climate-controlling thermal battery that can last up to 5,000 charge and discharge cycles while substantially increasing the driving range of EVs, thus reducing the drain on electric batteries.

Pacific Northwest National Laboratory

[Efficient Heat Pump for Electric Vehicles]

Program: HEATS

Project Term: 11/21/2011 to 01/04/2014

Project Status: ALUMNI

Project State: Washington

Technical Categories: Storage

PNNL is developing a new class of advanced nanomaterial called an electrical metal organic framework (EMOF) for EV heating and cooling systems. The EMOF would function similar to a conventional heat pump, which circulates heat or cold to the cabin as needed. However, by directly controlling the EMOF's properties with electricity, the PNNL design is expected to use much less energy than traditional heating and cooling systems. The EMOF-based heat pumps would be light, compact, efficient, and run using virtually no moving parts.

University of South Florida

[Efficient Phase-Change Materials]

Program: HEATS

Project Term: 12/13/2011 to 09/30/2015

Project Status: ALUMNI

Project State: Florida

Technical Categories: Storage

USF is developing low-cost, high-temperature phase-change materials (PCMs) for use in thermal energy storage systems. Heat storage materials are critical to the energy storage process. In solar thermal storage systems, heat can be stored in these materials during the day and released at night--when the sun is not out--to drive a turbine and produce electricity. In nuclear storage systems, heat can be stored in these materials at night and released to produce electricity during daytime peak-demand hours. Most PCMs do not conduct heat very well. Using an innovative, electroless encapsulation technique, USF is enhancing the heat transfer capability of its PCMs. The inner walls of the capsules will be lined with a corrosion-resistant, high-infrared emissivity coating, and the absorptivity of the PCM will be controlled with the addition of nano-sized particles. USF's PCMs remain stable at temperatures from 600 to 1,000°C and can be used for solar thermal power storage, nuclear thermal power storage, and other applications.

Pacific Northwest National Laboratory

[Metal Hydride Thermal Storage]

Program: HEATS

Project Term: 12/05/2011 to 04/30/2014

Project Status: ALUMNI

Project State: Washington

Technical Categories: Storage

PNNL is developing a thermal energy storage system based on a Reversible Metal Hydride Thermochemical (RMHT) system, which uses metal hydride as a heat storage material. Heat storage materials are critical to the energy storage process. In solar thermal storage systems, heat can be stored in these materials during the day and released at night--when the sun is not out--to drive a turbine and produce electricity. In nuclear storage systems, heat can be stored in these materials at night and released to produce electricity during daytime peak-demand hours. PNNL's metal hydride material can reversibly store heat as hydrogen cycles in and out of the material. In a RHMT system, metal hydrides remain stable in high temperatures (600- 800°C). A high-temperature tank in PNNL's storage system releases heat as hydrogen is absorbed, and a low-temperature tank stores the heat until it is needed. The low-cost material and simplicity of PNNL's thermal energy storage system is expected to keep costs down. The system has the potential to significantly increase energy density.

Massachusetts Institute of Technology

[Efficient Heat Storage Materials]

Program: HEATS

Project Term: 11/21/2011 to 11/30/2014

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Storage

MIT is developing efficient heat storage materials for use in solar and nuclear power plants. Heat storage materials are critical to the energy storage process. In solar thermal storage systems, heat can be stored in these materials during the day and released at night--when the sun's not out--to drive a turbine and produce electricity. In nuclear storage systems, heat can be stored in these materials at night and released to produce electricity during daytime peak-demand hours. MIT is designing nanostructured heat storage materials that can store a large amount of heat per unit mass and volume. To do this, MIT is using phase-change materials, which absorb a large amount of latent heat to melt from solid to liquid. MIT's heat storage materials are designed to melt at high temperatures and conduct heat well--this makes them efficient at storing and releasing heat and enhances the overall efficiency of the thermal storage and energy-generation process. MIT's low-cost heat storage materials also have a long life cycle, which further enhances their efficiency.

Abengoa Solar, LLC

[Conversion Tower for Dispatchable Solar Power]

Program: HEATS

Project Term: 01/11/2012 to 07/31/2014

Project Status: ALUMNI

Project State: Colorado

Technical Categories: Storage

Abengoa Solar is developing a high-efficiency solar-electric conversion tower to enable low-cost, fully dispatchable solar energy generation. Abengoa's conversion tower utilizes new system architecture and a two-phase thermal energy storage media with an efficient supercritical carbon dioxide (CO_2) power cycle. The company is using a high-temperature heat-transfer fluid with a phase change in between its hot and cold operating temperature. The fluid serves as a heat storage material and is cheaper and more efficient than conventional heat-storage materials, like molten salt. It also allows the use of a high heat flux solar receiver, advanced high thermal energy density storage, and more efficient power cycles.

NAVITASMAX

Advanced Thermal Energy Storage Technology

Program: HEATS

Project Term: 12/01/2011 to 08/30/2013

Project Status: ALUMNI

Project State: Arizona

Technical Categories: Storage

NAVITASMAX, along with their partners at Harvard University, Cornell University, and Barber-Nichols, is developing a novel thermal energy storage solution. This innovative technology is based on tuning the properties of simple and complex fluids to increase their ability to store more heat. In solar thermal storage systems, heat can be stored in NAVITASMAX's system during the day and released at night--when the sun is not shining--to drive a turbine and produce electricity. In nuclear storage systems, heat can be stored in NAVITASMAX's system at night and released to produce electricity during daytime peak-demand hours.

University of Texas, Austin

Thermal Batteries for Electric Vehicles

Program: HEATS

Project Term: 11/21/2011 to 06/30/2015

Project Status: ALUMNI

Project State: Texas

Technical Categories: Transportation Storage

UT Austin will demonstrate a high-energy density and low-cost thermal storage system that will provide efficient cabin heating and cooling for EVs. Compared to existing HVAC systems powered by electric batteries in EVs, the innovative hot-and-cold thermal batteries-based technology is expected to decrease the manufacturing cost and increase the driving range of next-generation EVs. These thermal batteries can be charged with off-peak electric power together with the electric batteries. Based on innovations in composite materials offering twice the energy density of ice and 10 times the thermal conductivity of water, these thermal batteries are expected to achieve a comparable energy density at 25% of the cost of electric batteries. Moreover, because UT Austin's thermal energy storage systems are modular, they may be incorporated into the heating and cooling systems in buildings, providing further energy efficiencies and positively impacting the emissions of current building heating/cooling systems.

Halotechnics, Inc.

Molten Glass for Thermal Storage

Program: HEATS

Project Term: 01/01/2012 to 09/30/2015

Project Status: ALUMNI

Project State: California

Technical Categories: Storage

Halotechnics is developing a high-temperature thermal energy storage system using a new thermal-storage and heat-transfer material: earth-abundant and low-melting-point molten glass. Heat storage materials are critical to the energy storage process. In solar thermal storage systems, heat can be stored in these materials during the day and released at night--when the sun is not out--to drive a turbine and produce electricity. In nuclear storage systems, heat can be stored in these materials at night and released to produce electricity during daytime peak-demand hours. Halotechnics new thermal storage material targets a price that is potentially cheaper than the molten salt used in most commercial solar thermal storage systems today. It is also extremely stable at temperatures up to 1200°C--hundreds of degrees hotter than the highest temperature molten salt can handle. Being able to function at high temperatures will significantly increase the efficiency of turning heat into electricity. Halotechnics is developing a scalable system to pump, heat, store, and discharge the molten glass. The company is leveraging technology used in the modern glass industry, which has decades of experience handling molten glass.

Sheetak, Inc.

High Energy Density Thermal Batteries

Program: HEATS

Project Term: 11/15/2011 to 03/31/2015

Project Status: ALUMNI

Project State: Texas

Technical Categories: Transportation Storage

Sheetak is developing a new HVAC system to store the energy required for heating and cooling in EVs. This system will replace the traditional refrigerant-based vapor compressors and inefficient heaters used in today's EVs with efficient, light, and rechargeable hot-and-cold thermal batteries. The high energy density thermal battery--which does not use any hazardous substances--can be recharged by an integrated solid-state thermoelectric energy converter while the vehicle is parked and its electrical battery is being charged. Sheetak's converters can also run on the electric battery if needed and provide the required cooling and heating to the passengers--eliminating the space constraint and reducing the weight of EVs that use more traditional compressors and heaters.

United Technologies Research Center

Hybrid Vapor Compression Adsorption System

Program: HEATS

Project Term: 01/04/2012 to 01/03/2015

Project Status: ALUMNI

Project State: Connecticut

Technical Categories: Transportation Storage

UTRC is developing a new climate-control system for EVs that uses a hybrid vapor compression adsorption system with thermal energy storage. The targeted, closed system will use energy during the battery-charging step to recharge the thermal storage, and it will use minimal power to provide cooling or heating to the cabin during a drive cycle. The team will use a unique approach of absorbing a refrigerant on a metal salt, which will create a lightweight, high-energy-density refrigerant. This unique working pair can operate indefinitely as a traditional vapor compression heat pump using electrical energy, if desired. The project will deliver a hot-and-cold battery that provides comfort to the passengers using minimal power, substantially extending the driving range of EVs.

University of Florida

Solar Thermochemical Fuel Production

Program: HEATS

Project Term: 12/19/2011 to 07/15/2016

Project Status: ALUMNI

Project State: Florida

Technical Categories: Distributed Generation, Transport

The University of Florida is developing a windowless high-temperature chemical reactor that converts concentrated solar thermal energy to syngas, which can be used to produce gasoline. The overarching project goal is lowering the cost of the solar thermochemical production of syngas for clean and synthetic hydrocarbon fuels like petroleum. The team will develop processes that rely on water and recycled CO2 as the sole feed-stock, and concentrated solar radiation as the sole energy source, to power the reactor to produce fuel efficiently. Successful large-scale deployment of this solar thermochemical fuel production could substantially improve our national and economic security by replacing imported oil with domestically produced solar fuels.

IDEAS Innovative Development in Energy-Related Applied Science (35)

The IDEAS program - short for Innovative Development in Energy-Related Applied Science - provides a continuing opportunity for the rapid support of early-stage applied research to explore pioneering new concepts with the potential for transformational and disruptive changes in energy technology. IDEAS awards, which are restricted to maximums of one year in duration and $500,000 in funding, are intended to be flexible and may take the form of analyses or exploratory research that provides the agency with information useful for the subsequent development of focused technology programs. IDEAS awards may also support proof-of-concept research to develop a unique technology concept, either in an area not currently supported by the agency or as a potential enhancement to an ongoing focused technology program. This program identifies potentially disruptive concepts in energy-related technologies that challenge the status quo and represent a leap beyond today's technology. That said, an innovative concept alone is not enough. IDEAS projects must also represent a fundamentally new paradigm in energy technology and have the potential to significantly impact ARPA-E's mission areas.

University of Nebraska, Lincoln

Electromagnetic Induction Power Converter

Program: IDEAS

Project Term: 09/01/2016 to 08/31/2017

Project Status: ACTIVE

Project State: Nebraska

Technical Categories: Electrical Efficiency

The University of Nebraska-Lincoln will develop an innovative concept for an electromagnetic induction-based static power converter for AC to AC electrical conversions. Their method will use a new device, the magnetic flux valve, to actively control the magnetic flux of the converter. The voltages induced across the device can be controlled by varying the magnetic fluxes. By synthesizing the induced voltages appropriately, the converter can take an AC input and generate an AC output with controllable amplitude, frequency, and waveform. During this project, the team plans to prove the concept of the magnetic flux valve; prove the concept for variable-frequency and variable voltage AC-AC electrical energy conversion; and conduct a study on the scalability of the magnetic flux valve and electromagnetic power converter concepts. If successful, the technology has the potential to achieve lower cost, higher energy density, and higher efficiency than traditional energy conversion technologies. More efficient conversion technologies for high voltage and high power applications can lead to new innovations in renewable power generation and smart grid applications.

California Institute of Technology

Acoustic Wave Enhanced Catalysis

Program: IDEAS

Project Term: 03/09/2015 to 12/31/2016

Project Status: ACTIVE

Project State: California

Technical Categories: Transportation Fuels

The California Institute of Technology team is using first-principles reasoning (i.e. a mode of examination that begins with the most basic physical principles related to an issue and "builds up" from there) and advanced computational modeling to ascertain the underlying mechanisms that cause acoustic waves to affect catalytic reaction pathways. The team will first focus their efforts on two types of reactions for which there is strong experimental evidence that acoustic waves can enhance catalytic activity: Carbon Monoxide (CO) oxidation, and Ethanol decomposition. Armed with this new understanding, the team will suggest promising applications for acoustic wave enhanced catalysis to new reactions with large energy and emissions footprints, such as ammonia synthesis. As an ARPA-E IDEAS project, this research is at a very early stage. However, this novel approach to acoustic wave enhanced catalysis has the potential to improve energy and resource efficiency across broad swathes of the chemical, industrial, and other sectors of the economy.

Johns Hopkins University

More information on Johns Hopkins' project is coming soon!

Program: IDEAS

Project Term: 10/01/2015 to 03/31/2017

Project Status: ACTIVE

Project State: Maryland

Technical Categories: Manufacturing Efficiency

University of Colorado, Boulder

Capacitive Wireless Power System

Program: IDEAS

Project Term: 10/15/2015 to 02/14/2017

Project Status: ACTIVE

Project State: Colorado

Technical Categories: Transportation Vehicles

The University of Colorado at Boulder proposes to develop a capacitive wireless power transfer (WPT) architecture to dynamically charge EVs. Dynamic charging poses serious technical challenges. Transmitters must be connected to the plates in the road while rectifiers and battery charging is integrated with the plates in the vehicle. While energy transfer through the air is efficient, the large distance between the embedded vehicle plates and the road results in a weaker pairing between the two. To effectively transfer kilowatts of power without exceeding safe voltages, the operating frequency of the resonant inverters has to be very high. Today's WPT systems operate with resonant magnetic fields focused with hefty ferrite cores and losses in these ferrites limit the frequency at which these systems can operate to less than 150 kHz. This project focuses on capacitive WPT with potentially higher efficiency than resonant inductive power transfer, while reducing size and cost. The team will develop a novel MHz frequency capacitive WPT system that safely operates within the industrial, scientific, and medical (ISM) radio spectrum. The team's WPT technology aims to improve EVs by reducing the need for expensive and bulky on-board batteries, enable unlimited driving range, and accelerate electric vehicle penetration. The project aims to design a 1-kW 12-cm air gap capacitive WPT, which targets >90% efficiency and 50 kW/m2 power transfer density, a power density improvement of 2 over current methods.

Iowa State University

Catalytic Autothermal Pyrolysis

Program: IDEAS

Project Term: 08/15/2016 to 08/14/2017

Project Status: ACTIVE

Project State: Iowa

Technical Categories: Transportation Fuels

Iowa State University will develop a catalytic autothermal pyrolysis (CAP) process for the production of aromatics and olefins that refiners blend into transportation fuels. Pyrolysis is the decomposition of substances by heating - the same process used to render wood into charcoal, caramelize sugar, and dry roast coffee beans. Traditionally, energy for pyrolysis is provided through indirect heat exchange, employing high temperature heat exchangers within reactors or conveying hot solids into reactors with the feedstock. This approach complicates the design and operation of reactors and requires a separate combustor to burn char, coke, or other fuel to generate the thermal energy. The Iowa State team plans to use an autothermal fluidized bed reactor, a specialized reactor where a gas is passed through solid granular material at high velocity. Air is used as the fluidizing gas to promote direct, partial combustion of biomass and pyrolysis products to supply the energy required for endothermic operation. This will replace indirect heating methods with direct heating within the reactor, simplifying the design and reducing capital cost while increasing throughput, improving catalyst life, and achieving product yield and quality similar to or greater than current processes. The teams seeks to demonstrate CAP in the laboratory and pilot-scale reactors; identify optimal CAP operating conditions to maximize the yield of hydrocarbons; and develop engineering scaling relationships for CAP reactors to facilitate the design of commercial-scale CAP reactors.

Cornell University

[Secondary Lithium Metal Batteries]

Program: IDEAS

Project Term: 08/17/2016 to 08/16/2017

Project Status: ACTIVE

Project State: New York

Technical Categories: Transportation Fuels

Cornell University will develop a new type of rechargeable lithium metal battery that provides superior performance over existing lithium-ion batteries. The anode, or negative side of a lithium-ion battery, is usually composed of a carbon-based material. In lithium metal batteries, the anode is made of metallic lithium. While using metallic lithium could result in double the storage capacity, lithium metal batteries have unreliable performance, safety issues, and premature cell failure. There are two major causes for this performance degradation. First, side reactions can occur between the lithium metal and the liquid or solid electrolyte placed between the positive and negative electrodes. Second, when recharged, branchlike metal fibers called dendrites can grow on the negative electrode. These dendrites can grow to span the space between the negative and positive electrodes, causing short-circuiting. To overcome these challenges, Cornell proposes research to pair a variety of cathodes with a lithium metal anode. The work builds upon recent theoretical and experimental discoveries by the team, which show that a class of structured electrolytes can provide multiple mechanisms for stabilizing lithium metal anodes and suppress dendrite growth. The team will also develop structured electrolyte coatings that provide barriers to oxygen and moisture, but do not impede lithium-ion transport across the electrolyte/electrode interface. Such coatings will suppress the unwelcome lithium metal/electrolyte reactions and will also enable manufacturing of lithium metal batteries under standard dry room conditions. The structures developed could also be used in batteries based on other metals, such as sodium and aluminum that are more abundant and less expensive than lithium, but also affected by dendrite formation.

Citrine Informatics

[Machine Learning for Solid Ion Conductors]

Program: IDEAS

Project Term: 12/22/2015 to 12/21/2016

Project Status: ACTIVE

Project State: California

Technical Categories: Storage, Transportation Storage

The Citrine Informatics team is demonstrating a proof-of-concept for a system that would use experimental work to intelligently guide the investigation of new solid ionic conductor materials. If successful, the project will create a new approach to material discovery generally and new direction for developing promising ionic conductors specifically. The project will aggregate data (both quantitative and meta-data related to experimental conditions) relevant to ionic conductors from the published literature and build advanced, machine learning models for prediction based upon the resulting large database. The team's system will also experimentally explore the new materials space identified and suggested by the models. The Citrine project could provide researchers near-real-time feedback as they perform experiments, allowing them to dynamically select the most promising research pathways. This would in turn unlock more rapid ionic conductor identification and development, and transform the fields of theoretical and experimental materials science at-large.

Johns Hopkins University

[Adsorption Compression on Chemical Reactions]

Program: IDEAS

Project Term: 02/05/2016 to 02/04/2017

Project Status: ACTIVE

Project State: Maryland

Technical Categories: Resource Efficiency

Johns Hopkins University will study the adsorption compression phenomenon for ways to enhance the reaction rate for commercially relevant reactions. Adsorption is the adhesion of molecules from a gas, liquid, or dissolved solid to a surface, creating layers of the “adsorbate” on the surface of the host material. The Johns Hopkins team will explore the physical state where the forces acting parallel to the surface of adsorbate molecules can in certain conditions be far higher than forces associated with adsorption of additional molecules on the surface. This phenomenon is called adsorption compression. This compression is important because it leads to a strain in intramolecular bonds and can change the activation energy for many chemical reactions – which can alter reaction pathways, increase reactivity, or improve selectivity for desired products. The team plans to explore this phenomenon as a method to improve the efficiency of commercial catalytic systems.

Princeton University

Acoustic Analysis for Battery Testing

Program: IDEAS

Project Term: 10/01/2015 to 03/30/2017

Project Status: ACTIVE

Project State: New Jersey

Technical Categories: Electrical Efficiency

The Princeton University team is developing a non-invasive, low-cost, ultrasonic diagnostic system to determine battery state-of-health and state-of-charge, and to monitor internal battery defects. This system links the propagation of sound waves through a battery to the material properties of components within the battery. As a battery is cycled, the density and mechanical properties of its electrodes change; as the battery ages, it experiences progressive formation and degradation of critical surface layers, mechanical degradation of electrodes, and consumption of electrolyte. All of these phenomena affect how the sound waves pass through the battery. There are very few sensing techniques available that can be used during battery production and operation which can quickly identify changes or faults within the battery as they occur. As an ARPA-E IDEAS project, this early stage research project will provide proof of concept for the sensing technique and build a database of acoustic signatures for different battery chemistries, form factors, and use conditions. If successful, this ultrasonic diagnostic system will improve battery quality, safety, and performance of electric vehicle and grid energy storage systems via two avenues: (1) more thorough and efficient cell screening during production, and (2) physically relevant information for more informed battery management strategies.

Columbia University

More information on Columbia's project is coming soon!

Program: IDEAS

Project Term: 06/10/2016 to 06/09/2017

Project Status: ACTIVE

Project State: New York

Technical Categories: Distributed Generation

Inventev LLC

More information on Inventev's project is coming soon!

Program: IDEAS

Project Term: 01/06/2016 to 01/05/2017

Project Status: ACTIVE

Project State: Michigan

Technical Categories: Transportation Vehicles

Palo Alto Research Center

More information on PARC's project is coming soon!

Program: IDEAS

Project Term: 12/17/2015 to 12/16/2016
Project Status: ACTIVE
Project State: California
Technical Categories: Distributed Generation, Resource

Northeastern University

Materials for Magnetocaloric Applications

Program: IDEAS
Project Term: 09/01/2016 to 08/31/2017
Project Status: ACTIVE
Project State: Massachusetts
Technical Categories: Building Efficiency

Northeastern University, in partnership with the Ames Laboratory, will evaluate a range of new magnetocaloric compounds (AlT2X2) for potential application in room-temperature magnetic cooling. Magnetic refrigeration is an environmentally friendly alternative to conventional vapor-compression cooling technology. The magnetocaloric effect is triggered by application and removal of an applied magnetic field--adjusting the magnetic field translates into an adjustment in the temperature of the material. The benchmark magnetocaloric materials are based on the rare earth metal gadolinium (Gd), but gadolinium is scarce in the earth's crust and prohibitively expensive. Other magnetocaloric materials have similar rarity and cost constraints, or are brittle and undergo large volume changes during magnetic transition. Volume changes are problematic because a magnetocaloric working material must maintain mechanical and magnetic integrity over 300 million cycles in a ten-year lifetime. The Northeastern-led team is proposing to explore new magnetocaloric materials, AlT2X2(where T=Fe, Mn, and/or Co, and X = B and/or C) comprised of abundant, non-toxic elements that can undergo a structural transition near room temperature. The material is projected to meet or exceed the performance of other candidate magnetocaloric materials due to its potential ease of fabrication, corrosion resistance, high mechanical integrity maintained through caloric phase change, and low heat capacity that fosters effective heat transfer. The project objectives are to ascertain the most promising compositions and magnetic field and temperature combinations to realize the optimal magnetocaloric response in this compound.

University of Maryland

Current Collectors for Aqueous Batteries

Program: IDEAS
Project Term: 04/14/2016 to 04/13/2017
Project Status: ACTIVE
Project State: Maryland
Technical Categories: Storage

The University of Maryland will develop a new type of current collector using a film that is composed of functionalized few-walled carbon nanotubes (FWNTs) and polymers. The team seeks to develop a thin, low-cost current collector that displays high conductivity, excellent mechanical strength, flexibility, and manufacturing scalability. Carbon nanotubes have high conductivity, but in their pure state lack the needed mechanical strength. The FWNT concept will "functionalize" or bolster the outer walls by integrating polymers to increase the mechanical strength. This will give the product the dual benefits of direct tube-on-tube contact for fast recharging and increased mechanical strength and stability from the polymers. Replacement of metal mesh by FWNT-polymer film will not only address current collector corrosion concerns, but will also offer increased energy density due to the substantially lighter weight of these carbon-based materials compared to traditional metallic current collectors.

Columbia University

Computing Through Silicon Photonics

Program: IDEAS
Project Term: 03/04/2016 to 03/03/2017
Project Status: ACTIVE

Project State: New York

Technical Categories: Electrical Efficiency

Columbia University will develop a new platform for generating multiple simultaneous optical channels (wavelengths) with low power dissipation, thereby enabling optical interconnects for low power computing. Optical interconnect links communicate using optical fibers that carry light. Wavelength-division multiplexing (WDM) is a technology that combines a number of optical carrier signals on a single optical fiber by using different wavelengths. This technique enables bidirectional communications over strands of fiber, dramatically increasing capacity. Low-power lasers generate the wavelengths used in a WDM system, but it is important to stabilize the wavelength for each channel to allow for precise separation and filtering. The importance of stabilization increases when the number and density of wavelength channels increases. Energy use also increases because each of the laser sources must be individually stabilized. In contrast, the Columbia team proposes using a single high-powered stabilized laser to generate greater than 50 wavelength sources with high efficiency using an on-chip comb. This approach can improve laser energy efficiency from 0.01% to 10%.

William Marsh Rice University

More information on Rice University's project is coming soon!

Program: IDEAS

Project Term: 09/15/2016 to 09/14/2017

Project Status: ACTIVE

Project State: Texas

Technical Categories: Transportation Fuels

Gas Technology Institute

Methane Soft Oxidation

Program: IDEAS

Project Term: 09/07/2016 to 09/06/2017

Project Status: ACTIVE

Project State: Illinois

Technical Categories: Transportation Fuels

Gas Technology Institute (GTI) will develop a sulfur-based methane oxidation process, known as soft oxidation, to convert methane into liquid fuels and chemicals. Current gas-to-liquid technology for converting methane to liquid hydrocarbons requires massive scale to achieve economic production. The large plant size makes this approach unsuitable to address the challenge of distributed methane emissions. Soft oxidation is a method better suited to address this challenge because of its modular nature. It also addresses a major limitation of conventional gas-to-liquid technology: the irreversible conversion of methane and oxygen to carbon dioxide. In this project, GTI will demonstrate and optimize a two-step methane soft oxidation process and develop a fully integrated system that converts methane to liquid hydrocarbons, recovers the valuable liquids and hydrogen gas, and recycles the remaining products. A key difference with traditional oxygen-based approaches is that GTI's method allows for some hydrogen recovery, whereas in oxygen-based approaches the hydrogen must be consumed completely. Soft oxidation has a higher efficiency because of this, and it lacks the need for complex heat integration and recovery methods that require large scale plants. If successful, this new process could provide an economic pathway to significantly reduce methane emissions through on-site conversion.

Georgia Tech Research Corporation

Hollow Fibers for Separations

Program: IDEAS

Project Term: 07/27/2016 to 07/26/2017

Project Status: ACTIVE

Project State: Georgia

Technical Categories: Manufacturing Efficiency

The Georgia Institute of Technology will develop hollow fiber membranes containing metal-organic framework (MOF) thin films to separate propylene from propane. The nanoporous MOF film is supported on the inside surfaces of the tubular polymeric hollow fibers. Chemicals introduced into the center of the tube are separated through the MOF membrane by a molecular sieving process. Traditional olefin production processes are performed at pressures up to 20 bar, requiring large energy and capital costs. A key feature of the team's technology is the ability to synthesize membranes at near-ambient liquid-phase conditions and perform olefin separation at lower pressures as low as 6 bar. As the team evaluates using its MOF membranes to separate propylene from propane, the team will also develop detailed correlations between processing conditions, membrane morphology, and membrane performance. Another important task is to perform a detailed economic evaluation of the technology and establish its economic advantages compared to existing and other proposed technologies. The general separations concept also has potential to be used for a larger range of petrochemical and gas separations.

Hi Fidelity Genetics LLC

More information on Hi Fidelity's project is coming soon!

Program: IDEAS

Project Term: 05/05/2016 to 05/04/2017

Project Status: ACTIVE

Project State: North Carolina

Technical Categories: Transportation Fuels

Colorado School of Mines

Ammonia Synthesis Membrane Reactor

Program: IDEAS

Project Term: 09/27/2016 to 09/26/2017

Project Status: ACTIVE

Project State: Colorado

Technical Categories: Storage

The Colorado School of Mines will develop a membrane reactor concept to synthesize ammonia at ambient pressure. In traditional ammonia production processes, nitrogen (N2) and hydrogen (H2) compete for identical catalyst sites, and the presence of each inhibits the other, with the overall rate reflecting a compromise. The team proposes decoupling and independently controlling the N2 and H2 dissociation by dedicating one side of the composite membrane to each. In this way, the catalysts may be individually optimized. Highly effective catalysts have been previously demonstrated for H2 dissociation, and the team's focus will be on exploring early transition metals which have shown great promise as catalysts for N2 dissociation. When perfected, this technology will allow the production of ammonia at ambient pressure, reducing the scale and number of steps required in the process. This method is also an improvement over electrochemical processes, which have a more complicated design and reduced efficiency due to the need for an external voltage.

University of California, Los Angeles

Renewable Production of Commodity Chemicals

Program: IDEAS

Project Term: 03/20/2015 to 12/31/2016

Project Status: ACTIVE

Project State: California

Technical Categories: Manufacturing Efficiency

The University of California, Los Angeles (UCLA) seek to develop a platform technology, Catalytic Units for Synthetic Biochemistry (CUSB). The method will use enzymes to convert biomass carbohydrate into a wide variety of useful carbon compounds in extremely high yield. The team envisions catalytic breakdown modules that will reduce the carbohydrate to simpler compounds, breakdown energy is released during this chemical process and can be stored in other high energy chemicals. Additional catalytic modules will be added to utilize the carbon and energy from the breakdown module to build useful chemicals that can replace petroleum products. This process can potentially generate new markets by producing complex chemicals more economically and with higher energy efficiency than current methods. The team predicts that their technology can reduce the non-renewable energy input required for chemical production by more than 2.5 fold. The system can also provide large-scale production of chemicals that are too costly or too environmentally damaging to produce by current methods. The UCLA team proposes to demonstrate CUSB by building a prototype system that can produce limonene, a colorless liquid hydrocarbon that could also be used as a fuel, at a much higher yield and productivity that has been previously achieved. The successful development of CUSB will represent a paradigm shift in the way high volume commodity chemicals can be produced from renewable resources.

Saint-Gobain Ceramics and Plastics, Inc.

High Temperature Ceramics for Solar Fuel Production

Program: IDEAS

Project Term: 01/19/2016 to 01/18/2017

Project Status: ACTIVE

Project State: Massachusetts

Technical Categories: Distributed Generation

The Saint-Gobain team is conducting early-stage research to extend operating temperatures of industrial ceramics in steam-containing atmospheres up to 1,500 °C. Materials that are able to adequately withstand these punishing conditions are needed to create durable solar fuel reactors. The most attractive material based on high-temperature strength and thermal shock resistance is sintered (the process of compacting solid material without melting it) silicon carbide (SiC). However, the highly reactive $H2O/H2/CO/CO2$atmosphere within a solar reactor causes most industrial ceramics, including SiC, to degrade at temperatures above 1,200 °C. At those temperatures volatile reaction products are formed, which continually eat away at the integrity of the reactor walls. The Saint-Gobain team is conducting research along three lines of inquiry: 1) Creating high-temperature coatings for the SiC material; 2) Creating "self-healing" SiC surfaces which are created via an oxidation reaction on an ongoing basis as the surface layer is damaged; and 3) Testing alternative ceramic materials which could be more robust. The results of the three lines of inquiry will be evaluated based on stability modeling and thermal cycling testing (i.e. repeatedly heating and cooling the materials) under simulated conditions. As an ARPA-E IDEAS project, this research is at a very early stage. If successful, the technology could potentially result in significant energy and cost savings to the U.S. economy by allowing liquid transportation fuel to be produced from water and carbon dioxide from the air via solar energy instead of conventional sources. In addition SiC materials with enhanced oxidation resistance could be applied to vessels and components across many industrial, thermal, chemical, and petrochemical processes.

Bigwood Systems, Inc.

Global-Optimal Power Flow (G-OPF)

Program: IDEAS

Project Term: 03/18/2015 to 06/30/2016

Project Status: ALUMNI

Project State: New York

Technical Categories: Grid

Bigwood Systems, Inc. is developing a comprehensive Optimal Power Flow (OPF) modelling engine that will enhance the energy efficiency, stability, and cost effectiveness of the national electric grid. Like water flowing down a hill, electricity takes the path of least resistance which depends on the grid network topology and on grid controls. However, in a complicated networked environment, this can easily lead to costly congestion or shortages in certain areas of the electric grid. Grid operators use imperfect solutions like approximations, professional judgments, or conservative estimates to try to ensure reliability while minimizing costs. Bigwood Systems' approach will combine four separate analytical technologies to develop an OPF modeling engine that could markedly improve management of the grid. As part of this project, Bigwood Systems will demonstrate the practical applications of this tool in partnership with the California Independent System Operator (CAISO).

University of California, San Diego

Novel Electrolytes

Program: IDEAS

Project Term: 04/01/2014 to 08/31/2015

Project Status: ALUMNI

Project State: California

Technical Categories: Storage, Transportation Storage

The University of California at San Diego (UCSD) is developing an early-stage concept for an advanced electrochemical energy storage system. If successful, the new approach would enable higher-energy density and higher-power systems that are able to operate over a much wider temperature and voltage range than today's technologies. Similar to how water is used as a suspension medium for the acid in a conventional lead-acid car battery, the research team is studying the use of certain gases liquefied under pressure as solvents in novel electrolyte systems. The team's work will enhance our understanding of the electrochemical mechanisms involved, and demonstrate their energy storage and cycling capabilities. The work will evaluate the new electrolyte solvents for safety, non-toxicity, non-flammability, performance and cost compared to the traditional organic solvents used today.

Signetron Inc.

More information about Signetron's project is coming soon!

Program: IDEAS

Project Term: 07/06/2015 to 07/05/2016

Project Status: ALUMNI

Project State: California

Technical Categories: Building Efficiency

Ricardo, Inc.

Reducing Automotive CAPEX Entry Barriers

Program: IDEAS

Project Term: 01/01/2015 to 09/30/2015

Project Status: ALUMNI

Project State: Michigan

Technical Categories: Manufacturing Efficiency

Ricardo Inc will develop a detailed cost model for 10 key automotive components (e.g. chassis, powertrain, controls, etc.), analyzing the investment barriers at production volumes. Prior studies of innovative manufacturing processes and lightweight materials have used differing cost analysis assumptions, which makes comparison of these individual studies difficult. The backbone of the project will be a detailed economic model built on a set of common assumptions that will allow the root cause of cost barriers to be identified. The model will then evaluate emerging alternative manufacturing techniques to determine how they might reduce or remove these barriers. This model will utilize a consistent set of assumptions, allowing for an accurate comparison of potential manufacturing techniques. If successful, this cost model will enable private-sector firms to make informed investment decisions, increasing the deployment of innovative vehicle technologies and saving the average consumer money.

University of Maryland

More information about UMD's project is coming soon!

Program: IDEAS

Project Term: 02/13/2015 to 02/12/2016

Project Status: ALUMNI

Project State: Maryland

Technical Categories: Electrical Efficiency

University of Maryland

[Next-Generation Air-Cooled Heat Exchangers]

Program: IDEAS

Project Term: 07/25/2014 to 10/24/2015

Project Status: ALUMNI

Project State: Maryland

Technical Categories: Manufacturing Efficiency

The University of Maryland (UMD) will leverage recent advances in additive manufacturing to develop a next-generation air-cooled heat exchanger. The UMD team will assess the performance and cost of current state-of-the-art technology, including innovative manufacturing processes. The team will then utilize computer models to simulate a wide-range of novel heat exchanger designs that can radically enhance air-side heat transfer performance. The team will then physically build and test two 1 kilowatt (kW) prototype devices. If successful, these heat exchangers would enable new, highly-efficient dry cooling of steam condensers that could eliminate evaporative water losses from power plant cooling. Advances in efficient air-side cooling could also have significant spillover benefits in aerospace, automobile, air-conditioning and refrigeration, electronics cooling, and chemical processing.

Columbia University

[Co-Generation of Fuels During Copper Bioleaching]

Program: IDEAS

Project Term: 03/01/2015 to 05/30/2016

Project Status: ALUMNI

Project State: New York

Technical Categories: Transportation Fuels

The innovation lies in the exploitation of novel natural energy source: reduced metal deposits. The energy released during oxidation of these metals could be used to reduce CO2 into fuels and chemicals reducing petroleum usage.This proposed project fits within the Chemical-Chemical Area of Interest, as it involves the coupling of the oxidation of reduced minerals in the Earth's crust to the production of reduced carbon chemicals for fuel utilization. This addresses both of Mission Areas of ARPA-E as the co-generation of fuels during copper bioleaching will potentially reduce the import of energy from foreign sources, reduce greenhouse gas emissions, improve energy efficiency in the mining industry, and ensure that the U.S. maintains a lead in the development of this disruptive new technology.

Princeton Optronics

[Development of a New Type of Laser Ignition System]

Program: IDEAS

Project Term: 10/01/2014 to 09/30/2015

Project Status: ALUMNI

Project State: New Jersey

Technical Categories: Transportation Vehicles

Princeton Optronics will develop a low-cost, high-temperature capable laser ignition system which can be mounted directly on the engine heads of stationary natural gas engines, just like regular spark plugs are today. This will be done using a newly developed high-temperature Vertical Cavity Surface Emitting Laser (VCSEL) pump combined with a solid-state laser gain material that can operate at temperatures typically experienced on a stationary natural gas engine. The key innovations of this project will allow the laser pump and complete laser ignition system to deliver the required pulse energy output at the engine block temperature and create a solution that is entirely exchangeable with a conventional spark plug. This avoids the need for an expensive and complicated fiber optics system to deliver the laser energy to the engine's combustion chamber from an off-board, cooled location. If successful, the high temperature laser ignition system will provide a reliable solution to extend the lean limit of combustion and increase the efficiency of stationary natural gas engines, resulting in significant fuel savings and emissions reductions.

Space Orbital Services

Low Temperature Methane Conversion Through Impacting Common Alloy Catalysts

Program: IDEAS

Project Term: 08/01/2014 to 12/31/2015

Project Status: ALUMNI

Project State: California

Technical Categories: Transportation Fuels

Space Orbital Services, in conjunction with SRI International, proposes to conduct laboratory-based, small-scale research to develop a methane conversion technology that employs unconventional chemistry at relatively low temperature, based on impacting a common alloy catalyst. The project uses laboratory experiments to establish, measure and refine operational parameters including conversion rates and efficiency, reaction products, and reactor design.

University of Michigan

Benchtop Growth of High Quality Thin Film Photovoltaics

Program: IDEAS

Project Term: 01/01/2015 to 03/31/2016

Project Status: ALUMNI

Project State: Michigan

Technical Categories: Distributed Generation

The University of Michigan is investigating a new, hybrid thin-film PV production technology that combines two different semiconductor production techniques: electrodeposition (the deposition of a substance on an electrode by the action of electricity) and epitaxial crystal growth (the growth of crystals of one substance on the crystal face of another substance). If successful, the University of Michigan's new hybrid approach would produce highly efficient (above 20%) gallium arsenide thin film solar cells using only simple process equipment, non-flammable precursor ingredients, and relatively low production temperatures (below 350 °C). This would radically decrease the production cost per watt of solar capacity, making it substantially less expensive and more competitive with other energy sources.

Grid Logic, Inc.

Nanostructured Core/Shell Powders for Magnets

Program: IDEAS

Project Term: 06/01/2015 to 06/30/2016

Project Status: ALUMNI

Project State: Michigan

Technical Categories: Electrical Efficiency

The Grid Logic team is adapting a form of vapor deposition technology to demonstrate a new approach to creating powerful hybrid magnets. This "physical vapor deposition particle encapsulation technology" utilizes an inert atmosphere chamber, which allows for precisely controlled and reproducible pressure, gas flow, and fluidization conditions for a powder vessel. The team will use this specialized chamber to fabricate nanostructured exchange-spring magnets, which require careful control of material dimension and composition. Nanostructured exchange-spring magnets are composite magnetic materials that use an exchange between soft magnetic materials, which have high saturation magnetization but are easily demagnetized, and hard magnetic materials that are difficult to demagnetize but have lower saturation magnetization and high coercivity. In this case, the team will create magnets consisting of Manganese Bismuth (MnBi) hard magnetic core particles with nanometer-scale Cobalt (Co) soft magnet shells. If successful, the team will demonstrate a process for producing: 1) A hard magnet core particle capable of withstanding a strong external magnetic field without becoming demagnetized; and 2) A soft magnet shell providing high magnetic saturation (i.e. maximum magnetization due to an external magnetic field). By combining precise control of nano-scale layering, material ratios, and material interfaces the project could develop a magnet that rivals permanent magnets made from rare earth elements. As an ARPA-E IDEAS project, this early stage research will provide proof of concept showing that the particle encapsulation system developed in this project can enable large-scale, cost-efficient production of composite magnets that do not require rare earth elements.

United Technologies Research Center

[High Performance Transportation Redox-Air Flow Cells]()

Program: IDEAS

Project Term: 07/02/2015 to 07/01/2016

Project Status: ALUMNI

Project State: Connecticut

Technical Categories: Storage

United Technologies Research Center (UTRC) will develop a proof-of-concept for an innovative new vehicle energy-storage system. The UTRC team is leveraging experience from a previous ARPA-E project focused on grid-scale energy storage, the GRIDS: Breakthrough Flow Battery Cell Stack project, to develop a high-performance redox-air flow cell (RFC) system for EVs. A flow battery is a cross between a traditional battery and a fuel cell. Flow batteries store their energy in external tanks instead of inside the cell itself. If successful, the RFC will: (1) store its energy in a liquid solution at ambient pressure in a conformable plastic tank; (2) be readily packaged inside of an EV given the RFC's high power and energy densities, and (3) be rechargeable either onboard the vehicle like a conventional battery or by rapidly exchanging the discharged solution in the tank with charged solution at a refueling station. A novel recharging method will be employed to dramatically improve the round-trip energy efficiency for cells operating with an air electrode. Technologies like the RFC hold the potential to dramatically decrease the cost of EVs and enable greater adoption of EVs, allowing for increased energy efficiency, decreased petroleum imports, and substantial savings to the average consumer.

Oregon State University

[Home Generator Benchmarking Program]()

Program: IDEAS

Project Term: 07/15/2014 to 07/31/2016

Project Status: ALUMNI

Project State: Oregon

Technical Categories: Distributed Generation, Transport

Oregon State University will precisely measure the performance of three commercially-available home generators. The team will collect data on engine efficiency, endurance, emissions, and calculate a levelized cost of electricity (LCOE) for each generator. Published data on the performance of small generators is scarce, which has hampered efforts to identify where new technologies can be applied to improve the efficiency of small generators. The rigorous and repeatable measurements collected through this project will be an important step forward in developing future high-performance distributed power generation systems.

IMPACCT Innovative Materials and Processes for Advanced Carbon Capture Technologies (15)

IMPACCT's projects seek to develop technologies for existing coal-fired power plants that will lower the cost of carbon capture. Short for "Innovative Materials and Processes for Advanced Carbon Capture Technologies," the IMPACCT program is geared toward minimizing the cost of removing carbon dioxide (CO2) from coal-fired power plant exhaust by developing materials and processes that have never before been considered for this application. Retrofitting coal-fired power plants to capture the CO2 they produce would enable greenhouse gas reductions without forcing these plants to close, shifting away from the inexpensive and abundant U.S. coal supply.

University of Notre Dame

[Phase-Changing Ionic Liquids]()

Program: IMPACCT

Project Term: 07/01/2010 to 12/31/2013

Project Status: ALUMNI

Project State: Indiana

Technical Categories: Resource Efficiency

Notre Dame is developing a new CO2 capture process that uses special ionic liquids (ILs) to remove CO2 from the gas exhaust of coal-fired power plants. ILs are salts that are normally liquid at room temperature, but Notre Dame has discovered a new class of ILs that are solid at room temperature and change to liquid when they bind to CO2. Upon heating, the CO2 is released for storage, and the ILs re-solidify and donate some of the heat generated in the process to facilitate further CO2 release. These new ILs can reduce the energy required to capture CO2 from the exhaust stream of a coal-fired power plant when compared to state-of-the-art technology.

University of California, Berkeley

Metal Organic Framework Research

Program: IMPACCT

Project Term: 07/01/2010 to 09/25/2015

Project Status: ALUMNI

Project State: California

Technical Categories: Resource Efficiency

UC Berkeley is developing a method for identifying the best metal organic frameworks for use in capturing CO2from the flue gas of coal-fired power plants. Metal organic frameworks are porous, crystalline compounds that, based on their chemical structure, vary considerably in terms of their capacity to grab hold of passing CO2molecules and their ability to withstand the harsh conditions found in the gas exhaust of coal-fired power plants. Owing primarily to their high tunability, metal organic frameworks can have an incredibly wide range of different chemical and physical properties, so identifying the best to use for CO2 capture and storage can be a difficult task. UC Berkeley uses high-throughput instrumentation to analyze nearly 100 materials at a time, screening them for the characteristics that optimize their ability to selectively adsorb CO2from coal exhaust. Their work will identify the most promising frameworks and accelerate their large-scale commercial development to benefit further research into reducing the cost of CO2capture and storage.

General Electric

CO2 Capture with Liquid-to-Solid Absorbents

Program: IMPACCT

Project Term: 10/01/2010 to 09/30/2013

Project Status: ALUMNI

Project State: Connecticut

Technical Categories: Resource Efficiency

GE and the University of Pittsburgh are developing a unique CO2 capture process in which a liquid absorbent changes into a solid upon contact with CO2. Once in solid form, the material can be separated and the CO2 can be released for storage by heating. Upon heating, the absorbent returns to its liquid form, where it can be reused to capture more CO2. The approach is more efficient than other solvent-based processes because it avoids the heating of extraneous solvents such as water. This ultimately leads to a lower cost of CO2capture and will lower the additional cost to produce electricity for coal-fired power plants that retrofit their facilities to include this technology.

Texas A&M University

Stimuli-Responsive Metal Organic Frameworks

Program: IMPACCT

Project Term: 07/01/2010 to 09/30/2012

Project Status: ALUMNI

Project State: Texas

Technical Categories: Resource Efficiency

A team led by three professors at Texas A&M is developing a subset of metal organic frameworks that respond to stimuli such as small changes in temperature to trap CO2 and then release it for storage. These frameworks are a promising class of materials for carbon capture applications because their structure and chemistry can be controlled with great precision. Because the changes in temperature required to trap and release CO2 in Texas A&M's frameworks are much smaller than in other carbon capture approaches, the amount of energy or stimulus that has to be diverted from coal-fired power plants to accomplish this is greatly reduced. The team is working to alter the materials so they bind only with CO2, and are stable enough to withstand the high temperatures found in the chimneys of coal-fired power plants.

Oak Ridge National Laboratory

[High Surface-Area CO2 Sponge]

Program: IMPACCT

Project Term: 07/01/2010 to 08/15/2013

Project Status: ALUMNI

Project State: Tennessee

Technical Categories: Resource Efficiency

The team from ORNL and Georgia Tech is developing a new technology that will act like a sponge, integrating a new, alcohol-based ionic liquid into hollow fibers to capture CO2from the exhaust produced by coal-fired power plants. Ionic liquids--salts that exist in liquid form--are promising materials for carbon capture and storage, but their tendency to thicken when combined with CO2limits their efficiency and poses a challenge for their development as a cost-effective alternative to current-generation solutions. Adding alcohol to the mix limits this tendency to thicken in the presence of CO2but can also make the liquid more likely to evaporate, which would add significantly to the cost of CO2 capture. To solve this problem, ORNL is developing new classes of ionic liquids with high capacity for absorbing CO2. ORNL's sponge would reduce the cost associated with the energy that would need to be diverted from power plants to capture CO2 and release it for storage.

ATK

[Supersonic Technology for CO2 Capture]

Program: IMPACCT

Project Term: 07/01/2010 to 06/30/2013

Project Status: ALUMNI

Project State: Minnesota

Technical Categories: Resource Efficiency

Researchers at ATK and ACENT Laboratories are developing a device that relies on aerospace wind-tunnel technologies to turn CO2 into a condensed solid for collection and capture. ATK's design incorporates a special nozzle that converges and diverges to expand flue gas, thereby cooling it off and turning the CO2 into solid particles which are removed from the system by a cyclonic separator. This technology is mechanically simple, contains no moving parts and generates no chemical waste, making it inexpensive to construct and operate, readily scalable, and easily integrated into existing facilities. The increase in the cost to coal-fired power plants associated with introduction of this system would be 50% less than current technologies.

Georgia Tech Research Corporation

[Composite Membranes for CO2 Capture]

Program: IMPACCT

Project Term: 07/01/2010 to 10/31/2012

Project Status: ALUMNI

Project State: Georgia

Technical Categories: Resource Efficiency

A team of six faculty members at Georgia Tech is developing an enhanced membrane by fitting metal organic frameworks, compounds that show great promise for improved carbon capture, into hollow fiber membranes. This new material would be highly efficient at removing CO2from the flue gas produced at coal-fired power plants. The team is analyzing thousands of metal organic frameworks to identify those that are most suitable for carbon capture based both on their ability to allow coal exhaust to pass easily through them and their ability to select CO2 from that exhaust for capture and storage. The most suitable frameworks would be inserted into the walls of the hollow fiber membranes, making the technology readily scalable due to their high surface area. This composite membrane would be highly stable, withstanding the harsh gas environment found in coal exhaust.

Lawrence Livermore National Laboratory

Synthetic Catalysts for CO2 Storage

Program: IMPACCT

Project Term: 08/15/2010 to 12/31/2014

Project Status: ALUMNI

Project State: California

Technical Categories: Resource Efficiency

LLNL is designing a process to pull CO2 out of the exhaust gas of coal-fired power plants so it can be transported, stored, or utilized elsewhere. Human lungs rely on an enzyme known as carbonic anhydrase to help separate CO2 from our blood and tissue as part of the normal breathing process. LLNL is designing a synthetic catalyst with the same function as this enzyme. The catalyst can be used to quickly capture CO2from coal exhaust, just as the natural enzyme does in our lungs. LLNL is also developing a method of encapsulating chemical solvents in permeable microspheres that will greatly increase the speed of binding of CO2. The goal of the project is an industry-ready chemical vehicle that can withstand the harsh environments found in exhaust gas and enable new, simple process designs requiring less capital investment.

Codexis, Inc.

Better Enzymes for Carbon Capture

Program: IMPACCT

Project Term: 07/01/2010 to 06/30/2012

Project Status: ALUMNI

Project State: California

Technical Categories: Resource Efficiency

Codexis is developing new and efficient forms of enzymes known as carbonic anhydrases to absorb CO2 more rapidly and under challenging conditions found in the gas exhaust of coal-fired power plants. Carbonic anhydrases are common and are among the fastest enzymes, but they are not robust enough to withstand the harsh environment found in the power plant exhaust steams. In this project, Codexis will be using proprietary technology to improve the enzymes' ability to withstand high temperatures and large swings in chemical composition. The project aims to develop a carbon-capture process that uses less energy and less equipment than existing approaches. This would reduce the cost of retrofitting today's coal-fired power plants.

Columbia University

Chemically Accelerated Carbon Mineralization

Program: IMPACCT

Project Term: 07/16/2010 to 01/15/2014

Project Status: ALUMNI

Project State: New York

Technical Categories: Resource Efficiency

Columbia University is developing a process to pull CO2 out of the exhaust gas of coal-fired power plants and turn it into a solid that can be easily and safely transported, stored above ground, or integrated into value-added products (e.g. paper filler, plastic filler, construction materials, etc.). In nature, the reaction of CO2 with various minerals over long periods of time will yield a solid carbonate--this process is known as carbon mineralization. The use of carbon mineralization as a CO2capture and storage method is limited by the speeds at which these minerals can be dissolved and CO2 can be hydrated. To facilitate this, Columbia University is using a unique process and a combination of chemical catalysts which increase the mineral dissolution rate, and the enzymatic catalyst carbonic anhydrase which speeds up the hydration of CO2.

Sustainable Energy Solutions

Capturing CO2 from Exhaust Gas

Program: IMPACCT

Project Term: 07/14/2010 to 03/31/2015

Project Status: ALUMNI
Project State: Utah
Technical Categories: Resource Efficiency

SES is developing a process to capture CO2from the exhaust gas of coal-fired power plants by desublimation--the conversion of a gas to a solid. Capturing CO2 as a solid and delivering it as a liquid avoids the large energy cost of CO2 gas compression. SES' capture technology facilitates the prudent use of available energy resources; coal is our most abundant energy resource and is an excellent fuel for baseline power production. SES capture technology can capture 99% of the CO2emissions in addition to a wide range of other pollutants more efficiently and at lower costs than existing capture technologies. SES' capture technology can be readily added to our existing energy infrastructure.

Research Triangle Institute

CO2 Capture and Regeneration at Low Temperatures

Program: IMPACCT
Project Term: 07/01/2010 to 09/30/2013
Project Status: ALUMNI
Project State: North Carolina
Technical Categories: Resource Efficiency

RTI is developing a solvent and process that could significantly reduce the temperature associated with regenerating solvent and CO2 captured from the exhaust gas of coal-fired power plants. Traditional CO2 removal processes using water-based solvents require significant amount of steam from power plants in order to regenerate the solvent so it can be reused after each reaction. RTI's solvents can be better at absorbing CO2than many water-based solvents, and are regenerated at lower temperatures using less steam. Thus, industrial heat that is normally too cool to re-use can be deployed for regeneration, rather than using high-value steam. This saves the power plant money, which results in increased cost savings for consumers.

University of Colorado, Boulder

Gelled Ionic Liquid-Based Membranes

Program: IMPACCT
Project Term: 02/01/2011 to 07/31/2014
Project Status: ALUMNI
Project State: Colorado
Technical Categories: Resource Efficiency

Alongside Los Alamos National Laboratory and the Electric Power Research Institute, CU-Boulder is developing a membrane made of a gelled ionic liquid to capture CO2 from the exhaust of coal-fired power plants. The membranes are created by spraying the gelled ionic liquids in thin layers onto porous support structures using a specialized coating technique. The new membrane is highly efficient at pulling CO2out of coal-derived flue gas exhaust while restricting the flow of other materials through it. The design involves few chemicals or moving parts and is more mechanically stable than current technologies. The team is now working to further optimize the gelled materials for CO2separation and create a membrane layer that is less than 1 micrometer thick.

Massachusetts Institute of Technology

CO2 Capture Using Electrical Energy

Program: IMPACCT
Project Term: 07/01/2010 to 01/31/2013
Project Status: ALUMNI
Project State: Massachusetts
Technical Categories: Resource Efficiency

MIT and Siemens Corporation are developing a process to separate CO2 from the exhaust of coal-fired power plants by using electrical energy to chemically activate and deactivate sorbents--materials that absorb gases. The team found that certain sorbents bond to CO2 when they are activated by electrical energy and then transported through a specialized separator that deactivates the molecule and releases it for storage. This method directly uses the electricity from the power plant, which is a more efficient but more expensive form of energy than heat, though the ease and simplicity of integrating it into existing coal-fired power plants reduces the overall cost of the technology. This process could cost as low as $31 per ton of CO2stored.

University of Kentucky

Hybrid Solvent-Membrane CO2 Capture

Program: IMPACCT

Project Term: 07/01/2010 to 04/18/2013

Project Status: CANCELLED

Project State: Kentucky

Technical Categories: Resource Efficiency

The University of Kentucky is developing a hybrid approach to capturing CO2 from the exhaust gas of coal-fired power plants. In the first, CO2 is removed as flue gas is passed through an aqueous ammonium-based solvent. In the second, carbon-rich solution from the CO2absorber is passed through a membrane that is designed to selectively transport the bound carbon, enhancing its concentration on the permeate side. The team's approach would combine the best of both membrane- and solvent-based carbon capture technologies. Under the ARPA-E award, the team is enabling the membrane operation to be a drop-in solution.

METALS Modern Electro/Thermochemical Advances in Light Metals Systems (19)

The projects that comprise ARPA-E's METALS program, short for "Modern Electro/Thermochemical Advances in Light Metal Systems," aim to find cost-effective and energy-efficient manufacturing techniques to process and recycle metals for lightweight vehicles and aircraft. Processing light metals such as aluminum, titanium, and magnesium more efficiently would enable competition with incumbent structural metals like steel to manufacture vehicles and aircraft that meet demanding fuel efficiency standards without compromising performance or safety.

Alcoa, Inc.

Aluminum Electrolytic Cell with Heat Recovery

Program: METALS

Project Term: 03/31/2014 to 05/28/2018

Project Status: ACTIVE

Project State: Pennsylvania

Technical Categories: Manufacturing Efficiency

Alcoa is designing a new, electrolytic cell that could significantly improve the efficiency and price point of aluminum production. Conventional cells reject a great deal of waste heat, have difficulty adjusting to electricity price changes, and emit significant levels of CO2. Alcoa is addressing these problems by improving electrode design and integrating a heat exchanger into the wall of the cell. Typically, the positive and negative electrodes--or anode and cathode, respectively--within a smelting cell are horizontal. Alcoa will angle their cathode, increasing the surface area of the cell and shortening the distance between anode and cathode. Further, the cathode will be protected by ceramic plates, which are highly conductive and durable. Together, these changes will increase the output from a particular cell and enable reduced energy usage. Alcoa's design also integrates a molten glass (or salt) heat exchanger to capture and reuse waste heat within the cell walls when needed and reduce global peak energy demand. Alcoa's new cell design could consume less energy, significantly reducing the CO2 emissions and costs associated with current primary aluminum production.

University of Utah

Direct Titanium Production from Titanium Slag

Program: METALS

Project Term: 02/18/2014 to 03/06/2017

Project Status: ACTIVE

Project State: Utah

Technical Categories: Manufacturing Efficiency

The University of Utah is developing a reactor that dramatically simplifies titanium production compared to conventional processes. Today's production processes are expensive and inefficient because they require several high-energy melting steps to separate titanium from its ores. The University of Utah's reactor utilizes a magnesium hydride solution as a reducing agent to break less expensive titanium ore into its components in a single step. By processing low-grade ore directly, the titanium can be chemically isolated from other impurities. This design eliminates the series of complex, high-energy melting steps associated with current titanium production. Consolidating several energy intensive steps into one reduces both the cost and energy inputs associated with titanium extraction.

University of Utah

Electromagnetic Light Metal Sorting

Program: METALS

Project Term: 01/10/2014 to 12/31/2017

Project Status: ACTIVE

Project State: Utah

Technical Categories: Manufacturing Efficiency

The University of Utah is developing a light metal sorting system that can distinguish multiple grades of scrap metal using an adjustable and varying magnetic field. Current sorting technologies based on permanent magnets can only separate light metals from iron-based metals and tend to be inefficient and expensive. The University of Utah's sorting technology utilizes an adjustable magnetic field rather than a permanent magnet to automate scrap sorting, which could offer increased accuracy, less energy consumption, lower CO_2 emissions, and reduced costs. Due to the flexibility of this design, the system could be set to sort for any one metal at a time rather than being limited to sorting for a specific metal.

Materials & Electrochemical Research (MER) Corporation

Advanced Electrowinning of Titanium

Program: METALS

Project Term: 01/13/2015 to 01/12/2017

Project Status: ACTIVE

Project State: Arizona

Technical Categories: Manufacturing Efficiency

MER is scaling up an advanced electrochemical process to produce low-cost titanium from domestic ore. While titanium is a versatile and robust structural metal, its widespread adoption for consumer applications has been limited due to its high cost of production. MER is developing an new electrochemical titanium production process that avoids the cyclical formation of undesired titanium ions, thus significantly increasing the electrical current efficiency. MER will test different cell designs, reduce unwanted side reactions to increase energy efficiency, and minimize the heat loss that occurs when processing titanium. By developing a scalable and stable electrochemical cell, MER could significantly reduce the costs and energy consumption associated with producing titanium.

UHV Technologies, Inc.

X-Ray Diagnostics for Scrap Metal Sorting

Program: METALS

Project Term: 01/01/2014 to 12/31/2016

Project Status: ACTIVE

Project State: Kentucky

Technical Categories: Manufacturing Efficiency

UHV is developing a sorting technology that uses X-rays to distinguish between high-value metal alloys found in scrap of many shapes and sizes. Existing identification technologies rely on manual sorting of light metals, which can be inaccurate and slow. UHV's system will rapidly sort scrap metal passed over a conveyer belt, making it possible to lower metals waste while simultaneously increasing the quality of recycled metal alloys. By analyzing the light emitted from X-rayed metal pieces, UHV's probe is able to identify alloy compositions for automated sorting. By automating this process, UHV would significantly reduce the costs associated with recycling light metal scrap.

Valparaiso University

Solar/Electrolytic Production of Magnesium from Ore

Program: METALS

Project Term: 01/01/2014 to 12/31/2016

Project Status: ACTIVE

Project State: Indiana

Technical Categories: Manufacturing Efficiency

Valparaiso University is developing a solar electro-thermal reactor that produces magnesium from magnesium oxide. Current magnesium production processes involve high-temperature steps that consume large amounts of energy. Valparaiso's reactor would extract magnesium using concentrated solar power to supply its thermal energy, minimizing the need for electricity. The reactor would be surrounded by mirrors that track the sun and capture heat for high-temperature magnesium electrolysis. Because Valparaiso's reactor is powered by solar energy as opposed to burning fossil fuels, integrating magnesium production into the solar reactor would significantly reduce CO2emissions associated with magnesium production.

University of Colorado, Boulder

Solar/Electric Powered Magnesium Production

Program: METALS

Project Term: 01/01/2014 to 03/06/2017

Project Status: ACTIVE

Project State: Colorado

Technical Categories: Manufacturing Efficiency

CU-Boulder is developing a new solar-powered magnesium production reactor with dramatically improved energy efficiency compared to conventional technologies. Today's magnesium production processes are expensive and require large amounts of electricity. CU-Boulder's reactor can be heated using either concentrated solar power during the day or by electricity at night. CU-Boulder's reactor would dramatically reduce CO2emissions compared to existing technologies at lower cost because it requires less electricity and can be powered using solar energy. In addition, the reactor can produce syngas, a synthetic gasoline precursor, which could be used to power cars and trucks.

Energy Research Company

Integrated Minimill to Produce Aluminum from Scrap

Program: METALS

Project Term: 01/01/2014 to 03/31/2018

Project Status: ACTIVE

Project State: New Jersey

Technical Categories: Manufacturing Efficiency

ERCo is developing an automated Aluminum Integrated Minimill (AIM) that can produce finished components from mixed metal scrap. Unlike most current approaches, ERCo's AIM can distinguish and accurately sort multiple grades of aluminum scrap for recycling. ERCo's AIM reduces energy consumption in several ways. First, the technology would provide real-time feedback controls to improve the accuracy of the sorting process. The sorted scrap is then melted and cast. Further, ERCo's design replaces the inefficient dryers used in conventional processes with advanced, high-efficiency equipment. ERCo's AIM enables significantly more efficient and less expensive scrap sorting and aluminum recovery for casting.

INFINIUM, Inc.

[Aluminum Production Using Zirconia Solid Electrolyte]

Program: METALS

Project Term: 12/12/2013 to 12/10/2016

Project Status: ACTIVE

Project State: Massachusetts

Technical Categories: Manufacturing Efficiency

INFINIUM is developing a technology to produce light metals such as aluminum and titanium using an electrochemical cell design that could reduce energy consumption associated with these processes by over 50%. The key component of this innovation lies within the anode assembly used to electrochemically refine these light metals from their ores. While traditional processes use costly graphite anodes that are reacted to produce CO2 during refining, INFINIUM's anode can use much cheaper fuels such as natural gas, and produce a high-purity oxygen by-product. Revenue from this by-product could significantly affect aluminum production economics. Traditional cell designs also waste a great deal of heat due to the necessity of keeping the reactor open to the air while contaminated CO2rapidly exits the chamber. Since INFINIUM's anode keeps the oxygen or CO2anode gas away from the main reactor chamber, the entire system may be far more effectively insulated.

Research Triangle Institute

[High-Temperature Thermal Storage for Light Metal Production]

Program: METALS

Project Term: 02/05/2014 to 02/04/2017

Project Status: ACTIVE

Project State: North Carolina

Technical Categories: Manufacturing Efficiency

RTI is developing a high-quality concentrating solar thermal energy transport and storage system for use in light metals manufacturing. A challenge with integrating renewable energy into light metals manufacturing has been the need for large quantities of very high temperature heat. RTI's technology overcomes this challenge with a specialized heat transfer powder. This powder can be heated to temperatures of 1100 degrees Celsius with concentrating solar thermal energy, some 400 degrees Celsius higher than conventional solutions. Because the heat transfer fluid can also store thermal energy, metal manufacturing plants can continue to operate even when the sun is not shining. RTI will also develop advanced materials that will protect the system's components from the accelerated degradation experienced at these high operating temperatures. This technology will enable constant, high-temperature operation of the light metals production process with reduced CO2 emissions.

SRI International

[Direct Production of Titanium Powder]

Program: METALS

Project Term: 12/10/2013 to 04/30/2015

Project Status: ALUMNI

Project State: California

Technical Categories: Manufacturing Efficiency

SRI is developing a reactor that is able to either convert titanium tetrachloride to titanium powder or convert multiple metal chlorides to titanium alloy powder in a single step. Conventional titanium extraction and conversion processes involve expensive and energy intensive melting steps. SRI is examining the reaction between hydrogen and metal chlorides, which could produce titanium alloys without multiple complicated steps. Using titanium powder for transportation applications has not been practical until now because of the high cost of producing powder from titanium ingots. SRI's reactor requires less material because it produces powder directly rather than converting it from intermediate materials such as sponge or ingot. Transforming titanium production into a direct process could reduce costs and energy consumption by eliminating energy intensive steps and decreasing material inputs.

Phinix, LLC

Electrochemical Magnesium Extraction from Scrap

Program: METALS

Project Term: 12/03/2013 to 03/01/2015

Project Status: ALUMNI

Project State: Kentucky

Technical Categories: Manufacturing Efficiency

Phinix is developing a specialized cell that recovers high-quality magnesium from aluminum-magnesium scrap. Current aluminum refining uses chlorination to separate aluminum from other alloys, which results in a significant amount of salt-contaminated waste. Rather than using the conventional chlorination approach, Phinix's cell relies on a three-layer electrochemical melting process that has proven successful in purifying primary aluminum. Phinix will adapt that process to purify aluminum-magnesium scrap, recovering magnesium by separating that scrap based on the different densities within its mix. Phinix's cell could offer increased flexibility in managing costs because it can handle scrap of various chemical compositions, making use of scrap that is currently in low demand. With a more efficient design, the cell can recover and reuse aluminum-magnesium scrap at low cost with minimal waste.

Palo Alto Research Center

Electrochemical Probe for Rapid Scrap Metal Sorting

Program: METALS

Project Term: 12/12/2013 to 05/31/2016

Project Status: ALUMNI

Project State: California

Technical Categories: Manufacturing Efficiency

PARC is developing an advanced diagnostic probe that identifies the composition of light metal scrap for efficient sorting and recycling. Current sorting technologies for light metals are costly and inefficient because they cannot distinguish between different grades of light metals for recycling. Additionally, state-of-the-art electrochemical probes rely on aqueous electrolytes that are not optimally suited for separating light metal scrap. PARC's probe, however, uses a novel liquid, which enables a chemical reaction with light metals to represent their alloy composition accurately. A probe that is more accurate than existing methods could separate scrap based on alloy quality to obtain low-cost, high-quality aluminum.

Case Western Reserve University

Segmented Cell for Electrowinning Titanium

Program: METALS

Project Term: 01/01/2014 to 06/30/2016

Project Status: ALUMNI

Project State: Ohio

Technical Categories: Manufacturing Efficiency

Case Western is developing a specialized electrochemical cell that produces titanium from titanium salts using a series of layered membranes. Conventional titanium production is expensive and inefficient due to the high temperatures and multiple process steps required. The Case Western concept is to reduce the energy required for titanium metal production using an electrochemical reactor with multiple, thin membranes. The multi-membrane concept would limit side reactions and use one third of the energy required by today's production methods.

Gas Technology Institute

Membrane Extraction for Aluminum Production

Program: METALS

Project Term: 01/01/2014 to 03/31/2015

Project Status: ALUMNI

Project State: Illinois

Technical Categories: Manufacturing Efficiency

GTI is developing a continuously operating cell that produces low-cost aluminum powder using less energy than conventional methods. Conventional aluminum production is done by pumping huge electrical currents into a vat of molten aluminum dissolved in mineral salts at nearly 2000 degrees Fahrenheit. GTI's technology occurs near room temperature using reusable solvents to dissolve the ore. Because GTI's design relies on chemical dissolution rather than heat, its cells can operate at room temperature, meaning it does not suffer from wasteful thermal energy losses associated with conventional systems. GTI's electrochemical cell could also make aluminum production significantly less expensive by using less costly, domestically available ore with no drop in quality.

BlazeTech Corp.

Specialized Imaging System for Light Metal Sorting

Program: METALS

Project Term: 01/01/2014 to 03/31/2015

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Manufacturing Efficiency

BlazeTech is developing advanced sorting software that uses a specialized camera to distinguish multiple grades of light metal scrap by examining how they reflect different wavelengths of light. Existing identification technologies rely on manual sorting of light metals, which can be inaccurate and slow. BlazeTech's sorting technology would identify scrap metal content based on the way that each light metal appears under BlazeTech's sorting camera, automating the sorting process and enabling more comprehensive metal recycling. The software developed under this program will be used to dramatically improve existing metal sorting systems. This technology offers great potential to improve the efficiency of light metals recycling, as similar techniques have proven successful in other industries, including vegetation surveying and plastics identification.

Pacific Northwest National Laboratory

Extracting Magnesium from Seawater

Program: METALS

Project Term: 01/01/2014 to 06/30/2016

Project Status: CANCELLED

Project State: Washington

Technical Categories: Manufacturing Efficiency

PNNL is developing a radically new process to produce magnesium from seawater. Today's methods are energy intensive and expensive because the magnesium concentration in seawater is so low that significant energy is needed to evaporate off water and precipitate magnesium chloride salt. Further, conventional technologies involve heating the salt to 900°C and then using electric current to break the chemical bond between magnesium and chlorine to produce the metal. PNNL's new process replaces brine spray drying with a low-temperature, low-energy dehydration process. That step is combined with a new catalyst-assisted process to generate an organometallic reactant directly from magnesium chloride. The organometallic is decomposed to magnesium metal via a proprietary process at temperatures less than 300°C, thus eliminating electrolysis of magnesium chloride salt. The overall process could be significantly less expensive and more efficient than any conventional magnesium extraction method available today and uses seawater as an abundant, free resource.

iMetalx Group, LLC

Advanced Electrowinning of Titanium

Program: METALS

Project Term: 02/24/2014 to 07/14/2014

Project Status: CANCELLED

Project State: California

Technical Categories: Manufacturing Efficiency iMetalx is scaling up an advanced electrochemical process to produce low-cost titanium from domestic ore. While titanium is a versatile and robust structural metal, its widespread adoption for consumer applications has been limited due to its high cost of production. iMetalx is developing an new electrochemical titanium production process that avoids the cyclical formation of undesired titanium ions, thus significantly increasing the electrical current efficiency. iMetalx will test different cell designs, reduce unwanted side reactions to increase energy efficiency, and minimize the heat loss that occurs when processing titanium. By developing a scalable and stable electrochemical cell, iMetalx could significantly reduce the costs and energy consumption associated with producing titanium.

Titanium Metals Corp.

Electrochemical Cell for Advanced Titanium Production

Program: METALS

Project Term: 01/13/2014 to 04/30/2016

Project Status: CANCELLED

Project State: Pennsylvania

Technical Categories: Manufacturing Efficiency

TIMET is developing an electrochemical process for producing pure titanium powder. Incumbent titanium production processes require the importation of high-grade titanium ores. TIMET's groundbreaking design will enable the use of abundant, low-cost, domestic ore to produce titanium powder electrolytically. By totally revolutionizing the electrolysis process, TIMET can fully optimize the process more effectively using a unique approach. TIMET's electrochemical methods could produce higher quality titanium powder at lower cost and reduced energy consumption compared to the conventional Kroll process.

MONITOR Methane Observation Networks with Innovative Technology to Obtain Reductions (12)

The projects that comprise ARPA-E's Methane Observation Networks with Innovative Technology to Obtain Reductions (MONITOR) program are developing innovative technologies to cost-effectively and accurately locate and measure methane emissions associated with natural gas production. Such low-cost sensing systems are needed to reduce methane leaks anywhere from the wellpad to local distribution networks, reduce safety hazards, promote more efficient use of our domestic natural gas resources, and reduce the overall greenhouse gas (GHG) impact from natural gas development. In order to evaluate the performance of each MONITOR technology to locate and quantify fugitive methane emissions, the MONITOR Field Test Site will develop a representative test facility that simulates real-world natural gas operations--at the wellpad and further downstream. Specifically, the MONITOR Test Site supports the operation of a multi-user field test site for MONITOR performers to validate performance under realistic use-case scenarios--and meet the MONITOR program's required metrics related to localization, quantification, communications and cost. Data generated during the field tests will demonstrate the performance capabilities of the technologies and could be used by the MONITOR performers to accelerate the commercialization and/or regulatory approval of their technologies.

Palo Alto Research Center

System of Printed Hybrid Intelligent Nano-Chemical Sensors (SPHINCS)

Program: MONITOR

Project Term: 04/15/2015 to 05/12/2018

Project Status: ACTIVE

Project State: California

Technical Categories: Resource Efficiency

Xerox Corporation's Palo Alto Research Center (PARC) will work with BP and NASA's Ames Research Center to combine Xerox's low-cost print manufacturing and NASA's gas-sensing technologies to develop printable sensing arrays that will be integrated into a cost-effective, highly sensitive methane detection system. The system will be based on sensor array foils containing multiple printed carbon nanotube (CNT) sensors and supporting electronics. Each sensor element will be modified with dopants, coatings, or nanoparticles such that it responds differently to different gases. Through principal component analysis and machine learning techniques, the system will be trained for high sensitivity and selectivity for components of natural gas and interfering compounds. The goal is to be able to detect methane emissions with a sensitivity of 1 ppm and localize the source of emissions to within 1 meter, offering enhanced precision when compared to current equipment. By using low-cost printing techniques, the project team's system could offer an affordable alternative to more expensive optical methane detectors on the market today.

Aeris Technologies, Inc.

Methane Leak Detection System

Program: MONITOR

Project Term: 03/01/2015 to 04/26/2018

Project Status: ACTIVE

Project State: California

Technical Categories: Resource Efficiency

Aeris Technologies, Inc. (Aeris) will partner with Rice University and Los Alamos National Laboratory to develop a complete methane leak detection system that allows for highly sensitive, accurate methane detection at natural gas systems. The team will combine its novel compact spectrometer based on a mid-infrared laser, its patent-pending multi-port sampling system, and an advanced computational approach to leak quantification and localization. Their approach will use artificial neural networks and dispersion models to quantify and locate leaks with increased accuracy and reduced computational time for use in a diverse range of meteorological conditions and wellpad configurations. At each wellpad, a control unit will house the core sensor, a computing unit to process data, and wireless capability to transmit leak information to an operator, while the multi-port gas-sampling system will be distributed across the wellpad. Aeris' goal is to be able to detect and measure methane leaks smaller than 1 ton per year from a 10 meter by 10 meter site. At this level of sensitivity, which is in the ppb range, Aeris estimates that its system can facilitate a 90% reduction in fugitive methane emissions. Compared to current monitoring systems that can cost $25,000 annually, Aeris' goal is a cost of $3,000 or less a year to operate.

Rebellion Photonics, Inc.

Portable Methane Detection System

Program: MONITOR

Project Term: 04/15/2015 to 04/15/2018

Project Status: ACTIVE

Project State: Texas

Technical Categories: Resource Efficiency

Rebellion Photonics, Inc. (Rebellion) plans to develop portable methane gas cloud imagers that can wirelessly transmit real-time data to a cloud-based computing service. This would allow data on the concentration, leak rate, location, and total emissions of methane to be streamed to a mobile device, like an iPad, smartphone, or Google Glass. The infrared imaging spectrometers will leverage snapshot spectral imaging technology to provide multiple bands of spectral information for each pixel in the image. Similar to a Go Pro camera, the miniature, lightweight camera is planned to be attached to a worker's hardhat or clothing, allowing for widespread deployment. By providing a real-time image of the plume to a mobile device, the technology's goal is to provide increased awareness of leaks for faster leak repair. This system could enable significant reduction in the cost associated with identifying, quantifying, and locating methane leaks as compared to currently available technologies.

Maxion Technologies, Inc.

Tunable Laser for Methane Detection

Program: MONITOR

Project Term: 06/01/2015 to 05/31/2018

Project Status: ACTIVE

Project State: Maryland

Technical Categories: Resource Efficiency

Maxion Technologies Inc. (Maxion) is partnering with Thorlabs Quantum Electronics (TQE), Praevium Research, Inc., and Rice University to develop a low cost, tunable, mid-infrared (mid-IR) laser source to be used in systems for detecting and measuring methane emissions. The new architecture is planned to reduce the cost of lasers capable of targeting methane optical absorption lines near 3.3 microns, enabling the development of affordable, high sensitivity sensors. The team will combine Praevium and TQE's state-of-the-art Micro-Electro-Mechanical-System tunable Vertical Cavity Surface Emitting Laser (MEMS-VCSEL) technology with an Interband Cascade Laser (ICL) active core developed by Maxion. The unique design offers advantages in manufacturing that are expected to yield a factor-of-40 reduction in the cost of the laser source, and the wide tunability will allow the same laser design to be shared across multiple applications. When integrated with a full methane detection system, this technology could enable significant reduction in the cost associated with identifying, quantifying, and locating methane leaks as compared to currently available technologies.

Colorado State University

MONITOR Field Test Site

Program: MONITOR

Project Term: 10/01/2016 to 03/31/2019

Project Status: ACTIVE

Project State: Colorado

Technical Categories: Resource Efficiency

The team, led by Colorado State University (CSU), will develop a test site facility near Fort Collins, CO where ARPA-E can evaluate the methane sensing technologies of the MONITOR project teams, as required by the MONITOR FOA. The CSU team will design, construct, and operate a natural gas testing facility that can determine whether MONITOR technologies have met or exceeded the technical performance targets set forth by the MONITOR program. The test facility will be designed to realistically mimic the layout of a broad range of natural gas facilities and equipment. The test facility will include a number of controlled natural gas emission release points that will be realistic in terms of location, magnitude, frequency, duration, and gas composition. The design will also include sub-facilities that can simulate different aspects of the natural gas industry supply chain such as dry gas production, wet gas production, midstream compression, metering and regulating stations, and underground pipeline releases. The test site is located in the Denver-Julesburg basin, but will be sufficiently far enough away from natural gas operations that background levels of methane will be very low. Thus, the site will provide a realistic, but highly controllable environment within which the MONITOR technologies can be accurately tested.

Bridger Photonics, Inc

Mobile Methane Sensing System

Program: MONITOR

Project Term: 06/15/2015 to 06/14/2018

Project Status: ACTIVE

Project State: Montana

Technical Categories: Resource Efficiency

Bridger Photonics, Inc. (Bridger) plans to build a mobile methane sensing system capable of surveying a 10 meter by 10 meter well platform in just over five minutes with precision that exceeds existing technologies used for large-scale monitoring. Bridger's complete light-detection and ranging (LiDAR) remote sensing system will use a novel, near-infrared fiber laser amplifier in a system mounted on a ground vehicle or an unmanned aerial vehicle (UAV), which can be programmed to survey multiple wellpads a day. Data captured by the LiDAR system will provide 3-D topographic and methane absorption imagery using integrated inertial navigation and global positioning system data to show precisely where a methane leak may be occurring and at what rate. This approach will also be used to identify objects on the wellsite to better inform the search optimization. Bridger's goal is for its devices to be able to service up to 85 sites, and thus cost $1,400 to $2,220 a year to operate per wellsite. By advancing an affordable methane detection system that can both pinpoint and assess leakage quickly, Bridger's system could help companies repair methane leaks and catalyze an overall reduction in methane emissions from natural gas development.

IBM T. J. Watson Research Center

Multi-Modal Methane Measurement System

Program: MONITOR

Project Term: 08/10/2015 to 08/09/2018
Project Status: ACTIVE
Project State: New York
Technical Categories: Resource Efficiency

IBM's T.J Watson Research Center (IBM) is working in conjunction with Harvard University and Princeton University to develop an energy-efficient, self-organizing mesh network to gather data over a distributed methane measurement system. Data will be passed to a cloud-based analytics system using custom models to quantify the amount and rate of methane leakage. Additionally, IBM is developing new, low-cost optical sensors that will use tunable diode laser absorption spectroscopy (TDLAS) for methane detection. While today's optical sensors offer excellent sensitivity and selectivity, their high cost and power requirements prevent widespread adoption. To overcome these hurdles, IBM and its partners plan to produce a miniaturized, integrated, on-chip version that is less expensive and consumes less power. At a planned cost of about $300 per sensor, IBM's sensors will be 10 to 100 times cheaper than TDLAS sensors on the market today. By advancing an affordable methane detection system that can be customized, IBM's technology could enable producers to more efficiently locate and repair methane leaks, and therefore reduce overall methane emissions.

Duke University

Advanced Spectrometer for Methane Detection

Program: MONITOR
Project Term: 05/15/2015 to 05/15/2018
Project Status: ACTIVE
Project State: North Carolina
Technical Categories: Resource Efficiency

Duke University (Duke), in conjunction with its partners, will build a coded aperture miniature mass spectrometer environmental sensor (CAMMS-ES) for use in a methane monitoring system. The team will also develop search, location, and characterization algorithms. Duke will apply its recent innovations in mass spectrometers to increase the throughput of the spectrometer, providing continuous sampling without diminishing its resolution by integrating spatially coded apertures and corresponding reconstruction algorithms. The coded aperture will also provide advanced specificity and sensitivity for methane detection and other volatile organic compounds (VOCs) associated with natural gas production. Duke's innovations could provide low-cost, advanced sensors to localize and characterize methane and VOC emissions, helping to accelerate detection and mitigation of methane and VOC emissions at natural gas sites.

General Electric

Optical Fibers for Methane Detection

Program: MONITOR
Project Term: 05/15/2015 to 05/15/2017
Project Status: ACTIVE
Project State: Connecticut
Technical Categories: Resource Efficiency

General Electric (GE) will partner with Virginia Tech to design, fabricate, and test a novel, hollow core, microstructured optical fiber for long path-length transmission of infrared radiation at methane absorption wavelengths. GE will drill micrometer-sized side-holes to allow gases to penetrate into the hollow core. The team will use a combination of techniques to quantify and localize the methane in the hollow core. GE's plans to develop fibers that can be designed to fit any natural gas system, providing flexibility to adapt to the needs of a monitoring program in a wide variety of places along the natural gas value chain, including transmission and gathering pipelines. GE anticipates that the fiber detector will be cost competitive with other highly selective methane detectors, and therefore offer innovative capabilities for more cost effective methane monitoring.

Physical Sciences Inc.

Methane Leak Detection System

Program: MONITOR
Project Term: 04/16/2015 to 04/15/2018

Project Status: ACTIVE
Project State: Massachusetts
Technical Categories: Resource Efficiency

Physical Sciences, Inc. (PSI), in conjunction with Heath Consultants Inc., Princeton University, the University of Houston, and Thorlabs Quantum Electronics, Inc., will miniaturize their laser-based Remote Methane Leak Detector (RMLD) and integrate it with PSI's miniature unmanned aerial vehicle (UAV), known as the InstantEye, to create the RMLD-Sentry. The measurement system is planned to be fully autonomous, providing technical and cost advantages compared to manual leak detection methods. The team anticipates that the system would have the ability to measure ethane, as well as methane, which would allow it to distinguish biogenic from thermogenic sources. The RMLD-Sentry is planned to locate wellpad leak sources and quantify emission rates by periodically surveying the wellpad, circling the facility at a low altitude, and dynamically changing its flight pattern to focus in on leak sources. When not in the air, RMLD-Sentry would monitors emissions around the perimeter of the site. If methane is detected, the UAV would self-deploy and search the wellpad until the leak location is identified and flow rate is quantified using algorithms to be developed by the team. PSI's design is anticipated to facilitate up to a 95% reduction in methane emissions at natural gas sites at an annualized cost of about $2,250 a year - a fraction of the cost of current systems that allow for continuous monitoring. In addition to requiring less manpower for continuous monitoring, the team expects to develop techniques to reduce manufacturing costs for the laser sources by applying economies of scale and streamlined manufacturing processes.

LI-COR Biosciences, Inc.

[Optical Sensors for Methane Detection]

Program: MONITOR
Project Term: 05/15/2015 to 05/15/2017
Project Status: ACTIVE
Project State: Nebraska
Technical Categories: Resource Efficiency

LI-COR is working with Colorado State University (CSU) and Gener8 to develop cost-effective, highly sensitive optical methane sensors that can be integrated into mobile or stationary methane monitoring systems. Their laser-based sensor utilizes optical cavity techniques, which provide long path lengths and high methane sensitivity and selectivity, but previously have been costly. The team will employ a novel sensor design developed in parallel with advanced manufacturing techniques to enable a substantial cost reduction. The sensors are expected to provide exceptional long-term stability, enabling robust, unattended field deployment and further reducing total cost-of-ownership. CSU will test representative sensor prototypes and demonstrate the sensor's application to leak detection and quantification. The team's proposed sensor could decrease the expense of today's monitoring technologies and encourage widespread adoption of methane monitoring and mitigation at natural gas wellpads.

University of Colorado, Boulder

[Frequency Combs for Methane Detection]

Program: MONITOR
Project Term: 05/11/2015 to 05/11/2017
Project Status: ACTIVE
Project State: Colorado
Technical Categories: Resource Efficiency

The University of Colorado-Boulder (CU-Boulder) will team up with the National Institute of Standards and Technology (NIST) and the Cooperative Institute for Research in Environmental Sciences (a partnership between CU-Boulder and the National Oceanic and Atmospheric Administration) to develop a reduced-cost, dual frequency comb spectrometer. The frequency comb would consist of 105 evenly spaced, sharp, single frequency laser lines covering a broad wavelength range that includes the unique absorption signatures of natural gas constituents like methane. The team has shown that frequency comb spectrometers can measure methane and other gases at parts-per-billion concentration levels over kilometer-long path lengths. Current, long-range sensing systems cannot detect methane with high sensitivity, accuracy, or stability. The team's frequency combs, however, are planned to be able to detect and distinguish methane, ethane, propane, and other gases without frequent calibration. When integrated into a complete methane detection system, the combs could lower the costs of methane sensing due to their ability to survey large areas or multiple gas fields simultaneously. When employed as part of a complete methane detection system, the team's innovation aims to improve the accuracy of methane detection while decreasing the costs of systems, which could encourage widespread adoption of methane emission mitigation at natural gas sites.

MOSAIC Micro-scale Optimized Solar-cell Arrays with Integrated Concentration (11)

ARPA-E's MOSAIC program seeks to develop technologies and concepts that will lower the cost of solar photovoltaic (PV) power systems and improve their performance. Project teams will develop micro-scale concentrated photovoltaic systems (CPV) that are similar in cost and size to conventional solar PV systems, but with greatly increased performance levels. Multidisciplinary teams will leverage expertise in conventional flat-plate PV, CPV, manufacturing, optical engineering, and material science to produce a new class of PV panels. If successful, these technologies could facilitate cost-effective deployment of solar power systems across a wide range of geographical locations, lowering U.S. greenhouse gas emissions and reducing dependence on imported energy.

Glint Photonics, Inc.

Stationary Wide-Angle Concentrator PV System

Program: MOSAIC

Project Term: 01/01/2016 to 12/31/2018

Project Status: ACTIVE

Project State: California

Technical Categories: Distributed Generation

Glint Photonics, Inc., in collaboration with the National Renewable Energy Laboratory (NREL), will develop a stationary wide-angle concentrator (SWAC) PV system. The SWAC concentrates light onto multi-junction solar cells, which efficiently convert sunlight into electrical energy. A sheet of arrayed PV cells moves passively within the module to maximize sunlight capture throughout the day. Two innovations allow this tracking to occur smoothly and without the expense or complexity of an active control system or a mechanical tracker. First, a fluidic suspension mechanism enables nearly frictionless movement of the sheet embedded in the module. Second, a thermal-gradient-driven alignment mechanism uses a tiny fraction of the collected energy to drive the movement of the sheet and keep it precisely aligned. Glint will develop the novel optical and fluidic components of the SWAC, while NREL will develop custom multi-junction solar cells for the prototype modules.

Texas Engineering Experiment Station

Waveguiding Solar Concentrator

Program: MOSAIC

Project Term: 02/01/2016 to 01/31/2018

Project Status: ACTIVE

Project State: Texas

Technical Categories: Distributed Generation

Texas A&M University (TAMU) and their partners will build a micro-CPV system that incorporates waveguide technology. A waveguide concentrates and directs light to a specific point. TAMU's system uses a grid of waveguides to concentrate sunlight onto a set of coupling elements which employ a 45 degree turning mirror to further concentrate the light and increase the efficiency of the system. Each coupling element is oriented to direct its specific beam of light towards high-efficiency, multi-junction solar cells. Further system efficiency is gained by capturing diffuse light in a secondary layer. The system also includes a secondary layer that captures diffuse sunlight, increasing its overall efficiency.

Pennsylvania State University

Wide-Angle Planar Microtracking Microcell Concentrating Photovoltaics

Program: MOSAIC

Project Term: 02/10/2016 to 02/09/2019

Project Status: ACTIVE

Project State: Pennsylvania

Technical Categories: Distributed Generation

The Pennsylvania State University (Penn State), along with their partner organizations, will develop a high efficiency micro-CPV system that features the same flat design of traditional solar panels, but with nearly twice the efficiency. The system is divided into three layers. The top and bottom layers use a refractive/reflective pair of tiny spherical lens arrays to focus sunlight onto a micro-CPV cell array in the center layer. The micro-CPV arrays will be printed on a transparent sheet that slides laterally between the top and bottom layer to ensure that the maximum amount of sunlight is delivered to the micro-PV cell throughout the day. Advanced manufacturing using high-throughput printing techniques will help reduce the cost of the micro-CPV cell arrays and allow the team to create five-junction micro-PV cells that can absorb a broader range of light and promote greater efficiency. By concentrating and focusing sunlight on a specific advanced micro-PV cell, the system can achieve much higher efficiency than standard FPV panels, while maintaining a similar flat panel architecture.

Massachusetts Institute of Technology

Wafer-Level Integrated Concentrating Photovoltaics

Program: MOSAIC

Project Term: 01/01/2016 to 01/04/2018

Project Status: ACTIVE

Project State: Massachusetts

Technical Categories: Distributed Generation

The Massachusetts Institute of Technology (MIT) with partner Sandia National Laboratories will develop a micro-CPV system. The team's approach integrates optical concentrating elements with micro-scale solar cells to enhance efficiency, reduce material and fabrication costs, and significantly reduce system size. The team's key innovation is the use of traditional silicon PV cells for more than one function. These traditional cells lay on a silicon substrate that has etched reflective cavities with high-performance micro-PV cells on the cavity floor. Light entering the system will hit a primary concentrator that then directs light into the reflective cavities and towards the high performance micro-PV cells. Diffuse light, which most CPV technologies do not capture, is collected by the lower performance silicon PV cells. The proposed technology could provide 40-55% more energy than conventional FPV and 15-40% more energy than traditional CPV with a significantly reduced system cost, because of the ability to collect both direct and diffuse light in a thin form factor.

University of Rochester

Planar Light Guide Concentrated Photovoltaics

Program: MOSAIC

Project Term: 01/01/2016 to 06/30/2017

Project Status: ACTIVE

Project State: New York

Technical Categories: Distributed Generation

The University of Rochester along with partners Arzon Solar and RPC Photonics will develop a micro-CPV system based on Planar Light Guide (PLG) solar concentrators. The PLG uses a top lenslet layer to focus and concentrate sunlight towards injection facets. These facets guide and redirect light, like a mirror, towards a PV cell at the edge of the device. Combined, these methods lead to higher efficiency over conventional FPV systems. At fewer than 3 mm thick, the system will be thin and flat, similar to traditional FPV panels. The PLG system also reduces complexity and costs by only requiring PV cells at the edge of the device, instead of an array of thousands of micro-PV cells. The team will also develop a scalable fabrication technique that uses grayscale lithography to produce the micro-optics.

Palo Alto Research Center

Micro-Chiplet Printer for MOSAIC

Program: MOSAIC

Project Term: 12/28/2015 to 12/31/2018

Project Status: ACTIVE

Project State: California

Technical Categories: Distributed Generation

The Palo Alto Research Center (PARC), a Xerox company, along with Sandia National Laboratories (SNL) will develop a prototype printer with the potential to enable economical, high-volume manufacturing of micro-PV cell arrays. This project will focus on creating a printing technology that can affordably manufacture micro-CPV system components. The envisioned printer would drastically lower assembly costs and increase manufacturing efficiency of micro-CPV systems. Leveraging their expertise in digital copier assembly, PARC intends to create a printer demonstration that uses micro-CPV cells or "chiplets" as the "ink" and arranges the chiplets in a precise, predefined location and orientation, similar to how a document printer places ink on a page. SNL will provide micro-scaled photovoltaic components to be used as the "ink," and the PARC system will "print" panel-sized micro-CPV substrates with digitally placed and interconnected PV cells. This micro-chiplet printer technology may reduce the assembly cost of micro-CPV systems by orders of magnitude, making them cost competitive with conventional FPV. To demonstrate the effectiveness of the printer, the project team will investigate two types of backplanes (electronically connected PV arrays arranged on a surface): one with a single type of micro-PV cell, and one with at least two types of micro-PV cells.

Panasonic R&D Company of America

Low Profile CPV Panel with Sun Tracking for Rooftop Installation

Program: MOSAIC

Project Term: 01/15/2016 to 01/14/2019

Project Status: ACTIVE

Project State: California

Technical Categories: Distributed Generation

Panasonic Boston Laboratory will develop a micro-CPV system that features a micro-tracking subsystem. This micro-tracking subsystem will eliminate the need for bulky trackers, allowing fixed mounting of the panel. The micro-tracking allows individual lenses containing PV cells to move within the panel. As the sun moves throughout the day, the lenses align themselves to the best position to receive sunlight, realizing the efficiency advantages of CPV without the cumbersome tilting of the entire panel. The Panasonic Boston Laboratory team will examine a number of methods to allow the individual lenses to track the sunlight. Each panel will be comparable in thickness and cost to a traditional FPV panel.

Sharp Laboratories of America

A High Efficiency Flat Plate PV with Integrated Micro-CPV Atop a 1-Sun Panel

Program: MOSAIC

Project Term: 01/01/2016 to 12/31/2018

Project Status: ACTIVE

Project State: Washington

Technical Categories: Distributed Generation

Sharp Laboratories of America (Sharp) along with the University of Arizona will develop a micro-CPV system that combines a CPV cell with dual-sided FPV panels to capture direct, diffuse, and reflected sunlight. The team's system will feature lenses that focus sunlight onto a horizontal waveguide, which further concentrates the light onto high-performance micro-CPV solar cells. Dual-sided solar panels, attached beneath the CPV cells, enable diffuse light collection on one side and reflected light collection on the other side. The system will be mounted on a two-axis tracker that will allow for optimal collection of sunlight throughout the day.

Semprius, Inc.

Micro-Scale Ultra-High Efficiency CPV/Diffuse Hybrid Arrays Using Transfer Printing

Program: MOSAIC

Project Term: 01/01/2016 to 12/31/2018

Project Status: ACTIVE

Project State: North Carolina

Technical Categories: Distributed Generation

Semprius, Inc. and their partners will develop a hybrid CPV concept that combines highly efficient multi-junction solar cells and low-cost single-junction solar cells. When direct sunlight hits the lens array, it is concentrated 1000-fold and is focused onto the multi-junction solar cells. Diffuse light not captured in this process is instead captured by the low-cost single-junction solar cells. The module design is lightweight, fewer than 10 mm thick, and has a profile similar to conventional FPV. Moreover, the combination of the two types of cells increases efficiency. Semprius will use its expertise in micro-transfer printing to fabricate and assemble the multi-junction cells. This process will reduce manufacturing costs and further increase efficiency.

Massachusetts Institute of Technology

Integrated Micro-Optical Concentrator Photovoltaics

Program: MOSAIC

Project Term: 12/15/2015 to 12/14/2018

Project Status: ACTIVE

Project State: Massachusetts

Technical Categories: Distributed Generation

The Massachusetts Institute of Technology (MIT) with partner Arizona State University will develop a new concept for PV power generation that achieves the 30% conversion efficiency associated with traditional concentrated PV systems while maintaining the low cost, low profile, and lightweight of conventional FPV modules. MIT aims to combine three technologies to achieve their goals: a dispersive lens system, laterally arrayed multiple bandgap (LAMB) solar cells, and a low-cost power management system. The dispersive lens concentrates and separates light that passes through it, providing 400-fold concentration for direct sunlight and 3-fold concentration for diffuse sunlight. The dispersive lens is a thin layer consisting of inexpensive, lightweight materials that can be manufactured at low cost using plastic molding, an improvement over traditional methods. The lens focuses the direct light onto the array of LAMB solar cells, while also focusing the diffuse light onto common PV cells integrated beneath the LAMB array. The power management system combines power from multiple cells into a single output so that the power from a panel of LAMB arrays can be processed with grid-interface power electronics, enabling as much as 20% additional energy capture in applications where the roof is partially shaded.

California Institute of Technology

Micro-Optical Tandem Luminescent Solar Concentrator

Program: MOSAIC

Project Term: 02/11/2016 to 02/10/2019

Project Status: ACTIVE

Project State: California

Technical Categories: Distributed Generation

Researchers at the California Institute of Technology (CalTech) and their partners will design and fabricate a new CPV module with features that can capture both direct and diffuse sunlight. The team's approach uses a luminescent solar concentrator (LSC) sheet that includes quantum dots to capture and re-emit sunlight, micro-PV cells matched to the color of the light from the quantum dots, and a coating of advanced materials that enhance concentration and delivery of sunlight to the micro-PV cells. In addition, the light not captured by the quantum dots will impinge on a tandem solar cell beneath the LSC sheet. The design of the LSC will focus on lowering the number of expensive micro-PV cells needed within the concentrator sheet, which will reduce system costs, but still maintain high efficiency. The design will also allow the module to be effective without any tracking system, making it potentially attractive for all PV markets, including space-constrained rooftops.

MOVE Methane Opportunities for Vehicular Energy (13)

The projects that comprise ARPA-E's MOVE Program, short for "Methane Opportunities for Vehicular Energy," are finding cost-effective ways to power passenger cars and other light-duty vehicles with America's abundant natural gas resources. Natural gas is currently less expensive than gasoline, and produces fewer harmful emissions than any other fossil fuel. Despite these advantages, significant technological and infrastructure barriers currently limit the use of natural gas as a major fuel source in the U.S. ARPA-E's MOVE projects are finding innovative ways to break through these barriers, creating practical and affordable natural gas storage tanks for passenger cars and quick-filling at-home refueling stations.

OnBoard Dynamics

On-Vehicle Engine-Compressor System

Program: MOVE

Project Term: 10/01/2012 to 01/14/2018

Project Status: ACTIVE

Project State: Oregon

Technical Categories: Transportation Fuels

OnBoard Dynamics is modifying a passenger vehicle to allow its internal combustion engine to be used to compress natural gas for storage on board the vehicle. Ordinarily, filling a compressed natural gas vehicle with natural gas would involve driving to a natural gas refueling station or buying an expensive stand-alone station for home use. OnBoard's design would allow natural gas compression to take place in a single cylinder of the engine itself, allowing the actual car to behave like a natural gas refueling station. Ultimately, the engine would then have the ability both to power the vehicle and to compress natural gas so it can be stored efficiently for future use. The design would cost approximately $400 and pay for itself with fuel savings in less than 6 months.

Gas Technology Institute

Low-Pressure Conformable Natural Gas Vehicle Tank

Program: MOVE

Project Term: 10/01/2012 to 03/31/2014

Project Status: ALUMNI

Project State: Illinois

Technical Categories: Transportation Fuels

GTI will partner with Northwestern University, NuMat Technologies, a Northwestern start-up company, and Westport Fuel Systems to identify materials with the best characteristics for low-pressure natural gas storage. The gas-storing materials, known as metal organic framework (MOF) adsorbents, hold natural gas the way a sponge holds liquids. The project team will further develop their computer modeling and screening technique to support the creation of a low-pressure adsorbent material specifically designed for natural gas vehicles. The team will also validate the materials properties in real-world conditions. Low-pressure gas tanks represent significant potential for lowering not only the cost of NGVs, but also the cost of fueling by reducing the need to compress the gas.

United Technologies Research Center

Modular Natural Gas Tank

Program: MOVE

Project Term: 10/01/2012 to 03/31/2016

Project Status: ALUMNI

Project State: Connecticut

Technical Categories: Transportation Fuels

UTRC is developing a conformable modular storage tank that could integrate easily into the tight spaces in the undercarriage of natural gas-powered vehicles. Traditional steel and carbon fiber natural gas storage tanks are rigid, bulky, and expensive, which adds to the overall cost of the vehicle and discourages broad use of natural gas vehicles. UTRC is designing modular natural gas storage units that can be assembled to form a wide range of shapes and fit a wide range of undercarriages. UTRC's modular tank could substantially improve upon the conformability level of existing technologies at a cost of approximately $1500, considerably less than today's tanks.

Texas A&M University

[Highly Adsorbent Materials for Natural Gas Storage]

Program: MOVE

Project Term: 09/17/2012 to 12/31/2014

Project Status: ALUMNI

Project State: Texas

Technical Categories: Transportation Fuels

Texas A&M University is developing a highly adsorbent material for use in on-board natural gas storage tanks that could drastically increase the volumetric energy density of methane, which makes up 95% of natural gas. Today's best tanks do not optimize their natural gas storage capacity and add too much to the sticker price of natural gas vehicles to make them viable options for most consumers. Texas A&M University will synthesize low-cost materials that adsorb high volumes of natural gas and increase the storage capacity of the tanks. This design could result in a natural gas storage tank that maximizes its ability to store methane and can be manufactured at low cost, side-stepping two major obstacles associated with the use of natural gas vehicles.

REL, Inc.

[Conformable Core Gas Tank]

Program: MOVE

Project Term: 09/01/2012 to 09/30/2016

Project Status: ALUMNI

Project State: Michigan

Technical Categories: Transportation Fuels

REL is developing a low-cost, conformable natural gas tank for light-duty vehicles that contains an internal structural cellular core. Traditional natural gas storage tanks are cylindrical and rigid. REL is exploring various materials that could be used to design a gas tank's internal structure that could allow the tank to be any shape. The REL team is exploring various methods of manufacturing the interconnected core structure and the tank skin to identify which combination best meets their target pressure-containment objectives. REL's conformable internal core would enable higher storage capacity than current carbon fiber-based tanks at 70% less cost. REL is developing small-scale prototypes that meet their durability, safety, and cost goals before scaling up to a full-sized prototype.

Pacific Northwest National Laboratory

[Ultra-Light Conformable Natural Gas Tank]

Program: MOVE

Project Term: 10/01/2012 to 09/30/2014

Project Status: ALUMNI

Project State: Washington

Technical Categories: Transportation Fuels

PNNL is developing a low-cost, conformable natural gas tank for light-duty vehicles utilizing the same metal forming techniques used to fabricate high-strength cruise missile fins. Traditional gas tanks are made using a method known as arc welding, where an electric arc is used to melt and combine metals, which can limit their conformability. PNNL's ultra-light design relies on friction stir welding, where metal is softened--like taffy--instead of melted, which allows the metal to retain its original properties and preserves its conformability. The manufacturing process for PNNL's tanks incorporates high-strength internal strut technology that efficiently fits into a vehicle, offering a tank that costs around $1500, a substantial price reduction compared to today's best tanks.

Gas Technology Institute

Adsorbent Materials for Natural Gas Storage

Program: MOVE

Project Term: 01/01/2013 to 12/31/2014

Project Status: ALUMNI

Project State: Illinois

Technical Categories: Transportation Fuels

GTI is developing a natural gas tank for light-duty vehicles that features a thin, tailored shell containing microscopic valves which open and close on demand to manage pressure within the tank. Traditional natural gas storage tanks are thick and heavy, which makes them expensive to manufacture. GTI's tank design uses unique adsorbent pellets with nano-scale pores surrounded by a coating that functions as valves to help manage the pressure of the gas and facilitate more efficient storage and transportation. GTI's low-pressure tanks would have thinner walls than today's best alternatives, resulting in a lighter, more affordable product with increased storage capacity.

University of Texas, Austin

Single-Piston Natural Gas Compressor

Program: MOVE

Project Term: 10/01/2012 to 12/31/2015

Project Status: ALUMNI

Project State: Texas

Technical Categories: Transportation Fuels

UT Austin is developing an at-home natural gas refueling system that compresses natural gas using a single piston. Typically, at-home refueling stations use reciprocating compressor technology, in which an electric motor rotates a crankshaft tied to several pistons in a multi-stage compressor. These compressor systems can be inefficient and their complex components make them expensive to manufacture, difficult to maintain, and short-lived. The UT Austin design uses a single piston compressor driven by a directly coupled linear motor. This would eliminate many of the moving components associated with typical reciprocating compressors, reducing efficiency losses from friction, increasing reliability and durability, and decreasing manufacturing and maintenance costs.

Blackpak, Inc.

Sorbent-Based Natural Gas Tank

Program: MOVE

Project Term: 10/01/2012 to 09/30/2016

Project Status: ALUMNI

Project State: California

Technical Categories: Transportation Fuels

Blackpak will use high-strength, high-surface-area carbon to develop a sorbent-based natural gas storage vessel in which the sorbent itself is the container, eliminating the external pressure vessel altogether. This design could store natural gas at comparable or lower weight and smaller size than conventional compressed gas tanks while reducing the pressure of the natural gas in the vehicle tank. By reducing tank pressure, the system will enable home vehicle refueling at greatly reduced complexity and cost, making these systems accessible to the general public. In addition, the container-less storage system can be easily formed into a range of shapes, allowing automobile designers to seamlessly integrate the natural gas storage into the vehicle design, without sacrificing passenger space.

Otherlab, Inc.

Intestinal Natural Gas Storage

Program: MOVE

Project Term: 09/03/2012 to 03/31/2016

Project Status: ALUMNI

Project State: California

Technical Categories: Transportation Fuels

Otherlab is developing a natural gas storage tank made of small-radius, high-pressure tubes that allow for maximum conformability to vehicle shape. Current storage options are too rigid, expensive, and inefficient to support adoption of natural gas vehicles. Otherlab's space-filling tube design, modeled after human intestines, provides for maximum storage capacity. This transformational system could be constructed from low-cost materials and well suited to highly automated manufacturing processes.

Eaton Corporation

[Liquid-Piston Isothermal Home Natural Gas Compressor]

Program: MOVE

Project Term: 01/01/2013 to 12/31/2015

Project Status: ALUMNI

Project State: Ohio

Technical Categories: Transportation Fuels

Eaton is developing an at-home natural gas refueling system that relies on a liquid piston to compress natural gas. A traditional compressor uses an electric motor to rotate a crankshaft, which is tied to several metal pistons that pump to compress gas. Traditional compressor systems can be inefficient and their complex components make them expensive to manufacture, difficult to maintain, and short-lived. Eaton's system replaces traditional pistons with a liquid that comes into direct contact with the natural gas without the need for the costly high-pressure piston seals that are used in conventional gas compression.

Ford Motor Company

[Low Pressure Material-Based Natural Gas Fuel System]

Program: MOVE

Project Term: 09/17/2012 to 03/31/2015

Project Status: CANCELLED

Project State: Michigan

Technical Categories: Transportation Fuels

ARPA-E and Ford agreed to mutually conclude this project. Ford is developing an on-board adsorbed natural gas tank system with a high-surface-area framework material that would increase the energy density of compressed natural gas at low pressures. Traditional natural gas tanks attempt to compensate for low-energy-density and limited driving range by storing compressed gas at high pressures, requiring expensive pressure vessels. Ford and their project partners will optimize advanced porous material within a system to reduce the pressure of on-board tanks while delivering the customer expected driving range. This porous material allows more gas to be stored inside a tank by utilizing a surface energy attraction to the natural gas. These materials would be efficiently and cost-effectively integrated into a natural gas vehicle system that will promote and contribute to the widespread use of natural gas vehicles.

General Electric

[Chilled Natural Gas for At-Home Refueling]

Program: MOVE

Project Term: 01/01/2013 to 04/20/2014

Project Status: CANCELLED

Project State: Connecticut

Technical Categories: Transportation Fuels

GE is developing a low-cost, at-home natural gas refueling system that reduces fueling time and eliminates compression stages. Traditional compressor-based natural gas refueling systems require removal of water from natural gas through complicated desiccant cycles to avoid damage. GE's design uses a chiller to cool the gas to a temperature below -50°C, which would separate water and other contaminants from the natural gas. This design has very few moving parts, will operate quietly, and will be virtually maintenance-free. This simplified, compressor-free design could allow fast refueling at 10% of the cost of today's systems.

NODES Network Optimized Distributed Energy Systems (12)

The Network Optimized Distributed Energy Systems (NODES) Program aspires to enable renewables penetration at the 50% level or greater, by developing transformational grid management and control methods to create a virtual energy storage system based on use of flexible load and distributed energy resources (DERs). The challenge is to cost-effectively and reliably manage dynamic changes in the grid by leveraging these additional grid resources, while maintaining customer quality of service. The expected benefits include reduced periods of costly peak demand, reduced energy waste and increased penetration of renewable energy production. The NODES Program will bring together different scientific communities such as power systems, control systems, computer science, and distributed systems to accelerate the development of new technologies enabling active control of load and DERs in coordination with the grid.

Northwestern University

Frequency-Based Load Control Architecture

Program: NODES

Project Term: 06/15/2016 to 06/14/2019

Project Status: ACTIVE

Project State: Illinois

Technical Categories: Grid

Northwestern University and its partners will develop a frequency-based load control architecture to provide additional frequency response capability and allow increased renewable generation on the grid. The work will focus on developing and demonstrating algorithms that adapt to rapid changes of loads, generation, and system configuration while taking into account various constraints arising from the transmission and distribution networks. The multi-layer control architecture makes it possible to simultaneously ensure system stability at the transmission network level, control frequency at the local distribution network level, and maintain the quality-of-service for individual customers at the building level, all under a single framework. At the transmission level, coordination among different areas will be achieved through a centralized scheme to ensure stable frequency synchronization, while the control decisions within a single area will be made based on local information. The efficiency of the centralized scheme will be ensured by decomposing the network into smaller components on which the control problem is solved individually. At the local distribution network level, the control scheme will be decentralized, in which control decisions are made based on the state of the neighboring nodes. At the building level, dynamic models for flexible appliances and DERs will be developed and used to design algorithms to optimally follow a given aggregated load profile.

University of Minnesota

Enabling the Grid of the Future

Program: NODES

Project Term: 07/15/2016 to 07/14/2019

Project Status: ACTIVE

Project State: Minnesota

Technical Categories: Grid

The University of Minnesota will develop a comprehensive approach that addresses the challenges to system reliability and power quality presented by widespread renewable power generation. By developing techniques for both centralized cloud-based and distributed peer-to-peer networks, the proposed system will enable coordinated response of many local units to adjust consumption and generation of energy, satisfy physical constraints, and provide ancillary services requested by a grid operator. The project will apply concepts from nonlinear and robust control theory to design self-organizing power systems that effectively respond to the grid events and variability. A key feature enabled by the proposed methodology is a flexible plug-and-play architecture wherein devices and small power networks can easily engage or disengage from other power networks or the grid. The project's design approach will be tested across many different scenarios while using more than 100 actual physical devices such as photovoltaics, battery storage inverters, and home appliances.

Arizona State University

[Stochastic Optimal Power Flow]

Program: NODES

Project Term: 07/11/2016 to 07/10/2018

Project Status: ACTIVE

Project State: Arizona

Technical Categories: Grid

Arizona State University (ASU) will develop a stochastic optimal power flow (SOPF) framework, which would integrate uncertainty from renewable resources, load, distributed storage, and demand response technologies into bulk power system management in a holistic manner. The team will develop SOPF algorithms for the security-constrained economic dispatch (SCED) problem used to manage variability in the electric grid. The algorithms will be implemented in a software tool to provide system operators with real-time guidance to help coordinate between bulk generation and large numbers of DERs and demand response. ASU's project features unique data-analytics based short-term forecast for bulk and distributed wind and solar generation utilized by the advisory tool that generates real-time recommendations for market operators based on the SOPF algorithm outputs.

Pacific Northwest National Laboratory

[Incentive-Based Control of Distributed Assets]

Program: NODES

Project Term: 09/06/2016 to 03/05/2019

Project Status: ACTIVE

Project State: Washington

Technical Categories: Grid

Pacific Northwest National Laboratory (PNNL) will develop and test a hierarchical control framework for coordinating the flexibility of a full range of DERs, including flexible building loads, to supply reserves to the electric power grid. The hierarchical control framework consists of incentive-based control strategies across multiple time-scales. The system will use a slower incentive-based approach to acquire flexible assets that provide services, combined with faster device-level controls that use minimal communication to provide desired responses to the grid. Each DER that chooses to participate will communicate its ability to provide flexibility and the time scale over which it can provide the service. A distribution reliability coordinator will act as an interface between the DERs and the bulk system, coordinating the resources in an economic and reliable manner. The team will characterize various DER types to quantify the maximum flexibility that can be extracted from a collection of DERs in aggregate in order to provide service-level guarantees to the bulk energy market operator. The performance of the resulting hierarchical control system will be tested at scale in a co-simulation environment spanning transmission, distribution, ancillary markets, and communication systems.

National Rural Electric Cooperative Association

[Autonomous Load Control]

Program: NODES

Project Term: 08/15/2016 to 08/14/2019

Project Status: ACTIVE

Project State: Virginia

Technical Categories: Grid

The National Rural Electric Cooperative Association will develop GridBallast, a low-cost demand-side management technology, to address resiliency and stability concerns accompanying the exponential growth in DERs deployment in the U.S. electric grid. Specifically, devices based on GridBallast technology will monitor grid voltage and frequency and control the target load in order to address excursions from grid operating targets. The devices will operate autonomously to provide rapid local response, removing the need for costly infrastructure to communicate with a central controller. If the devices are installed with an optional radio, they will be able to support traditional demand response through peer-to-peer collaborative operation from a central operator. The team includes experts from Carnegie Mellon University, Eaton Corporation, and SparkMeter, and will focus development on two specific devices: a water heater controller, and a smart circuit controller. The GridBallast project aims to improve resiliency and reduce the cost of demand side management for voltage and frequency control by at least 50% using a streamlined design and removing the need for extensive communications infrastructure.

National Renewable Energy Laboratory

Real-time Distributed Energy Resource Optimization

Program: NODES

Project Term: 07/19/2016 to 07/18/2019

Project Status: ACTIVE

Project State: Colorado

Technical Categories: Grid

The National Renewable Energy Laboratory (NREL) lead team will develop a comprehensive distribution network management framework that unifies real-time voltage and frequency control at the home/DER controllers' level with network-wide energy management at the utility/aggregator level. The distributed control architecture will continuously steer operating points of DERs toward optimal solutions of pertinent optimization problems, while dynamically procuring and dispatching synthetic reserves based on current system state and forecasts of ambient and load conditions. The control algorithms invoke simple mathematical operations that can be embedded on low-cost microcontrollers, and enable distributed decision making on time scales that match the dynamics of distribution systems with high renewable integration.

General Electric

Synthetic Reserves from Distributed Flexible Resources

Program: NODES

Project Term: 06/10/2016 to 06/09/2019

Project Status: ACTIVE

Project State: Connecticut

Technical Categories: Grid

General Electric Global Research along with its partners will develop a novel distributed flexibility resource (DFR) technology that aggregates responsive flexible loads and DERs to provide synthetic reserve services to the grid while maintaining customer quality-of-service. A key innovation of the project is to develop a forecast tool that will use short-term and real-time weather forecasts along with other data to estimate the reserve potential of aggregate loads and DERs. An optimization framework that will enable aggregation of large numbers of flexible loads and DERs and determine the optimal schedule to bid into the wholesale market will be designed. A scalable control and communication architecture will enable coordination and control of the resources in real-time based on a novel two-tier hierarchical optimal control algorithm.

Stanford University

Distributed Energy Resource Networks

Program: NODES

Project Term: 07/27/2016 to 07/26/2019

Project Status: ACTIVE

Project State: California

Technical Categories: Grid

Stanford University will develop Powernet, an open-source and open architecture platform for scalable and secure coordination of consumer flexible load and DERs. Powernet will be based on the principle of connecting information networks to the power network (connecting bits and watts). It uses a layered architecture that enables real-time coordination of centralized resources with millions of DERs by integrating embedded sensing and computing, power electronics, and networking with cloud computing. The team will develop a Home Hub system capable of networking with existing inverters and appliances in a home and controlling power via smart switches that replace traditional fuses. The Home Hub will also use algorithms for aggregating local customer resources to meet local constraints and global coordination objectives. A cloud-based cloud coordinator platform will be developed that executes optimization and monitoring functions to coordinate Home Hubs by minimizing costs while increasing aggregate consumer quality-of-service.

University of California, San Diego

[Distributed Grid Control of Flexible Loads]

Program: NODES

Project Term: 06/13/2016 to 06/12/2019

Project Status: ACTIVE

Project State: California

Technical Categories: Grid

The University of California, San Diego (UCSD) will develop coordination algorithms and software using intelligent control and optimization for flexible load and DERs to provide reliable frequency regulation services for the bulk power grid. The project will develop a multi-layer framework for larger-scale energy aggregators to act on behalf of their smaller-sized customers to help respond to incoming requests from regional transmission operators. The team will develop approaches that aggregators can use to quantify reserves, system objectives and constraints, customer usage patterns, and generation forecasts. Aggregators will use distributed coordination algorithms to rapidly respond to operators while considering network constraints and quality of services for customers. The UCSD's technology to manage flexible loads and DERs offers economic and operational advantages for utilities, operators and customers.

KEMA Inc.

[Internet of Energy for Optimized Distributed Energy Resources]

Program: NODES

Project Term: 08/15/2016 to 08/14/2019

Project Status: ACTIVE

Project State: Massachusetts

Technical Categories: Grid

DNV GL together with its partners, Geli and Group NIRE, will develop an Internet of Energy (IoEn) platform for the automated scheduling, aggregation, dispatch, and performance validation of network optimized DERs and controllable loads. The IoEn platform will simultaneously manage both system-level regulation and distribution-level support functions to facilitate large-scale integration of distributed generation onto the grid. The IoEn will demonstrate a novel and scalable approach for the fast registration and automated dispatch of DERs by combining DNV GL's power system simulation tools and independent third-party validation with Geli's networking, control, and market balancing software. The platform will demonstrate the ability of customer-sited DERs to provide grid frequency regulation and distribution reliability functions with minimal impact to their local behind-the-meter demand management applications. The IoEn will be demonstrated and tested at Group NIRE's utility-connected microgrid test facility in Lubbock, Texas, where it will be integrated with local utility monitoring, control and data acquisition systems. By increasing the number of local devices able to connect and contribute to the IoEn, this project aims to increase renewables penetration above 50% while maintaining required levels of grid performance.

University of Vermont

[Packetized Energy Management]

Program: NODES

Project Term: 05/25/2016 to 05/24/2019

Project Status: ACTIVE

Project State: Vermont

Technical Categories: Grid

The University of Vermont (UVM) will develop and test a new approach for demand-side management called packetized energy management (PEM) that builds on approaches used to manage data packets in communication networks without centralized control and with a high level of privacy. The PEM system will allow millions of small end-use devices to cooperatively balance energy supply and demand in real time without jeopardizing the reliability of the grid or the quality of service to consumers. The project will develop the PEM method to optimally manage the rapid fluctuations that come with large amounts of renewable power generation, while simultaneously managing reliability constraints in the bulk transmission and local distribution infrastructure. To ensure UVM's PEM methods are effective, the integrated system will undergo extensive simulation testing with large-scale hardware implementation for the bulk power grid and an industry-scale micro-grid environments.

Eaton Corporation

[Cloud-Based DER Control]

Program: NODES

Project Term: 09/01/2016 to 09/28/2019

Project Status: ACTIVE

Project State: Ohio

Technical Categories: Grid

Eaton will develop and validate a disruptive cloud-computing-based technology aimed at providing agile and robust synthetic regulating reserve services to the power grid. This approach separates the decision-making of synthetic regulating reserve services into two-levels to significantly reduce the computational complexity, thereby enabling large-scale coordinated control of a vast number of DERs and flexible load. The system-operator level estimates and predicts reserve capacity of the distribution network and decides on the appropriate economic incentives for DERs to participate in future services. At the local level, an energy node comprised of a cluster of DERs and flexible loads will automatically decide its own reserve services strategy that takes into account short-term net load and economic incentives. By splitting these decisions between the two levels, the solution does not require extensive communication or negotiation between the local DERs and the system operators in the cloud.

OPEN 2009 Open Funding Solicitation (41)

In 2009, ARPA-E issued an open call for the most revolutionary energy technologies to form the agency's inaugural program. The first open solicitation was open to ideas from all energy areas and focused on funding projects already equipped with strong research and development plans for their potentially high-impact technologies. The projects chosen received a level of financial support that could accelerate technical progress and catalyze additional investment from the private sector. After only 2 months, ARPA-E's investment in these projects catalyzed an additional $33 million in investments. In response to ARPA-E's first open solicitation, more than 3,700 concept papers flooded into the new agency, which were thoroughly reviewed by a team of 500 scientists and engineers in just 6 months. In the end, 36 projects were selected as ARPA-E's first award recipients, receiving $176 million in federal funding.

Kohana Technologies, Inc.

[Dynamically Adjustable Wind Turbine Blades]

Program: OPEN 2009

Project Term: 03/08/2013 to 10/31/2017

Project Status: ACTIVE

Project State: California

Technical Categories: Distributed Generation

Kohana is developing wind turbines with a control system that delivers compressed air from special slots located in the surface of its blades. The compressed air dynamically adjusts the aerodynamic performance of the blades, and can essentially be used to control lift, drag, and ultimately power. This control system has been shown to exhibit high levels of control in combination with an exceptionally fast response rate. The deployment of such a control system in modern wind turbines would lead to better management of the load on the system during peak usage, allowing larger blades to be deployed with a resulting increase in energy production.

Stanford University

[Behavioral Initiatives for Energy Efficiency]

Program: OPEN 2009

Project Term: 01/14/2010 to 11/30/2016

Project Status: ACTIVE

Project State: California

Technical Categories: Resource Efficiency

A team of researchers from more than 10 departments at Stanford University is collaborating to transform the way Americans interact with our energy-use data. The team built a web-based platform that collects historical electricity data, which it uses to perform a variety of experiments to learn what triggers people to respond. Experiments include new financial incentives, a calculator to understand the potential savings of efficient appliances, new Facebook interface designs, communication studies using Twitter, and educational programs with the Girl Scouts. Economic modeling is underway to better understand how results from the San Francisco Bay Area can be broadened to other parts of the country.

University of California, Los Angeles

Cost-Effective Solar Thermal Energy Storage

Program: OPEN 2009

Project Term: 02/01/2011 to 09/30/2016

Project Status: ALUMNI

Project State: California

Technical Categories: Storage

UCLA and NASA's Jet Propulsion Laboratory (JPL) are creating cost-effective storage systems for solar thermal energy using new materials and designs. A major drawback to the widespread use of solar thermal energy is its inability to cost-effectively supply electric power at night. State-of-the-art energy storage for solar thermal power plants uses molten salt to help store thermal energy. Molten salt systems can be expensive and complex, which is not attractive from a long-term investment standpoint. UCLA and JPL are developing a supercritical fluid-based thermal energy storage system, which would be much less expensive than molten-salt-based systems. The team's design also uses a smaller, modular, single-tank design that is more reliable and scalable for large-scale storage applications.

Michigan State University

Shockwave Engine

Program: OPEN 2009

Project Term: 01/14/2010 to 09/30/2013

Project Status: ALUMNI

Project State: Michigan

Technical Categories: Distributed Generation

MSU is developing a new engine for use in hybrid automobiles that could significantly reduce fuel waste and improve engine efficiency. In a traditional internal combustion engine, air and fuel are ignited, creating high-temperature and high-pressure gases that expand rapidly. This expansion of gases forces the engine's pistons to pump and powers the car. MSU's engine has no pistons. It uses the combustion of air and fuel to build up pressure within the engine, generating a shockwave that blasts hot gas exhaust into the blades of the engine's rotors causing them to turn, which generates electricity. MSU's redesigned engine would be the size of a cooking pot and contain fewer moving parts--reducing the weight of the engine by 30%. It would also enable a vehicle that could use 60% of its fuel for propulsion.

Algaeventure Systems

Fuel from Algae

Program: OPEN 2009

Project Term: 01/15/2010 to 01/31/2012

Project Status: ALUMNI

Project State: Ohio

Technical Categories: Transportation Fuels

Led by CEO Ross Youngs, AVS has patented a cost-effective dewatering technology that separates micro-solids (algae) from water. Separating micro-solids from water traditionally requires a centrifuge, which uses significant energy to spin the water mass and force materials of different densities to separate from one another. In a comparative analysis, dewatering 1 ton of algae in a centrifuge costs around $3,400. AVS's Solid-Liquid Separation (SLS) system is less energy-intensive and less expensive, costing $1.92 to process 1 ton of algae. The SLS technology uses capillary dewatering with filter media to gently facilitate water separation, leaving behind dewatered algae which can then be used as a source for biofuels and bio-products. The biomimicry of the SLS technology emulates the way plants absorb and spread water to their capillaries.

Envia Systems

Long-Range Electric Vehicle Batteries

Program: OPEN 2009

Project Term: 01/01/2010 to 12/31/2011

Project Status: ALUMNI

Project State: California

Technical Categories: Transportation Storage

In a battery, metal ions move between the electrodes through the electrolyte in order to store energy. Envia Systems is developing new silicon-based negative electrode materials for Li-Ion batteries. Using this technology, Envia will be able to produce commercial EV batteries that outperform today's technology by 2-3 times. Many other programs have attempted to make anode materials based on silicon, but have not been able to produce materials that can withstand charge/discharge cycles multiple times. Envia has been able to make this material which can successfully cycle hundreds of times, on a scale that is economically viable. Today, Envia's batteries exhibit world-record energy densities.

Ohio State University

Syngas into Fuel

Program: OPEN 2009

Project Term: 04/01/2010 to 09/30/2014

Project Status: ALUMNI

Project State: Ohio

Technical Categories: Resource Efficiency

Ohio State has developed an iron-based material and process for converting syngas--a synthetic gas mixture--into electricity, H_2, and/or liquid fuel with zero CO_2emissions. Traditional carbon capture methods use chemical solvents or special membranes to separate CO_2 from the gas exhaust from coal-fired power plants. Ohio State's technology uses an iron-based oxygen carrier to generate $CO_2$and H_2 from syngas in separate, pure product streams by means of a circulating bed reactor configuration. The end products of the system are H_2, electricity, and/or liquid fuel, all of which are useful sources of power that can come from coal or syngas derived from biomass. Ohio State is developing a high-pressure pilot-scale unit to demonstrate this process at the National Carbon Capture Center.

General Electric

Nanocomposite Magnets

Program: OPEN 2009

Project Term: 10/01/2010 to 09/30/2013

Project Status: ALUMNI

Project State: Connecticut

Technical Categories: Transportation Vehicles

GE is using nanomaterials technology to develop advanced magnets that contain fewer rare earth materials than their predecessors. Nanomaterials technology involves manipulating matter at the atomic or molecular scale, which can represent a stumbling block for magnets because it is difficult to create a finely grained magnet at that scale. GE is developing bulk magnets with finely tuned structures using iron-based mixtures that contain 80% less rare earth materials than traditional magnets, which will reduce their overall cost. These magnets will enable further commercialization of HEVs, EVs, and wind turbine generators while enhancing U.S. competitiveness in industries that heavily utilize these alternatives to rare earth minerals.

Bio Architecture Lab

Macroalgae Butanol

Program: OPEN 2009

Project Term: 04/30/2012 to 06/30/2013

Project Status: ALUMNI

Project State: California

Technical Categories: Transportation Fuels

E. I. du Pont de Nemours & Company (DuPont) and Bio Architecture Lab are exploring the commercial viability of producing fuel-grade isobutanol from macroalgae (seaweed). Making macroalgae an attractive substrate for biofuel applications however, will require continued technology development. Assuming these developments are successful, initial assessments suggest macroalgae aquafarming in our oceans has the potential to produce a feedstock with cost in the same range as terrestrial-based substrates (crop residuals, energy crops) and may be the feedstock of choice in some locations. The use of macroalgae also diversifies the sources of U.S. biomass in order to provide more options in meeting demand for biofuels. The process being developed will use a robust industrial biocatalyst (microorganism) capable of converting macroalgal-derived sugars directly into isobutanol. Biobutanol is an advanced biofuel with significant advantages over ethanol, including higher energy content, lower greenhouse gas emissions, and the ability to be blended in gasoline at higher levels than ethanol without changes to existing automobiles or the fuel industry infrastructure. Butamax is currently commercializing DuPont's biobutanol fermentation technology that uses sugar and starch feedstocks.

Porifera, Inc.

Carbon Nanotube Membranes

Program: OPEN 2009

Project Term: 03/01/2010 to 03/31/2013

Project Status: ALUMNI

Project State: California

Technical Categories: Resource Efficiency

Porifera is developing carbon nanotube membranes that allow more efficient removal of CO_2 from coal plant exhaust. Most of today's carbon capture methods use chemical solvents, but capture methods that use membranes to draw CO_2 out of exhaust gas are potentially more efficient and cost effective. Traditionally, membranes are limited by the rate at which they allow gas to flow through them and the amount of CO_2 they can attract from the gas. Smooth support pores and the unique structure of Porifera's carbon nanotube membranes allows them to be more permeable than other polymeric membranes, yet still selective enough for CO_2removal. This approach could overcome the barriers facing membrane-based approaches for capturing CO_2 from coal plant exhausts.

Exelus, Inc.

High-Octane Fuel from Refinery Exhaust Gas

Program: OPEN 2009

Project Term: 12/01/2009 to 05/31/2012

Project Status: ALUMNI

Project State: New Jersey

Technical Categories: Transportation Fuels

Exelus is developing a method to convert olefins from oil refinery exhaust gas into alkylate, a clean-burning, high-octane component of gasoline. Traditionally, olefins must be separated from exhaust before they can be converted into another source of useful fuel. Exelus' process uses catalysts that convert the olefin to alkylate without first separating it from the exhaust. The ability to turn up to 50% of exhaust directly into gasoline blends could result in an additional 46 million gallons of gasoline in the U.S. each year.

Massachusetts Institute of Technology

Electroville: Grid-Scale Batteries

Program: OPEN 2009

Project Term: 01/15/2010 to 09/30/2013

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Storage

Led by MIT professor Donald Sadoway, the Electroville project team is creating a community-scale electricity storage device using new materials and a battery design inspired by the aluminum production process known as smelting. A conventional battery includes a liquid electrolyte and a solid separator between its 2 solid electrodes. MIT's battery contains liquid metal electrodes and a molten salt electrolyte. Because metals and salt don't mix, these 3 liquids of different densities naturally separate into layers, eliminating the need for a solid separator. This efficient design significantly reduces packaging materials, which reduces cost and allows more space for storing energy than conventional batteries offer. MIT's battery also uses cheap, earth-abundant, domestically available materials and is more scalable. By using all liquids, the design can also easily be resized according to the changing needs of local communities.

Sun Catalytix

Energy from Water and Sunlight

Program: OPEN 2009

Project Term: 12/31/2009 to 12/31/2012

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Resource Efficiency

Sun Catalytix is developing wireless energy-storage devices that convert sunlight and water into renewable fuel. Learning from nature, one such device mimics the ability of a tree leaf to convert sunlight into storable energy. It is comprised of a silicon solar cell coated with catalytic materials, which help speed up the energy conversion process. When this cell is placed in a container of water and exposed to sunlight, it splits the water into bubbles of oxygen and hydrogen. The hydrogen and oxygen can later be recombined to create electricity, when the sun goes down for example. The Sun Catalytix device is novel in many ways: it consists primarily of low-cost, earth-abundant materials where other attempts have required more expensive materials like platinum. Its operating conditions also facilitate the use of less costly construction materials, whereas other efforts have required extremely corrosive conditions.

Makani Power, Inc.

Airborne Wind Turbine

Program: OPEN 2009

Project Term: 09/01/2010 to 10/16/2013

Project Status: ALUMNI

Project State: California

Technical Categories: Distributed Generation

Makani Power is developing an Airborne Wind Turbine that eliminates 90% of the mass of a conventional wind turbine and accesses a stronger, more consistent wind at altitudes of near 1,000 feet. At these altitudes, 85% of the country can offer viable wind resources compared to only 15% accessible with current technology. Additionally, the Makani Power wing can be economically deployed in deep offshore waters, opening up a resource which is 4 times greater than the entire U.S. electrical generation capacity. Makani Power has demonstrated the core technology, including autonomous launch, land, and power generation with an 8 meter wingspan, 20 kW prototype. At commercial scale, Makani Power aims to develop a 600 kW, 28 meter wingspan product capable of delivering energy at an unsubsidized cost competitive with coal, the current benchmark for low-cost power.

Lehigh University

[CO2 Capture Using Electric Fields]

Program: OPEN 2009

Project Term: 01/01/2010 to 06/30/2012

Project Status: ALUMNI

Project State: Pennsylvania

Technical Categories: Resource Efficiency

Two faculty members at Lehigh University created a new technique called supercapacitive swing adsorption (SSA) that uses electrical charges to encourage materials to capture and release CO2. Current CO2 capture methods include expensive processes that involve changes in temperature or pressure. Lehigh University's approach uses electric fields to improve the ability of inexpensive carbon sorbents to trap CO2. Because this process uses electric fields and not electric current, the overall energy consumption is projected to be much lower than conventional methods. Lehigh University is now optimizing the materials to maximize CO2 capture and minimize the energy needed for the process.

Research Triangle Institute

[Biofuels from Pyrolysis]

Program: OPEN 2009

Project Term: 01/01/2010 to 09/30/2013

Project Status: ALUMNI

Project State: North Carolina

Technical Categories: Transportation Fuels

RTI is developing a new pyrolysis process to convert second-generation biomass into biofuels in one simple step. Pyrolysis is the decomposition of substances by heating--the same process used to render wood into charcoal, caramelize sugar, and dry roast coffee and beans. RTI's catalytic biomass pyrolysis differs from conventional flash pyrolysis in that its end product contains less oxygen, metals, and nitrogen--all of which contribute to corrosion, instability, and inefficiency in the fuel-production process. This technology is expected to easily integrate into the existing domestic petroleum refining infrastructure, making it an economically attractive option for biofuels production.

Teledyne Scientific & Imaging, LLC

[Efficient Solar Concentrators]

Program: OPEN 2009

Project Term: 10/01/2010 to 04/19/2013

Project Status: ALUMNI

Project State: California

Technical Categories: Distributed Generation

Teledyne is developing a liquid prism panel that tracks the position of the sun to help efficiently concentrate its light onto a solar cell to produce power. Typically, solar tracking devices have bulky and expensive mechanical moving parts that require a lot of power and are often unreliable. Teledyne's liquid prism panel has no bulky and heavy supporting parts--instead it relies on electrowetting. Electrowetting is a process where an electric field is applied to the liquid to control the angle at which it meets the sunlight above and to control the angle of the sunlight to the focusing lens--the more direct the angle to the focusing lens, the more efficiently the light can be concentrated to solar panels and converted into electricity. This allows the prism to be tuned like a radio to track the sun across the sky and steer sunlight into the solar cell without any moving mechanical parts. This process uses very little power and requires no expensive supporting hardware or moving parts, enabling efficient and quiet rooftop operation for integration into buildings.

1366 Technologies, Inc.

[Cost-Effective Silicon Wafers for Solar Cells]

Program: OPEN 2009

Project Term: 03/01/2010 to 06/30/2012

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Distributed Generation

1366 is developing a process to reduce the cost of solar electricity by up to 50% by 2020--from $0.15 per kilowatt hour to less than $0.07. 1366's process avoids the costly step of slicing a large block of silicon crystal into wafers, which turns half the silicon to dust. Instead, the company is producing thin wafers directly from molten silicon at industry-standard sizes, and with efficiencies that compare favorably with today's state-of-the-art technologies. 1366's wafers could directly replace wafers currently on the market, so there would be no interruptions to the delivery of these products to market. As a result of 1366's technology, the cost of silicon wafers could be reduced by 80%.

Phononic Devices, Inc.

Improved Thermoelectric Devices

Program: OPEN 2009

Project Term: 12/11/2009 to 03/30/2012

Project Status: ALUMNI

Project State: North Carolina

Technical Categories: Storage

Phononic Devices is working to recapture waste heat and convert it into usable electric power. To do this, the company is using thermoelectric devices, which are made from advanced semiconductor materials that convert heat into electricity or actively remove heat for refrigeration and cooling purposes. Thermoelectric devices resemble computer chips, and they manage heat by manipulating the direction of electrons at the nanoscale. These devices aren't new, but they are currently too inefficient and expensive for widespread use. Phononic Devices is using a high-performance, cost-effective thermoelectric design that will improve the device's efficiency and enable electronics manufacturers to more easily integrate them into their products.

Arizona State University

Metal-Air Electric Vehicle Battery

Program: OPEN 2009

Project Term: 12/21/2009 to 06/30/2012

Project Status: ALUMNI

Project State: Arizona

Technical Categories: Transportation Storage

ASU is developing a new class of metal-air batteries. Metal-air batteries are promising for future generations of EVs because they use oxygen from the air as one of the battery's main reactants, reducing the weight of the battery and freeing up more space to devote to energy storage than Li-Ion batteries. ASU technology uses Zinc as the active metal in the battery because it is more abundant and affordable than imported lithium. Metal-air batteries have long been considered impractical for EV applications because the water-based electrolytes inside would decompose the battery interior after just a few uses. Overcoming this traditional limitation, ASU's new battery system could be both cheaper and safer than today's Li-Ion batteries, store from 4-5 times more energy, and be recharged over 2,500 times.

FastCAP Systems Corp.

High Energy Density Ultracapacitors

Program: OPEN 2009

Project Term: 04/01/2010 to 12/31/2013

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Transportation Storage

FastCAP is improving the performance of an ultracapacitor--a battery-like electronic device that can complement, and possibly even replace, an HEV or EV battery pack. Ultracapacitors have many advantages over conventional batteries, including long lifespans (over 1 million cycles, as compared to 10,000 for conventional batteries) and better durability. Ultracapacitors also charge more quickly than conventional batteries, and they release energy more quickly. However, ultracapacitors have fallen short of batteries in one key metric: energy density--high energy density means more energy storage. FastCAP is redesigning the ultracapacitor's internal structure to increase its energy density. Ultracapacitors traditionally use electrodes made of irregularly shaped, porous carbon. FastCAP's ultracapacitors are made of tiny, aligned carbon nanotubes. The nanotubes provide a regular path for ions moving in and out of the ultracapacitor's electrode, increasing the overall efficiency and energy density of the device.

University of Minnesota

Biofuel from Bacteria and Sunlight

Program: OPEN 2009

Project Term: 01/01/2010 to 08/31/2012

Project Status: ALUMNI

Project State: Minnesota

Technical Categories: Transportation Fuels

The University of Minnesota is developing clean-burning, liquid hydrocarbon fuels from bacteria. The University is finding ways to continuously harvest hydrocarbons from a type of bacteria called Shewanella by using a photosynthetic organism to constantly feed Shewanella the sugar it needs for energy and hydrocarbon production. The two organisms live and work together as a system. Using Shewanella to produce hydrocarbon fuels offers several advantages over traditional biofuel production methods. First, it eliminates many of the time-consuming and costly steps involved in growing plants and harvesting biomass. Second, hydrocarbon biofuels resemble current petroleum-based fuels and would therefore require few changes to the existing fuel refining and distribution infrastructure in the U.S.

Delphi Automotive Systems, LLC

More Efficient Power Conversion for EVs

Program: OPEN 2009

Project Term: 02/01/2010 to 12/31/2013

Project Status: ALUMNI

Project State: Michigan

Technical Categories: Electrical Efficiency, Transportatio

Delphi is developing power converters that are smaller and more energy efficient, reliable, and cost-effective than current power converters. Power converters rely on power transistors which act like a very precisely controlled on-off switch, controlling the electrical energy flowing through an electrical circuit. Most power transistors today use silicon (Si) semiconductors. However, Delphi is using semiconductors made with a thin layer of gallium-nitride (GaN) applied on top of the more conventional Si material. The GaN layer increases the energy efficiency of the power transistor and also enables the transistor to operate at much higher temperatures, voltages, and power-density levels compared to its Si counterpart. Delphi is packaging these high-performance GaN semiconductors with advanced electrical connections and a cooling system that extracts waste heat from both sides of the device to further increase the device's efficiency and allow more electrical current to flow through it. When combined with other electronic components on a circuit board, Delphi's GaN power transistor package will help improve the overall performance and cost-effectiveness of HEVs and EVs.

Ceres, Inc.

Improving Biomass Yields

Program: OPEN 2009

Project Term: 01/01/2010 to 12/31/2013

Project Status: ALUMNI

Project State: California

Technical Categories: Transportation Fuels

Ceres is developing bigger and better grasses for use in biofuels. The bigger the grass yield, the more biomass, and more biomass means more biofuel per acre. Using biotechnology, Ceres is developing grasses that will grow bigger with less fertilizer than current grass varieties. Hardier, higher-yielding grass also requires less land to grow and can be planted in areas where other crops can't grow instead of in prime agricultural land. Ceres is conducting multi-year trials in Arizona, Texas, Tennessee, and Georgia which have already resulted in grass yields with as much as 50% more biomass than yields from current grass varieties.

Arizona State University

Turning Bacteria into Fuel

Program: OPEN 2009

Project Term: 01/01/2010 to 06/30/2013

Project Status: ALUMNI

Project State: Arizona

Technical Categories: Transportation Fuels

ASU is engineering a type of photosynthetic bacteria that efficiently produce fatty acids--a fuel precursor for biofuels. This type of bacteria, called Synechocystis, is already good at converting solar energy and carbon dioxide (CO_2) into a type of fatty acid called lauric acid. ASU has modified the organism so it continuously converts sunlight and CO_2 into fatty acids--overriding its natural tendency to use solar energy solely for cell growth and maximizing the solar-to-fuel conversion process. ASU's approach is different because most biofuels research focuses on increasing cellular biomass and not on excreting fatty acids. The project has also identified a unique way to convert the harvested lauric acid into a fuel that can be easily blended with existing transportation fuels.

University of Delaware

Affordable Hydrogen Fuel Cell Vehicles

Program: OPEN 2009

Project Term: 02/15/2012 to 12/31/2014

Project Status: ALUMNI

Project State: Delaware

Technical Categories: Distributed Generation

The University of Delaware is developing a new fuel cell membrane for vehicles that relies on cheaper and more abundant materials than those used in current fuel cells. Conventional fuel cells are very acidic, so they require acid-resistant metals like platinum to generate electricity. The University of Delaware is developing an alkaline fuel cell membrane that can operate in a non-acidic environment where cheaper materials like nickel and silver, instead of platinum, can be used. In addition to enabling the use of cheaper metals, the University of Delaware's membrane is 500 times less expensive than other polymer membranes used in conventional fuel cells.

University of Illinois, Urbana Champaign

Silicon-Based Thermoelectrics

Program: OPEN 2009

Project Term: 03/01/2010 to 08/31/2012

Project Status: ALUMNI

Project State: Illinois

Technical Categories: Resource Efficiency

UIUC is experimenting with silicon-based materials to develop flexible thermoelectric devices--which convert heat into energy--that can be mass-produced at low cost. A thermoelectric device, which resembles a computer chip, creates electricity when a different temperature is applied to each of its sides. Existing commercial thermoelectric devices contain the element tellurium, which limits production levels because tellurium has become increasingly rare. UIUC is replacing this material with microscopic silicon wires that are considerably cheaper and could be equally effective. Improvements in thermoelectric device production could return enough wasted heat to add up to 23% to our current annual electricity production.

General Motors

Waste Heat Recovery System

Program: OPEN 2009

Project Term: 01/01/2010 to 03/31/2012
Project Status: ALUMNI
Project State: Michigan
Technical Categories: Resource Efficiency

GM is using shape memory alloys that require as little as a 10°C temperature difference to convert low-grade waste heat into mechanical energy. When a stretched wire made of shape memory alloy is heated, it shrinks back to its pre-stretched length. When the wire cools back down, it becomes more pliable and can revert to its original stretched shape. This expansion and contraction can be used directly as mechanical energy output or used to drive an electric generator. Shape memory alloy heat engines have been around for decades, but the few devices that engineers have built were too complex, required fluid baths, and had insufficient cycle life for practical use. GM is working to create a prototype that is practical for commercial applications and capable of operating with either air- or fluid-based heat sources. GM's shape memory alloy based heat engine is also designed for use in a variety of non-vehicle applications. For example, it can be used to harvest non-vehicle heat sources, such as domestic and industrial waste heat and natural geothermal heat, and in HVAC systems and generators.

Foro Energy, Inc.
Laser-Mechanical Drilling for Geothermal Energy
Program: OPEN 2009
Project Term: 01/15/2010 to 09/30/2013
Project Status: ALUMNI
Project State: Colorado
Technical Categories: Centralized Generation, Distribute

Foro Energy is developing a unique capability and hardware system to transmit high power lasers over long distances via fiber optic cables. This laser power is integrated with a mechanical drilling bit to enable rapid and sustained penetration of hard rock formations too costly to drill with mechanical drilling bits alone. The laser energy that is directed at the rock basically softens the rock, allowing the mechanical bit to more easily remove it. Foro Energy's laser-assisted drill bits have the potential to be up to 10 times more economical than conventional hard-rock drilling technologies, making them an effective way to access the U.S. energy resources currently locked under hard rock formations.

ITN Energy Systems, Inc.
Electrochromic Film for More Efficient Windows
Program: OPEN 2009
Project Term: 01/01/2010 to 06/30/2013
Project Status: ALUMNI
Project State: Colorado
Technical Categories: Building Efficiency

ITN is addressing the high cost of electrochromic windows with a new manufacturing process: roll-to-roll deposition of the film onto flexible plastic surfaces. Production of electrochromic films on plastic requires low processing temperatures and uniform film quality over large surface areas. ITN is overcoming these challenges using its previous experience in growing flexible thin-film solar cells and batteries. By developing sensor-based controls, ITN's roll-to-roll manufacturing process yields more film over a larger area than traditional film deposition methods. Evaluating deposition processes from a control standpoint ultimately strengthens the ability for ITN to handle unanticipated deviations quickly and efficiently, enabling more consistent large-volume production. The team is currently moving from small-scale prototypes into pilot-scale production to validate roll-to-roll manufacturability and produce scaled prototypes that can be proven in simulated operating conditions. Electrochromic plastic films could also open new markets in building retrofit applications, vastly expanding the potential energy savings.

FloDesign Wind Turbine Corp.
Mixer-Ejector Wind Turbine
Program: OPEN 2009
Project Term: 02/22/2010 to 03/31/2013

Project Status: ALUMNI
Project State: Massachusetts
Technical Categories: Distributed Generation

FloDesign's innovative wind turbine, inspired by the design of jet engines, could deliver 300% more power than existing wind turbines of the same rotor diameter by extracting more energy over a larger area. FloDesign's unique shrouded design expands the wind capture area, and the mixing vortex downstream allows more energy to flow through the rotor without stalling the turbine. The unique rotor and shrouded design also provide significant opportunity for mass production and simplified assembly, enabling mid-scale turbines (approximately 100 kW) to produce power at a cost that is comparable to larger-scale conventional turbines.

University of Delaware

High-Energy Composite Permanent Magnets

Program: OPEN 2009
Project Term: 02/15/2010 to 09/30/2013
Project Status: ALUMNI
Project State: Delaware
Technical Categories: Transportation Vehicles

The University of Delaware is developing permanent magnets that contain less rare earth material and produce twice the energy of the strongest rare earth magnets currently available. The University of Delaware is creating these magnets by mixing existing permanent magnet materials with those that are more abundant, like iron. Both materials are first prepared in the form of nanoparticles via techniques ranging from wet chemistry to ball milling. After that, the nanoparticles must be assembled in a 3-D array and consolidated at low temperatures to form a magnet. With small size particles and good contact between these two materials, the best qualities of each allow for the development of exceptionally strong composite magnets.

Soraa, Inc.

Ammonothermal Growth of GaN Substrates for LEDs

Program: OPEN 2009
Project Term: 06/06/2012 to 01/31/2016
Project Status: ALUMNI
Project State: California
Technical Categories: Building Efficiency

The new GaN crystal growth method is adapted from that used to grow quartz crystals, which are very inexpensive and represent the second-largest market for single crystals for electronic applications (after silicon). More extreme conditions are required to grow GaN crystals and therefore a new type of chemical growth chamber was invented that is suitable for large-scale manufacturing. A new process was developed that grows GaN crystals at a rate that is more than double that of current processes. The new technology will enable GaN substrates with best-in-world quality at lowest-in-world prices, which in turn will enable new generations of white LEDs, lasers for full-color displays, and high-performance power electronics.

Agrivida

Engineering Enzymes in Energy Crops

Program: OPEN 2009
Project Term: 01/15/2010 to 03/31/2015
Project Status: ALUMNI
Project State: Massachusetts
Technical Categories: Transportation Fuels

Enzymes are required to break plant biomass down into the fermentable sugars that are used to create biofuel. Currently, costly enzymes must be added to the biofuel production process. Engineering crops to already contain these enzymes will reduce costs and produce biomass that is more easily digested. In fact, enzyme costs alone account for

$0.50-$0.75/gallon of the cost of a biomass-derived biofuel like ethanol. Agrivida is genetically engineering plants to contain high concentrations of enzymes that break down cell walls. These enzymes can be "switched on" after harvest so they won't damage the plant while it's growing.

NanOasis Technologies, Inc.

Use of Carbon Nanotubes for Efficient Reverse Osmosis

Program: OPEN 2009

Project Term: 01/01/2010 to 10/14/2011

Project Status: CANCELLED

Project State: California

Technical Categories: Resource Efficiency

NanOasis is developing better membranes to filter salt from water during the reverse osmosis desalination process. Conventional reverse osmosis desalination processes pump water through a thin film membrane to separate out the salt. However, these membranes only provide modest water permeability, making the process highly energy intensive and expensive. NanOasis is developing membranes that consist of a thin, dense film with carbon nanotube pores that significantly enhance water transport, while effectively excluding the salt. Water can flow through the tiny pores of these carbon nanotubes quickly and with less pressure, drastically reducing the overall energy use and cost of the desalination process. In addition, NanOasis technology was purported to not require any modifications to existing desalination plants, so it could be easily deployed.

Iowa State University

Optimized Breeding of Microalgae for Biofuels

Program: OPEN 2009

Project Term: 01/15/2010 to 10/14/2011

Project Status: CANCELLED

Project State: Iowa

Technical Categories: Transportation Fuels

ISU is genetically engineering a species of aquatic microalgae called Chlamydomonas for more energy efficient conversion of sunlight and carbon dioxide to biofuels. Current microalgae genetic technologies are imprecise and hinder the rapid engineering of a variety of desirable traits into Chlamydomonas. In the absence of genetic engineering, it remains unlikely that current microalgae technologies for biofuel production will be able to economically compete with traditional fossil fuels. ISU is developing a portfolio of technologies for rapid genetic modification and breeding that will enable greater flexibility for genetic modification on a routine basis. The ISU project will optimize microalgae breeding and genetic engineering to develop efficient, large-scale industrial biofuel production.

Inorganic Specialists, Inc.

Long-Range Li-Ion Batteries for Electric Vehicles

Program: OPEN 2009

Project Term: 12/01/2009 to 11/03/2011

Project Status: CANCELLED

Project State: Ohio

Technical Categories: Transportation Storage

Inorganic Specialists' project consists of material and manufacturing development for a new type of Li-Ion battery material, a silicon-coated paper. Silicon-based batteries are advantageous due to silicon's ability to store large amounts of energy. Yet, the technology has not been able to withstand multiple charge/discharge cycles. The thinner the silicon-based material, the better it can handle multiple charge/discharge cycles. Inorganic Specialists' extremely thin silicon-coated paper can store 4 times more energy than existing Li-Ion batteries. The team is improving manufacturing capability in two key areas: 1) expanding existing papermaking equipment to continuously produce the silicon-coated paper, and 2) creating machinery that will silicon-coat the paper via a moving process, to demonstrate manufacturing feasibility. These manufacturing improvements could meet the energy storage criteria required for multiple charge/discharge cycles. Inorganic Specialists' silicon-coated paper's properties have the potential to make it a practical, cost-effective transformative Li-Ion battery material.

Pennsylvania State University

Solar Conversion of CO2 and Water Vapor to Hydrocarbon Fuels

Program: OPEN 2009

Project Term: 12/14/2009 to 07/09/2010

Project Status: CANCELLED

Project State: Pennsylvania

Technical Categories: Transportation Fuels

Pennsylvania State University is developing a novel sunlight to chemical fuel conversion system. This innovative technology is based on tuning the properties of nanotube arrays with co-catalysts to achieve efficient solar conversion of CO2and water vapor to methane and other hydrocarbons. The goal of this project is to build a stand-alone collector which can achieve ~2% sunlight to chemical fuel conversion efficiency via CO2 reduction.

EaglePicher

Sodium-Beta Batteries for Grid-Scale Storage

Program: OPEN 2009

Project Term: 02/01/2010 to 03/31/2016

Project Status: CANCELLED

Project State: Missouri

Technical Categories: Storage

EaglePicher is developing a sodium-beta alumina (Na-Beta) battery for grid-scale energy storage. High-temperature Na-Beta batteries are a promising grid-scale energy storage technology, but existing approaches are expensive and unreliable. EaglePicher has modified the shape of the traditional, tubular-shaped Na-Beta battery. It is using an inexpensive stacked design to improve performance at lower temperatures, leading to a less expensive overall storage technology. The new design greatly simplifies the manufacturing process for beta alumina membranes (a key enabling technology), providing a subsequent pathway to the production of scalable, modular batteries at half the cost of the existing tubular designs.

Nalco Company

Using Enzymes to Capture CO2 in Smokestacks

Program: OPEN 2009

Project Term: 01/18/2010 to 10/13/2011

Project Status: CANCELLED

Project State: Illinois

Technical Categories: Resource Efficiency

Nalco is developing a process to capture carbon in the smokestacks of coal-fired power plants. Conventional CO2capture methods require the use of a vacuum or heat, which are energy-intensive and expensive processes. Nalco's approach to carbon capture involves controlling the acidity of the capture mixture and using an enzyme to speed up the rate of carbon capture from the exhaust gas. Changing the acidity drives the removal of CO2 from the gas without changing temperature or pressure, and the enzyme speeds up the capture rate of CO2. In addition, Nalco's technology would be simpler to retrofit to existing coal-fired plants than current technologies, so it could be more easily deployed.

United Technologies Research Center

Using Synthetic Enzymes for Carbon Capture

Program: OPEN 2009

Project Term: 12/15/2009 to 01/09/2012

Project Status: CANCELLED

Project State: Connecticut

Technical Categories: Resource Efficiency

UTRC is developing a process for capturing the CO2emitted by coal-fired power plants. Conventional carbon capture methods use high temperatures or chemical solvents to separate CO2 from the exhaust gas, which are energy intensive and expensive processes. UTRC is developing membranes that separate the CO2 out of the exhaust gas using a synthetic version of a naturally occurring enzyme used to manage CO2. This enzyme is used by all air-breathing organisms on Earth to regulate CO2 levels. The enzyme would not survive within the gas exhaust of coal-fired power plants in its natural form, so UTRC is developing a synthetic version designed to withstand these harsh conditions. UTRC's technology does not require heat during processing, which could allow up to a 30% reduction in the cost of carbon

OPEN 2012 Open Funding Solicitation (66)

In 2012, ARPA-E issued its second open funding opportunity designed to catalyze transformational breakthroughs across the entire spectrum of energy technologies. ARPA-E received more than 4,000 concept papers for OPEN 2012, which hundreds of scientists and engineers thoroughly reviewed over the course of several months. In the end, ARPA-E selected 66 projects for its OPEN 2012 program, awarding them a total of $130 million in federal funding. OPEN 2012 projects cut across 11 technology areas: advanced fuels, advanced vehicle design and materials, building efficiency, carbon capture, grid modernization, renewable power, stationary power generation, water, as well as stationary, thermal, and transportation energy storage.

Harvard University

Organic Flow Battery for Energy Storage

Program: OPEN 2012

Project Term: 02/01/2013 to 03/25/2017

Project Status: ACTIVE

Project State: Massachusetts

Technical Categories: Storage

Harvard is developing an innovative grid-scale flow battery to store electricity from renewable sources. Flow batteries store energy in external tanks instead of within the battery container, permitting larger amounts of stored energy at lower cost per kWh. Harvard is designing active material for a flow battery that uses small, inexpensive organic molecules in aqueous electrolyte. Relying on low-cost organic materials, Harvard's innovative storage device concept would yield one or more systems that may be developed by their partner, Sustainable Innovations, LLC, into viable grid-scale electrical energy storage systems.

Research Triangle Institute

Compact Inexpensive Reformers for Natural Gas

Program: OPEN 2012

Project Term: 03/15/2013 to 12/31/2016

Project Status: ACTIVE

Project State: North Carolina

Technical Categories: Transportation Fuels

RTI is leveraging existing engine technology to develop a compact reformer for natural gas conversion. Reformers produce synthesis gas--the first step in the commercial process of converting natural gas to liquid fuels. As a major component of any gas-to-liquid plant, the reformer represents a substantial cost. RTI's re-designed reformer would be compact, inexpensive, and easily integrated with small-scale chemical reactors. RTI's technology allows for significant cost savings by harnessing equipment that is already manufactured and readily available. Unlike other systems that are too large to be deployed remotely, RTI's reformer could be used for small, remote sources of gas.

Dioxide Materials, Inc.

Converting CO2 into Fuel and Chemicals

Program: OPEN 2012

Project Term: 02/01/2013 to 01/21/2017

Project Status: ACTIVE

Project State: Illinois

Technical Categories: Resource Efficiency

Dioxide Materials is developing technology to produce carbon monoxide, or "synthesis gas" electrochemically from CO2 emitted by power plants. Synthesis gas can be used as a feedstock for the production of industrial chemicals and liquid fuels. The current state-of-the-art process for capturing and removing CO2 from the flue gas of power plants is expensive and energy intensive, and therefore faces significant hurdles towards widespread implementation. The technologies being developed by Dioxide Materials aim to convert CO2 into something useful in an economical and practical way. The technology has the potential to create an entirely new industry where waste CO2--rather than oil--is used to produce gasoline, diesel fuel, jet fuel, and industrial chemicals.

Bio2Electric, LLC

Electrogenerative Gas-to-Liquid Reactor

Program: OPEN 2012

Project Term: 02/01/2013 to 07/15/2017

Project Status: ACTIVE

Project State: New Jersey

Technical Categories: Transportation Fuels

Bio2Electric is developing a small-scale reactor that converts natural gas into a feedstock for industrial chemicals or liquid fuels. Conventional, large-scale gas-to-liquid reactors are expensive and not easily scaled down. Bio2Electric's reactor relies on a chemical conversion and fuel cell technology resulting in fuel cells that create a valuable feedstock, as well as electricity. In addition, the reactor relies on innovations in material science by combining materials that have not been used together before, thereby altering the desired output of the fuel cell. The reactors can be efficiently built as modular units, therefore reducing the manufacturing costs of the reactor. Bio2Electric's small-scale reactor could be deployed in remote locations to provide electricity in addition to liquid fuel, increasing the utility of geographically isolated gas reserves.

Ceramatec, Inc.

Mid-Temperature Fuel Cells for Vehicles

Program: OPEN 2012

Project Term: 02/01/2013 to 03/31/2017

Project Status: ACTIVE

Project State: Utah

Technical Categories: Transportation Storage

Ceramatec is developing a solid-state fuel cell that operates in an 'intermediate' temperature range that could overcome persistent challenges faced by both high temperature and low temperature fuel cells. The advantages compared to higher temperature fuel cells are less expensive seals and interconnects, as well as longer lifetime. The advantages compared to low temperature fuel cells are reduced platinum requirements and the ability to run on fuels other than hydrogen, such as natural gas or methanol. Ceramatec's design would use a new electrolyte material to transport protons within the cell and advanced electrode layers. The project would engineer a fuel cell stack that performs at lower cost than current automotive designs, and culminate in the building and testing of a short fuel cell stack capable of meeting stringent transportation requirements.

General Electric

High-Power Gas Tube Switches

Program: OPEN 2012

Project Term: 04/30/2013 to 04/30/2017

Project Status: ACTIVE

Project State: Connecticut

Technical Categories: Grid

GE is developing a new gas tube switch that could significantly improve and lower the cost of utility-scale power conversion. A switch breaks an electrical circuit by interrupting the current or diverting it from one conductor to another. To date, solid state semiconductor switches have completely replaced gas tube switches in utility-scale power converters because they have provided lower cost, higher efficiency, and greater reliability. GE is using new materials and innovative designs to develop tubes that not only operate well in high-power conversion, but also perform better and cost less than non-tube electrical switches. A single gas tube switch could replace many semiconductor switches, resulting in more cost effective high power converters.

Stanford University

Radiative Coolers for Rooftops and Cars

Program: OPEN 2012

Project Term: 02/20/2013 to 06/30/2017

Project Status: ACTIVE

Project State: California

Technical Categories: Building Efficiency

Stanford is developing a device for the rooftops of buildings and cars that will reflect sunlight and emit heat, enabling passive cooling, even when the sun is shining. This device requires no electricity or fuel and would reduce the need for air conditioning, leading to energy and cost savings. Stanford's technology relies on recently developed state-of-the-art concepts and techniques to tailor the absorption and emission of light and heat in nanostructured materials. This project could enable buildings, cars, and electronics to cool without using electric power.

University of Delaware

High-Storage Double-Membrane Flow Battery

Program: OPEN 2012

Project Term: 01/09/2013 to 12/31/2016

Project Status: ACTIVE

Project State: Delaware

Technical Categories: Storage

The University of Delaware is developing a low-cost flow battery that uses membrane technology to increase voltage and energy storage capacity. Flow batteries store chemical energy in external tanks instead of within the battery container, which allows for cost-effective scalability because adding storage capacity is as simple as expanding the tank, offering large-scale storage capacity for renewable energy sources. However, traditional flow batteries have limited cell voltages, which lead to low power and low energy density. The University of Delaware is addressing this limitation by adding an additional exchange membrane within the electrolyte material of the battery, creating 3 separate compartments of electrolytes. Separating the electrolytes in this manner allows unprecedented freedom for the battery to exchange ions back and forth between the positive and negative end of the battery, which improves the voltage of the system.

University of Southern California

Inexpensive, Metal-free, Organic Flow Battery

Program: OPEN 2012

Project Term: 03/01/2013 to 05/31/2017

Project Status: ACTIVE

Project State: California

Technical Categories: Storage

USC is developing a water-based, metal-free, grid-scale flow battery that will be cheaper and more rapidly produced than other batteries. Flow batteries store chemical energy in external tanks instead of within the battery container. This allows for cost-effective scalability because adding storage capacity is as simple as expanding the tank. Batteries for grid-scale energy storage must be inexpensive, robust, and sustainable--many of today's mature battery technologies do not meet all these requirements. Using innovative designs and extremely low-cost organic materials, USC's new flow battery has the potential to reduce cost, increase durability, and store increased amounts of excess energy, thereby promoting greater renewable energy deployment.

Tai-Yang Research Company

[High-Power, Low-Cost Superconducting Cable]

Program: OPEN 2012

Project Term: 02/15/2013 to 03/06/2017

Project Status: ACTIVE

Project State: Tennessee

Technical Categories: Transportation Storage

TYRC is developing a superconducting cable, which is a key enabling component for a grid-scale magnetic energy storage device. Superconducting magnetic energy storage systems have not established a commercial foothold because of their relatively low energy density and the high cost of the superconducting material. TYRC is coating their cable in yttrium barium copper oxide (YBCO) to increase its energy density. This unique, proprietary cable could be manufactured at low cost because it requires less superconducting material to produce the same level of energy storage as today's best cables.

Glint Photonics, Inc.

[Self-Tracking Concentrator Photovoltaics]

Program: OPEN 2012

Project Term: 04/01/2013 to 03/31/2017

Project Status: ACTIVE

Project State: California

Technical Categories: Distributed Generation

Glint is developing an inexpensive solar concentrating PV (CPV) module that tracks the sun's position over the course of the day to channel sunlight into PV materials more efficiently. Conventional solar concentrator technology requires complex moving parts to track the sun's movements. In contrast, Glint's inexpensive design can be mounted in a stationary configuration and adjusts its properties automatically in response to the solar position. By embedding this automated tracking function within the concentrator, Glint's design enables CPV modules to use traditional mounting technology and techniques, reducing installation complexity and cost. These self-tracking concentrators can significantly decrease the cost of solar power modules by enabling high efficiency while eliminating the additional costs of precision trackers and specialized mounting hardware. The concentrator itself is designed to be manufactured at extremely low-cost due to low material usage and compatibility with high-speed fabrication techniques. Glint's complete module costs are estimated to be $0.35/watt-peak.

Arizona State University

[Electrochemical Carbon Capture]

Program: OPEN 2012

Project Term: 03/12/2013 to 02/28/2017

Project Status: ACTIVE

Project State: Arizona

Technical Categories: Resource Efficiency

ASU is developing an innovative electrochemical technology for capturing the CO2 released by coal-fired power plants. ASU's technology aims to cut both the energy requirements and cost of CO2 capture technology in half compared to today's best methods. Presently, the only proven commercially viable technology for capturing CO2 from coal plants uses a significant amount of energy, consuming roughly 40% of total power plant output. If installed today, this technology would increase the cost of electricity production by 85%. ASU is advancing a fundamentally new paradigm for CO2capture using novel electrochemical reactants to separate and capture CO2. This process could be easily scaled and integrated in conventional fossil fuel power generation facilities.

Otherlab, Inc.

[Small Mirrors for Solar Power Tower Plants]

Program: OPEN 2012

Project Term: 02/19/2013 to 09/30/2017
Project Status: ACTIVE
Project State: California
Technical Categories: Distributed Generation

Otherlab is developing an inexpensive small mirror system with an innovative drive system to reflect sunlight onto concentrating solar power towers at greatly reduced cost. This system is an alternative to expensive and bulky 20-30 foot tall mirrors and expensive sun-tracking drives used in today's concentrating solar power plants. In order for solar power tower plants to compete with conventional electricity generation, these plants need dramatic component cost reductions and lower maintenance and operational expenses. Otherlab's approach uses a smaller modular mirror design that reduces handling difficulty, suffers less from high winds, and allows the use of mass manufacturing processes for low-cost component production. These mirrors can be driven by mechanisms that utilize simpler, more readily serviceable parts which decreases system downtime and efficiency. The incorporation of low-cost and highly-scalable manufacturing approaches could significantly reduce the cost of solar electricity generation below conventional solar tower plant technologies.

Case Western Reserve University

All-Iron Flow Battery

Program: OPEN 2012
Project Term: 01/01/2013 to 03/30/2018
Project Status: ACTIVE
Project State: Ohio
Technical Categories: Storage

Case Western is developing a water-based, all-iron flow battery for grid-scale energy storage at low cost. Flow batteries store chemical energy in external tanks instead of within the battery container. Using iron provides a low-cost, safe solution for energy storage because iron is both abundant and non-toxic. This design could drastically improve the energy storage capacity of stationary batteries at 10-20% of today's cost. Ultimately, this technology could help reduce the cost of stationary energy storage enough to facilitate the adoption and deployment of renewable energy technology.

Plant Sensory Systems

Better Biofuel Feedstock from Beets

Program: OPEN 2012
Project Term: 03/15/2013 to 03/14/2017
Project Status: ACTIVE
Project State: Maryland
Technical Categories: Transportation Fuels

PSS is developing an enhanced energy beet that will provide an improved fermentable feedstock. A gene that has been shown to increase biomass and soluble sugars in other crop species will be introduced into beets in order produce higher levels of non-food-grade sugars and use both nutrients and water more efficiently. These engineered beets will have a lower cost of production and increased yield of fermentable sugars to help diversify feedstocks for bioproduction of fuel molecules.

Brown University

Customized Tidal Power Conversion Devices

Program: OPEN 2012
Project Term: 03/20/2013 to 05/31/2017
Project Status: ACTIVE
Project State: Rhode Island
Technical Categories: Distributed Generation

Brown University is developing a power conversion device to maximize power production and reduce costs to capture energy from flowing water in rivers and tidal basins. Conventional methods to harness energy from these water resources face a number of challenges, including the costs associated with developing customized turbine technology to a specific site. Additionally, sites with sufficient energy exist near coastal habitats which depend on the natural water flow to transport nutrients. Brown University's tidal power conversion devices can continuously customize themselves by using an onboard computer and control software to respond to real-time measurements, which will increase tidal power conversion efficiency. Brown University's technology will allow for inexpensive installation and software upgrades and optimized layout of tidal power generators to maximize power generation and mitigate environmental impacts.

University of California, Berkeley

Rapid Building Energy Modeler - RAPMOD

Program: OPEN 2012

Project Term: 04/08/2013 to 11/30/2016

Project Status: ACTIVE

Project State: California

Technical Categories: Building Efficiency

University of California Berkeley (UC Berkeley) and Indoor Reality are developing a portable scanning system and the associated software to rapidly generate indoor thermal and physical building maps. This will allow for cost-effective identification of building inefficiencies and recommendation of energy-saving measures. The scanning system is contained in a backpack which an operator would wear while walking through a building along with a handheld scanner. The backpack features sensors that collect building data such as room size and shape along with associated thermal characteristics. These data can then be automatically processed to detect building elements, such as windows and lighting, and then generate 2D floor plans and 3D maps of the building geometry and thermal features. The backpack technology enables rapid data collection and export to existing computer models to guide strategies that could reduce building energy usage. Because the skills required to operate this technology are less than required for a traditional energy audit and the process is significantly faster, the overall cost of the audit can be reduced and the accuracy of the collected data is improved. This reduced cost should incentivize more building managers to conduct energy audits and implement energy saving measures.

Integral Consulting

Measuring Real-Time Wave Data with Ocean Wave Buoy

Program: OPEN 2012

Project Term: 04/05/2013 to 08/31/2017

Project Status: ACTIVE

Project State: Washington

Technical Categories: Distributed Generation

Integral Consulting is developing a cost-effective ocean wave buoy system that will accurately measure its own movements as it follows the surface wave motions of the ocean and relay this real-time wave data. Conventional real-time wave measurement buoys are expensive, which limits the ability to deploy large networks of buoys. Data from Integral Consulting's buoys can be used as input to control strategies of wave energy conversion (WEC) devices and allow these controlled WECs to capture significantly more energy than systems that do not employ control strategies. Integral Consulting's system will also enable assessment of the optimal locations and designs of WEC systems. Integral Consulting's ocean wave buoy system could measure and relay real-time wave data at 10% the cost of commercially available wave measurement systems.

University of Colorado, Boulder

Small-Scale Reactors for Natural Gas Conversion

Program: OPEN 2012

Project Term: 05/01/2013 to 06/29/2017

Project Status: ACTIVE

Project State: Colorado

Technical Categories: Transportation Fuels

CU-Boulder is using nanotechnology to improve the structure of natural gas-to-liquids catalysts. The greatest difficulty in industrial-scale catalyst activity is temperature control, which can only be solved by improving reactor design. CU-Boulder's newly structured catalyst creates a small-scale reactor for converting natural gas to liquid fuels that can operate at moderate temperatures. Additionally, CU's small-scale reactors could be located near remote, isolated sources of natural gas, further enabling their use as domestic fuel sources.

University of California, Berkeley

Measuring Phase Angle Change in Power Lines

Program: OPEN 2012

Project Term: 03/01/2013 to 12/31/2016

Project Status: ACTIVE

Project State: California

Technical Categories: Grid

UC Berkeley is developing a device to monitor and measure electric power data from the grid's distribution system. The new instrument--known as a micro-phasor measurement unit (μPMU)--is designed to measure critical parameters such as voltage and phase angle at different locations, and correlate them in time via extremely precise GPS clocks. The amount of phase angle difference provides information about the stability and direction of power flow. Data collected from a network of these μPMUs would facilitate better monitoring and control of grid power flow--a critical element for integrating intermittent and renewable resources, such as rooftop solar and wind energy, and other technologies such as electric vehicles and distributed storage.

Electron Energy Corporation

New Processing Technology for Permanent Magnets

Program: OPEN 2012

Project Term: 04/15/2013 to 02/14/2017

Project Status: ACTIVE

Project State: Pennsylvania

Technical Categories: Transportation Vehicles

EEC and its team are developing a new processing technology that could transform how permanent magnets found in today's EV motors and renewable power generators are fabricated. This new process, known as friction consolidation extrusion (FC&E), could produce stronger magnets at a lower cost and with reduced rare earth mineral content. The advantage of FC&E over today's best fabrication processes is that it can be applied to unconsolidated powders as opposed to solid alloys, which can allow magnets to be compacted from much smaller grains of two different types, a process which could double its magnetic energy density. EEC's process could reduce the need for rare earth mineral in permanent magnets by as much 30%.

National Renewable Energy Laboratory

Solar Thermoelectric Generator

Program: OPEN 2012

Project Term: 02/01/2013 to 10/31/2017

Project Status: ACTIVE

Project State: Colorado

Technical Categories: Distributed Generation

NREL is developing a solar thermoelectric generator to directly convert heat from concentrated sunlight to electricity. Thermoelectric devices can directly convert heat to electricity, yet due to cost and efficiency limitations they have not been viewed as a viable large-scale energy conversion technology. However, new thermoelectric materials have dramatically increased the efficiency of direct heat-to-electricity conversion. NREL is using these innovative materials to develop a new solar thermoelectric generator. This device will concentrate sunlight onto an absorbing surface on top of a thermoelectric stage, the resulting temperature difference between the top and bottom of the device will drive the generator to produce electricity at 3 times the efficiency of current systems. NREL's solar thermoelectric generator could reduce the cost associated with converting large amounts of solar energy into electricity through a much simpler and scalable process which does not rely upon moving parts and transfer fluids.

Cornell University

[Efficient Photobioreactor for Algae-Based Fuel]

Program: OPEN 2012

Project Term: 02/01/2013 to 05/01/2014

Project Status: ALUMNI

Project State: New York

Technical Categories: Transportation Fuels

Cornell is developing a new photobioreactor that is more efficient than conventional bioreactors at producing algae-based fuels. Traditional photobioreactors suffer from several limitations, particularly poor light distribution, inefficient fuel extraction, and the consumption of large amounts of water and energy. Cornell's bioreactor is compact, making it more economical to grow engineered algae and collect the fuel the algae produces. Cornell's bioreactor also delivers sunlight efficiently through low-cost, plastic, light-guiding sheets. By distributing optimal amounts of sunlight, Cornell's design would increase efficiency and decrease water use compared to conventional algae reactors.

RamGoss, Inc.

[High-Performance Transistors]

Program: OPEN 2012

Project Term: 02/11/2013 to 08/10/2014

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Grid

RamGoss is using innovative device designs and high-performance materials to develop utility-scale electronic switches that would significantly outperform today's state-of-the-art devices. Switches are the fundamental building blocks of electronic devices, controlling the electrical energy that flows around an electrical circuit. Today's best electronic switches for large power applications are bulky and inefficient, which leads to higher cost and wasted power. RamGoss is optimizing new, low-cost materials and developing a new, completely different switch designs. Combined, these innovations would increase the efficiency and reduce the overall size and cost of power converters for a variety of electronic devices and grid-scale applications, including electric vehicle (EV) chargers, large-scale wind plants, and solar power arrays.

Pratt & Whitney Rocketdyne

[Efficient Conversion of Natural Gas]

Program: OPEN 2012

Project Term: 05/02/2013 to 03/15/2016

Project Status: ALUMNI

Project State: California

Technical Categories: Transportation Fuels

PWR is developing two distinct--but related--technologies that could revolutionize how we convert natural gas. First, PWR will work with Pennsylvania State University to create a high-efficiency gas turbine which uses supercritical fluids to cool the turbine blades. Allowing gas turbines to operate at higher temperatures can drive significant improvements in performance, particularly when coupled with the recapture of waste heat. This advancement could reduce the cost of electricity by roughly 60% and resulting in significantly lower greenhouse gas emissions. Drawing upon lessons learned from this technology, PWR will then work with the Gas Technology Institute to build a system that partially oxidizes natural gas in the high-temperature, high-pressure combustor of a natural gas turbine, efficiently facilitating its conversion into a liquid fuel. This approach could simultaneously improve the efficiency of gas conversion into fuels and chemicals, and also generate high-quality waste heat in the process which could be used to generate electricity.

Ceramatec, Inc.

[A One-Step, Gas-to-Liquid Chemical Converter]

Program: OPEN 2012

Project Term: 02/01/2013 to 02/15/2015
Project Status: ALUMNI
Project State: Utah
Technical Categories: Resource Efficiency

Ceramatec is developing a small-scale reactor to convert natural gas into benzene--a feedstock for industrial chemicals or liquid fuels. Natural gas as a byproduct is highly abundant, readily available, and inexpensive. Ceramatec's reactor will use a one-step chemical conversion process to convert natural gas into benzene. This one-step process is highly efficient and prevents the build-up of solid residue that can occur when gas is processed. The benzene that is produced can be used as a starting material for nylons, polycarbonates, polystyrene, epoxy resins, and as a component of gasoline.

Grid Logic, Inc.
High-Power Superconductors
Program: OPEN 2012
Project Term: 03/05/2013 to 06/04/2016
Project Status: ALUMNI
Project State: Michigan
Technical Categories: Electrical Efficiency

Grid Logic is developing a new type of electrical superconductor that could significantly improve the performance (in $/kA-m) and lower the cost of high-power energy generation, transmission, and distribution. Grid Logic is using a new manufacturing technique to coat very fine particles of superconducting material with an extremely thin layer--less than 1/1,000 the width of a human hair--of a low-cost metal composite. This new manufacturing process is not only much simpler and more cost effective than the process used to make today's state-of-the-art high-power superconductors, but also it makes superconductive cables easier to handle and improves their electrical properties in certain applications.

Applied Materials
Low-Cost Silicon Wafers for Solar Modules
Program: OPEN 2012
Project Term: 06/01/2013 to 09/30/2016
Project Status: ALUMNI
Project State: California
Technical Categories: Centralized Generation, Distribute

Applied Materials is working with ARPA-E and the Office of Energy Efficiency and Renewable Energy (EERE) to build a reactor that produces the silicon wafers used in solar panels at a dramatically lower cost than existing technologies. Current wafer production processes are time consuming and expensive, requiring the use of high temperatures to produce ingots from molten silicon that can be sliced into wafers for use in solar cells. This slicing process results in significant silicon waste--or "kerf loss"--much like how sawdust is created when sawing wood. With funding from ARPA-E, Applied Materials is developing a reactor where ultra-thin silicon wafers are created by depositing silicon directly from vapor onto specialized reusable surfaces, allowing a significant reduction in the amount of silicon used in the process. Since high purity silicon is one of the most significant costs in producing solar cells, this kerf-less approach could significantly reduce the overall cost of producing solar panels. Applied Materials is partnering with Suniva, who will use funds from EERE to integrate these low-cost wafers into solar cells and modules that generate low-cost electricity, and with Arizona State University, who will develop high-efficiency devices on ultra-thin kerfless substrates. This partnership could enable low-cost, domestic manufacturing of solar modules, allowing the U.S. to reduce the amount of equipment we import from other countries.

University of Tennessee
High Throughput Bioengineering of Switchgrass
Program: OPEN 2012
Project Term: 02/01/2013 to 07/31/2016
Project Status: ALUMNI

Project State: Tennessee

Technical Categories: Transportation Fuels

UT is developing technology to rapidly screen the genetic traits of individual plant cells for their potential to improve biofuel crops. By screening individual cells, researchers can identify which lines are likely to be good cellulosic feedstocks without waiting for the plants to grow to maturity. UT's technology will allow high throughput screening of engineered plant cells to identify those with traits that significantly reduce the time and resources required to maximize biofuel production from switchgrass.

Colorado State University

More Options for Bioenergy Crops

Program: OPEN 2012

Project Term: 04/04/2013 to 10/03/2015

Project Status: ALUMNI

Project State: Colorado

Technical Categories: Transportation Fuels

CSU is developing technology to rapidly introduce novel traits into crops that currently cannot be readily engineered. Presently, a limited number of crops can be engineered, and the processes are not standardized - restricting the agricultural sources for engineered biofuel production. More--and more diverse--biofuel crops could substantially improve the efficiency, time scale, and geographic range of biofuel production. CSU's approach would enable simple and efficient engineering of a broad range of bioenergy crops using synthetic biology tools to standardize their genetic modification.

Pacific Northwest National Laboratory

Real-Time Transmission Optimization

Program: OPEN 2012

Project Term: 04/12/2013 to 07/17/2016

Project Status: ALUMNI

Project State: Washington

Technical Categories: Grid

PNNL is developing innovative high-performance-computing techniques that can assess unused power transmission capacity in real-time in order to better manage congestion in the power grid. This type of assessment is traditionally performed off-line every season or every year using only conservative, worst-case scenarios. Finding computing techniques that rate transmission capacity in real-time could improve the utilization of the existing transmission infrastructure by up to 30% and facilitate increased integration of renewable generation into the grid--all without having to build costly new transmission lines.

Massachusetts Institute of Technology

Scalable, Low-Power Water Treatment System

Program: OPEN 2012

Project Term: 06/01/2013 to 12/31/2014

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Resource Efficiency

MIT is developing a water treatment system to treat contaminated water from hydraulic fracking and seawater. There is a critical need for small to medium-sized, low-powered, low-cost water treatment technologies, particularly for regions lacking centralized water and energy infrastructure. Conventional water treatment methods, such as reverse osmosis, are not effective for most produced water clean up based on the high salt levels resulting from fracking. MIT's water treatment system will remove high-levels of typical water contaminants such as salt, metals, and microorganisms. The water treatment system is based on low-powered generation enabling efficient on-demand, on-site potable water production. The process allows for a 50% water recovery rate and is cost-competitive with conventional water treatment technology. MIT's water treatment device would require less power than competing technologies and has important applications for mining, oil and gas production, and water treatment for remote locations.

Georgia Tech Research Corporation

High-Efficiency Solar Fuel Reactor

Program: OPEN 2012

Project Term: 04/17/2013 to 10/17/2016

Project Status: ALUMNI

Project State: Georgia

Technical Categories: Distributed Generation

Georgia Tech is developing a high-efficiency concentrating solar receiver and reactor for the production of solar fuels. The team will develop a system that uses liquid metal to capture and transport heat at much higher temperatures compared to state-of-the-art concentrating solar power facilities. This high temperature system will be combined with the team's novel reactor to produce solar fuels that allow the flexibility to store and transport solar energy for later use or for immediate power production. Higher temperatures should result in much higher efficiencies and therefore lower costs of produced fuel or electricity. Additionally, plant operators would have the flexibility to match electricity or fuel production with the changing market demand to improve the cost effectiveness of the plant.

Yale University

Closed-Loop System Using Waste Heat for Electricity

Program: OPEN 2012

Project Term: 04/24/2013 to 12/31/2015

Project Status: ALUMNI

Project State: Connecticut

Technical Categories: Resource Efficiency

Yale is developing a system to generate electricity using low-temperature waste heat from power plants, industrial facilities, and geothermal wells. Low-temperature waste heat is a vast, mostly untapped potential energy source. Yale's closed loop system begins with waste heat as an input. This waste heat will separate an input salt water stream into two output streams, one with high salt concentration and one with low salt concentration. In the next stage, the high and low concentration salt streams will be recombined. Mixing these streams releases energy which can then be captured. The mixed saltwater stream is then sent back to the waste heat source, allowing the process to begin again. Yale's system for generating electricity from low-temperature waste heat could considerably increase the efficiency of power generation systems.

Teledyne Scientific & Imaging, LLC

High Energy Density Potassium-Based Flow Battery

Program: OPEN 2012

Project Term: 02/04/2013 to 01/31/2014

Project Status: ALUMNI

Project State: California

Technical Categories: Storage

Teledyne is developing a water-based, potassium-ion flow battery for low-cost stationary energy storage. Flow batteries store chemical energy in external tanks instead of within the battery container. This allows for cost-effective scalability because adding storage capacity is as simple as expanding the tank. Teledyne is increasing the energy and power density of their battery by 2-5 times compared to today's state-of-the-art vanadium flow battery. Their safe, scalable, low-cost energy storage technology would facilitate more widespread adoption and deployment of renewable energy technology.

University of Illinois, Urbana Champaign

Power Grid Security

Program: OPEN 2012

Project Term: 04/05/2013 to 08/31/2016
Project Status: ALUMNI
Project State: Illinois
Technical Categories: Grid

UIUC is developing scalable grid modeling, monitoring, and analysis tools that would improve its resiliency to system failures as well as cyber attacks, which can significantly improve the reliability of grid operations. Power system operators today lack the ability to assess the grid's reliability with respect to potential cyber failures and attacks. UIUC is using theoretical and practical techniques from both the cyber security and power engineering domains to develop new algorithms and software tools capable of analyzing real-world threats against power grid critical infrastructures including cyber components (e.g. communication networks), physical components (e.g. power lines), and interdependencies between the two in its models and simulations.

HexaTech, Inc.
Semiconductors that Improve Electricity Flow
Program: OPEN 2012
Project Term: 02/05/2013 to 05/31/2016
Project Status: ALUMNI
Project State: North Carolina
Technical Categories: Grid

HexaTech is developing new semiconductors for electrical switches that will more efficiently control the flow of electricity across high-voltage electrical lines. A switch helps control electricity: switching it on and off, converting it from one voltage to another, and converting it from an Alternating Current (A/C) to a Direct Current (D/C) and back. Most switches today use silicon or silicon-based semiconductors, which are not able to handle high voltages, fast switching speeds, or high operating temperatures. HexaTech has developed highest quality, single crystalline Aluminum Nitride (AlN) semiconductor wafers. HexaTech AlN wafers are the enabling platform for power converters which can handle 50 times more voltage than silicon, as well as higher switching speeds and operating temperatures.

University of Minnesota
Ultra-Thin Membranes for Biofuels Production
Program: OPEN 2012
Project Term: 03/22/2013 to 09/21/2016
Project Status: ALUMNI
Project State: Minnesota
Technical Categories: Resource Efficiency

UMN is developing an ultra-thin separation membrane to decrease the cost of producing biofuels, plastics, and other industrial materials. Nearly 6% of total U.S. energy consumption comes from the energy used in separation and purification processes. Today's separation methods used in biofuels production are not only energy intensive, but also very expensive. UMN is developing a revolutionary membrane technology based on a recently discovered class of ultra-thin, porous, materials that will enable energy efficient separations necessary to prepare biofuels that would also be useful in the chemical, petrochemical, water purification, and fossil fuel industries. These membranes, made from nanometer-thick layers of silicon dioxide, are highly selective in separating nearly-identical chemicals and can handle high flow rates of the chemicals. When fully developed, these membranes could substantially reduce the amount and cost of energy required in the production of biofuels and many other widely used industrial chemicals.

Gas Technology Institute
Efficient Natural Gas-to-Methanol Conversion
Program: OPEN 2012
Project Term: 01/01/2013 to 09/30/2015
Project Status: ALUMNI
Project State: Illinois

Technical Categories: Transportation Fuels

GTI is developing a new process to convert natural gas or methane-containing gas into methanol and hydrogen for liquid fuel. Methanol serves as the main feedstock for dimethyl ether, which could be used for vehicular fuel. Unfortunately, current methods to produce liquid fuels from natural gas require large and expensive facilities that use significant amounts of energy. GTI's process uses metal oxide catalysts that are continuously regenerated in a reactor, similar to a battery, to convert the methane into methanol. These metal oxide catalysts reduce the energy required during the conversion process. This process operates at room temperature, is more energy efficient, and less capital-intensive than existing methods.

University of North Dakota Energy & Environmental Research Center

Water-Efficient Power Generation

Program: OPEN 2012

Project Term: 04/01/2013 to 06/30/2014

Project Status: ALUMNI

Project State: North Dakota

Technical Categories: Resource Efficiency

UND-EERC is developing an air-cooling alternative for power plants that helps maintain operating efficiency during electricity production with low environmental impact. The project addresses the shortcomings of conventional dry cooling, including high cost and degraded cooling performance during daytime temperature peaks. UND-EERC's device would use an air-cooled adsorbent liquid that results in more efficient power production with no water consumption. The technology could be applied to a broad range of plants including fossil, nuclear, solar thermal, and geothermal.

PolyPlus Battery Company

Low-Cost, High-Performance Lithium-Sulfur Batteries

Program: OPEN 2012

Project Term: 02/06/2013 to 03/31/2016

Project Status: ALUMNI

Project State: California

Technical Categories: Storage

PolyPlus is developing an innovative, water-based Lithium-Sulfur (Li-S) battery. Today, Li-S battery technology offers the lightest high-energy batteries that are completely self-contained. New features in these water-based batteries make PolyPlus' lightweight battery ideal for a variety of military and consumer applications. The design could achieve energy densities between 400-600 Wh/kg, a substantial improvement from today's state-of-the-art Li-Ion batteries that can hold only 150 Wh/kg. PolyPlus' technology--with applications for vehicle transportation as well as grid storage--would be able to transition to a widespread commercial and military market.

University of Nevada, Las Vegas

Fire-Resistant Solid Electrolytes

Program: OPEN 2012

Project Term: 02/14/2013 to 02/13/2016

Project Status: ALUMNI

Project State: Nevada

Technical Categories: Transportation Storage

UNLV is developing a solid-state, non-flammable electrolyte to make today's Li-Ion vehicle batteries safer. Today's Li-Ion batteries use a flammable liquid electrolyte--the material responsible for shuttling Li-Ions back and forth across the battery--that can catch fire when overheated or overcharged. UNLV will replace this flammable electrolyte with a fire-resistant material called lithium-rich anti-perovskite. This new electrolyte material would help make vehicle batteries safer in an accident while also increasing battery performance by extending vehicle range and acceleration.

e Nova, Inc.

Waste Heat-Powered Gas Compressor

Program: OPEN 2012

Project Term: 05/01/2013 to 02/17/2014

Project Status: ALUMNI

Project State: Texas

Technical Categories: Resource Efficiency

eNova is developing a gas compressor powered by waste heat from the exhaust of a gas turbine. A conventional gas turbine facility releases the exhaust heat produced during operation into the air--this heat is a waste by-product that can be used to improve power generation system efficiency. eNova's gas compressor converts the exhaust waste heat from the simple cycle gas turbine to compressed air for injection into the turbine, thereby lessening the burden on the turbine's air compressor. This new compressor design is ideal for use with a remote gas turbine--such as that typically used in the natural gas industry to compress pipeline natural gas--with limited options for waste heat recovery and access to high voltage power lines and water.

National Renewable Energy Laboratory

Efficient Plastic Solar Cells

Program: OPEN 2012

Project Term: 02/01/2013 to 04/30/2014

Project Status: ALUMNI

Project State: Colorado

Technical Categories: Electrical Efficiency

NREL and the University of Colorado (CU) are developing a way to enhance plastic solar cells to capture a larger part of the solar spectrum. Conventional plastic solar cells can be inexpensive to fabricate but do not efficiently convert light into electricity. NREL is designing novel device architecture for plastic solar cells that would enhance the utilization of parts of the solar spectrum for a wide array of plastic solar cell types. To develop these plastic solar cells, NREL and CU will leverage computational modeling and advanced facilities specializing in processing plastic PVs. NREL's plastic solar cell devices have the potential to exceed the power conversion efficiencies of traditional plastic solar cells by up to threefold.

University of Pittsburgh

CO2 Thickeners for Enhanced Oil and Gas Recovery

Program: OPEN 2012

Project Term: 05/01/2013 to 04/30/2016

Project Status: ALUMNI

Project State: Pennsylvania

Technical Categories: Resource Efficiency

Pitt is developing a compound to increase the viscosity of--or thicken--liquid carbon dioxide (CO2). This higher-viscosity CO2 compound could be used to improve the performance of enhanced oil recovery techniques. Crude oil is found deep below the surface of the earth in layers of sandstone and limestone, and one of the ways to increase our ability to recover it is to inject a high-pressure CO2solvent into these layers. Unfortunately, because the solvent is less viscous--or thinner--than oil, it is not robust enough to uniformly sweep the oil out of the rock and toward the oil well. Pitt's CO2-thickeners would improve the performance of the solvents involved in this process, allowing it to carry higher concentrations of oil to the surface. The thickeners would decrease the cost and increase the efficiency of enhanced oil recovery, and could also serve to enable liquid CO2 as a replacement for the water used during recovery, offering significant environmental benefits.

Evolva, Inc.

High Performance Aviation Fuels from Terpenes

Program: OPEN 2012

Project Term: 04/11/2013 to 09/30/2016
Project Status: ALUMNI
Project State: Kentucky
Technical Categories: Transportation Fuels

Allylix is producing terpenes--energy dense molecules that can be used as high-performance aviation fuels--from simple sugars using engineered microbes. These terpenes will provide better performance than existing petroleum-based aviation fuels. Allylix will draw upon their industrial-scale terpene manufacturing experience to produce aviation sesquiterpenes at a low cost and large scale. Going forward, Allylix will validate the performance of its aviation fuels in unmanned aerial vehicles (UAVs), and further engineer its process to utilize biomass feedstocks.

Rensselaer Polytechnic Institute

High-Power Transistor Switch

Program: OPEN 2012
Project Term: 03/07/2013 to 03/06/2016
Project Status: ALUMNI
Project State: New York
Technical Categories: Grid

RPI is working to develop and demonstrate a new bi-directional transistor switch that would significantly simplify the power conversion process for high-voltage, high-power electronics systems. A transistor switch helps control electricity, converting it from one voltage to another or from an Alternating Current (A/C) to a Direct Current (D/C). High-power systems, including solar and wind plants, usually require multiple switches to convert energy into electricity that can be transmitted through the grid. These multi-level switch configurations are costly and complex, which drives down their overall efficiency and reliability. RPI's new switch would require fewer components than conventional high-power switches. This simple design would in turn simplify the overall power conversion process and enable renewable energy sources to more easily connect to the grid.

United Technologies Research Center

Additive Manufacturing for Electric Vehicle Motors

Program: OPEN 2012
Project Term: 02/15/2013 to 03/31/2016
Project Status: ALUMNI
Project State: Connecticut
Technical Categories: Manufacturing Efficiency

UTRC is using additive manufacturing techniques to develop an ultra-high-efficiency electric motor for automobiles. The process and design does not rely on rare earth materials and sidesteps any associated supply concerns. Additive manufacturing uses a laser to deposit copper and insulation, layer-by-layer, instead of winding wires. EV motors rely heavily on permanent magnets, which are expensive given the high concentrations of rare earth material required to deliver the performance required in today's market. UTRC's efficient manufacturing method would produce motors that reduce electricity use and require less rare earth material. This project will also examine the application of additive manufacturing more widely for other energy systems, such as renewable power generators.

University of Washington

Microbe-Based Methane to Diesel Conversion

Program: OPEN 2012
Project Term: 02/01/2013 to 06/30/2016
Project Status: ALUMNI
Project State: Washington
Technical Categories: Transportation Fuels

UW is developing technologies for microbes to convert methane found in natural gas into liquid diesel fuel. Specifically the project seeks to significantly increase the amount of lipids produced by the microbe, and to develop novel catalytic technology to directly convert these lipids to liquid fuel. These engineered microbes could enable small-scale methane-to-liquid conversion at lower cost than conventional methods. Small-scale, microbe-based conversion would leverage abundant, domestic natural gas resources and reduce U.S. dependence on foreign oil.

Palo Alto Research Center

Innovative Manufacturing Process for Li-Ion Batteries

Program: OPEN 2012

Project Term: 03/01/2013 to 06/11/2014

Project Status: ALUMNI

Project State: California

Technical Categories: Transportation Storage

PARC is developing a new way to manufacture Li-Ion batteries that reduces manufacturing costs and improves overall battery performance. Traditionally, Li-Ion manufacturers make each layer of the battery separately and then integrate the layers together. PARC is working to manufacture a Li-ion battery by printing each layer simultaneously into an integrated battery, thereby streamlining the manufacturing process. Additionally, the battery structure includes narrow stripes inside the layers that increase the battery's overall energy storage. Together, these innovations should allow the production of higher capacity batteries at dramatically lower manufacturing costs compared to today's Li-ion batteries.

Georgia Tech Research Corporation

Graphene-Based Supercapacitors

Program: OPEN 2012

Project Term: 03/20/2013 to 03/19/2016

Project Status: ALUMNI

Project State: Georgia

Technical Categories: Transportation Storage

Georgia Tech is developing a supercapacitor using graphene--a two-dimensional sheet of carbon atoms--to substantially store more energy than current technologies. Supercapacitors store energy in a different manner than batteries, which enables them to charge and discharge much more rapidly. The Georgia Tech team approach is to improve the internal structure of graphene sheets with 'molecular spacers,' in order to store more energy at lower cost. The proposed design could increase the energy density of the supercapacitor by 10-15 times over established capacitor technologies, and would serve as a cost-effective and environmentally safe alternative to traditional storage methods.

Alveo Energy

Prussian Blue Dye Batteries

Program: OPEN 2012

Project Term: 02/21/2013 to 03/31/2016

Project Status: ALUMNI

Project State: California

Technical Categories: Storage

Alveo is developing a grid-scale storage battery using Prussian Blue dye as the active material within the battery. Prussian Blue is most commonly known for its application in blueprint documents, but it can also hold electric charge. Though it provides only modest energy density, Prussian Blue is so readily available and inexpensive that it could provide a cost-effective and sustainable storage solution for years to come. Alveo will repurpose this inexpensive dye for a new battery that is far cheaper and less sensitive to temperature, air, and other external factors than comparable systems. This will help to facilitate the adoption and deployment of renewable energy technology. Alveo's Prussian Blue dye-based grid-scale storage batteries would be safe and reliable, have long operational lifetime, and be cheaper to produce than any existing battery technology.

University of Texas, Austin

[Smart Window Coatings]

Program: OPEN 2012

Project Term: 03/28/2013 to 09/26/2016

Project Status: ALUMNI

Project State: Texas

Technical Categories: Building Efficiency

UT Austin is developing low-cost coatings that control how light enters buildings through windows. By individually blocking infrared and visible components of sunlight, UT Austin's design would allow building occupants to better control the amount of heat and the brightness of light that enters the structure, saving heating, cooling, and lighting costs. These coatings can be applied to windows using inexpensive techniques similar to spray-painting a car to keep the cost per window low. Windows incorporating these coatings and a simple control system have the potential to dramatically enhance energy efficiency and reduce energy consumption throughout the commercial and residential building sectors, while making building occupants more comfortable.

Vorbeck Materials Corp.

[High-Performance, Low-Cost Lithium-Sulfur Batteries]

Program: OPEN 2012

Project Term: 03/06/2013 to 06/05/2015

Project Status: ALUMNI

Project State: Maryland

Technical Categories: Transportation Storage, Transport

Vorbeck is developing a low-cost, fast-charging storage battery for hybrid vehicles. The battery cells are based on lithium-sulfur (Li-S) chemistries, which have a greater energy density compared to today's Li-Ion batteries. Vorbeck's approach involves developing a Li-S battery with radically different design for both cathode and anode. The technology has the potential to capture more energy, increasing the efficiency of hybrid vehicles by up to 20% while reducing cost and greenhouse gas emissions.

Pratt & Whitney Rocketdyne

[Continuous Detonation Engine Combustors]

Program: OPEN 2012

Project Term: 06/14/2013 to 03/15/2015

Project Status: ALUMNI

Project State: California

Technical Categories: Distributed Generation

PWR is developing a new combustor for gas turbine engines that uses shockwaves for more efficient combustion through a process known as continuous detonation. These combustors would enable more electricity to be generated from a given amount of natural gas, increasing the efficiency of gas turbine engines while reducing greenhouse gas emissions. PWR will design and build continuous detonation combustors and test them in a simulated gas turbine environment to demonstrate the feasibility of incorporating the technology into natural gas-fueled turbine electric power generators.

Harvard University

[Slippery Coatings to Reduce Friction and Energy Loss]

Program: OPEN 2012

Project Term: 04/26/2013 to 07/25/2016

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Transportation Fuels

Harvard is developing a slippery coating that can be used for a number of technology applications including oil and water pipelines, wastewater treatment systems, solar panels (to prevent dust accumulation), refrigeration (to prevent ice buildup), as well as many other energy-relevant applications. Contamination, build-up of microorganisms, and corrosion of untreated surfaces can lead to inefficiencies in the system. Harvard's liquid-based coating is tailored to adhere to and then spread out evenly over a rough surface, forming a completely smooth surface that inhibits buildup. Since it is liquid-based, it can easily repair itself if scratched or damaged, resulting in a stable coating with the potential to significantly outperform conventional technologies, such as Teflon, in friction and drag reduction and in repelling a broad range of contaminants.

Texas Engineering Experiment Station

Electricity from Low-Temperature Waste Heat

Program: OPEN 2012

Project Term: 04/01/2013 to 09/30/2015

Project Status: ALUMNI

Project State: Texas

Technical Categories: Distributed Generation

TEES is developing a system to generate electricity from low-temperature waste heat streams. Conventional waste heat recovery technology is proficient at harnessing energy from waste heat streams that are at a much higher temperature than ambient air. However, existing technology has not been developed to address lower temperature differences. The proposed system cycles between heating and cooling a metal hydride to produce a flow of pressurized hydrogen. This hydrogen flow is then used to generate electricity via a turbine generator. TEES's system has the potential to be more efficient than conventional waste heat recovery technologies based on its ability to harness smaller temperature differences than are necessary for conventional waste heat recovery.

University of California, Santa Barbara

Boosted Capacitors

Program: OPEN 2012

Project Term: 03/15/2013 to 06/30/2016

Project Status: ALUMNI

Project State: California

Technical Categories: Transportation Storage

UCSB is developing an energy storage device for HEVs that combines the properties of capacitors and batteries in one technology. Capacitors enjoy shorter charging times, better durability, and higher power than batteries, but offer less than 5% of their energy density. By integrating the two technologies, UCSB's design would offer a much reduced charge time with a product lifetime that matches or surpasses that of typical EV batteries. Additionally, the technology would deliver significantly higher power density than any current battery. This feature would extend EV driving range and provide a longer life expectancy than today's best EV batteries.

California Institute of Technology

Improving Solar Generation Efficiency with Solar Modules

Program: OPEN 2012

Project Term: 03/28/2013 to 09/27/2016

Project Status: ALUMNI

Project State: California

Technical Categories: Distributed Generation

Caltech is developing a solar module that splits sunlight into individual color bands to improve the efficiency of solar electricity generation. For PV to maintain momentum in the marketplace, the energy conversion efficiency must increase significantly to result in reduced power generation costs. Most conventional PV modules provide 15-20% energy conversion efficiency because their materials respond efficiently to only a narrow band of color in the sun's spectrum, which represents a significant constraint on their efficiency. To increase the light conversion efficiency, Caltech will assemble a solar module that includes several cells containing several different absorbing materials, each tuned to a different color range of the sun's spectrum. Once light is separated into color bands, Caltech's tailored solar cells will match each separated color band to dramatically improve the overall efficiency of solar energy conversion. Caltech's approach to improve the efficiency of PV solar generation should enable improved cost-competitiveness for PV energy.

Georgia Tech Research Corporation

[Power Generation Using Solar-Heated Ground Air]

Program: OPEN 2012

Project Term: 05/03/2013 to 09/30/2016

Project Status: ALUMNI

Project State: Georgia

Technical Categories: Distributed Generation

Georgia Tech is developing a method to capture energy from wind vortices that form from a thin layer of solar-heated air along the ground. "Dust devils" are a random and intermittent example of this phenomenon in nature. Naturally, the sun heats the ground creating a thin air layer near the surface that is warmer than the air above. Since hot air rises, this layer of air will naturally want to rise. The Georgia Tech team will use a set of vanes to force the air to rotate as it rises, forming an anchored columnar vortex that draws in additional hot air to sustain itself. Georgia Tech's technology uses a rotor and generator to produce electrical power from this rising, rotating air similar to a conventional wind turbine. This solar-heated air, a renewable energy resource, is broadly available, especially in the southern U.S. Sunbelt, yet has not been utilized to date. This technology could offer more continuous power generation than conventional solar PV or wind. Georgia Tech's technology is a, low-cost, scalable approach to electrical power generation that could create a new class of renewable energy ideally suited for arid low-wind regions.

Sharp Laboratories of America

[Sodium-Based Energy Storage]

Program: OPEN 2012

Project Term: 03/28/2013 to 03/27/2016

Project Status: ALUMNI

Project State: Washington

Technical Categories: Storage

Sharp Labs and their partners at the University of Texas and Oregon State University are developing a sodium-based battery that could dramatically increase battery cycle life at a low cost while maintaining a high energy capacity. Current storage approaches use either massive pumped reservoirs of water or underground compressed air storage, which carry serious infrastructure requirements and are not feasible beyond specific site limitations. Therefore, there is a critical need for a scalable, adaptable battery technology to enable widespread deployment of renewable power. Sodium ion batteries have the potential to perform as well as today's best lithium-based designs at a significantly lower cost. Sharp Labs' new battery would provide long cycle life, high energy density, and safe operation if deployed throughout the electric grid.

Silicon Power Corporation

[Optical Switches for High-Power Systems]

Program: OPEN 2012

Project Term: 05/15/2013 to 08/10/2015

Project Status: CANCELLED

Project State: Pennsylvania

Technical Categories: Grid

Silicon Power is developing a semiconducting device that switches high-power and high-voltage electricity using optical signals as triggers for the switches, instead of conventional signals carried through wires. A switch helps control electricity, converting it from one voltage or current to another. High-power systems generally require multiple switches to convert energy into electricity that can be transmitted through the grid. These multi-level switch configurations use many switches which may be costly and inefficient. Additionally, most switching mechanisms use silicon, which cannot handle the high switching frequencies or voltages that high-power systems demand. Silicon Power is using light to trigger its switching mechanisms, which could greatly simplify the overall power conversion process. Additionally, Silicon Power's switching device is made of silicon carbide instead of straight silicon, which is more efficient and allows it to handle higher frequencies and voltages.

General Electric

[Fabric-Based Wind Turbine Blades]

Program: OPEN 2012

Project Term: 05/01/2013 to 12/31/2014

Project Status: CANCELLED

Project State: Connecticut

Technical Categories: Distributed Generation

GE is developing fabric-based wind turbine blades that could significantly reduce the production costs and weight of the blades. Conventional wind turbines use rigid fiberglass blades that are difficult to manufacture and transport. GE will use tensioned fabric uniquely wrapped around a spaceframe blade structure, a truss-like, lightweight rigid structure, replacing current clam shell wind blades design. The blade structure will be entirely altered, allowing for easy access and repair to the fabric while maintaining conventional wind turbine performance. This new design could reduce production costs by 70% and enable automated manufacturing while reducing the processing time by more than 50%. GE's fabric-based blades could be manufactured in sections and assembled on-site, enabling the construction of much larger wind turbines that can capture more wind with significantly lower production and transportation costs.

MicroLink Devices

[High-Efficiency Solar Cells]

Program: OPEN 2012

Project Term: 03/20/2013 to 09/01/2015

Project Status: CANCELLED

Project State: Illinois

Technical Categories: Distributed Generation

MicroLink is developing low-cost, high-efficiency solar cells to capture concentrated sunlight in an effort to increase the amount of electricity generated by concentrating solar power plants. The continued growth of the CPV market depends strongly on continuing to reduce the cost of CPV solar cell technologies. MicroLink will make an all-lattice-matched solar cell that can achieve greater power conversion efficiency than conventional CPV technologies, thereby reducing the cost of generating electricity. In addition, MicroLink will use manufacturing techniques that allow for the reuse of expensive solar cell manufacturing templates to minimize costs. MicroLink's innovative high-efficiency solar cell design has the potential to reduce PV electricity costs well below the cost of electricity from conventional non-concentrating PV modules.

University of Wisconsin

[Turning Sunlight, CO2, and Water into Fuel]

Program: OPEN 2012

Project Term: 02/12/2013 to 05/31/2014

Project Status: CANCELLED

Project State: Wisconsin

Technical Categories: Transportation Fuels

University of Wisconsin and the University of Massachusetts-Lowell are developing a low-cost metal catalyst to produce fuel precursors using abundant and renewable solar energy, water, and waste CO2inputs. When placed in sunlight, the catalyst's nanostructured surface enables the formation of hydrocarbons from CO2and water by a plasmonic catalytic effect. These hydrocarbons can be refined and blended to produce a fuel compatible with typical cars and trucks. Wisconsin is proving the technology in a small reactor before scaling up conceptual designs that could be implemented in a large solar refinery. The ability to convert CO2waste into a viable fuel would decrease the transportation sector's carbon footprint and provide an alternative domestic source of fuel.

University of California, Santa Cruz

Efficient Collection of Concentrated Solar

Program: OPEN 2012

Project Term: 05/01/2013 to 12/31/2014

Project Status: CANCELLED

Project State: California

Technical Categories: Distributed Generation

UC Santa Cruz is developing an optical device that enables the use of concentrated solar energy at locations remote to the point of collection. Conventional solar concentration systems typically use line of sight optical components to concentrate solar energy onto a surface for direct conversion of light into electricity or heat. UC Santa Cruz's innovative approach leverages unique thin-film materials, processes, and structures to build a device that will efficiently guide sunlight into an optical fiber for use away from the point of collection. UC Santa Cruz's optical device improves the coupling of high-power, concentrated solar energy systems into fiber-optic cables for use in applications such as thermal storage, photovoltaic conversion, or solar lighting.

OPEN 2015 Open Funding Solicitation (39)

In 2015, ARPA-E issued its third open funding opportunity designed to catalyze transformational breakthroughs across the entire spectrum of energy technologies. ARPA-E received more than 2,000 concept papers for OPEN 2015, which hundreds of scientists and engineers thoroughly reviewed over the course of several months. In the end, ARPA-E selected 41 projects for its OPEN 2015 program, awarding them a total of $125 million in federal funding. OPEN 2015 projects cut across ten technology areas: building efficiency, industrial processes and waste heat, data management and communication, wind, solar, tidal and distributed generation, grid scale storage, power electronics, power grid system performance, vehicle efficiency, storage for electric vehicles, and alternative fuels and bio-energy.

Accio Energy, Inc.

New Option for Wind Energy

Program: OPEN 2015

Project Term: 04/01/2016 to 03/31/2018

Project Status: ACTIVE

Project State: Michigan

Technical Categories: Distributed Generation

The team led by Accio Energy, Inc. will develop an ElectroHydroDynamic (EHD) system that harvests energy from the wind through physical separation of charge rather than through rotation of an electric machine. The EHD technology entrains a mist of positively charged water droplets into the wind, which pulls the charge away from the electrically-grounded tower, thereby directly converting wind energy into a mounting voltage. The resulting High-Voltage Direct Current (HVDC) can then be transferred across higher efficiency power lines without the need for a generator, a gearbox, or costly high power AC-DC conversion required by traditional wind energy systems. The simple design of the EHD wind system is highly modular, and can be built with low-cost, mass manufacturing approaches. EHD systems also have minimal moving parts, and can be "containerized" for easy transport and installation at offshore sites. In contrast to the current trend for larger (and relatively expensive) turbines with increased power-per-tower, the EHD approach would utilize low-cost hardware with simple transport and installation, and native HVDC operation to reduce the cost of electricity from offshore wind. EHD technology can also operate at lower wind velocities than traditional turbines, and can thus increase the capacity factor at locations with highly variable winds. If successful, this project will demonstrate EHD technology as an entirely new option for offshore wind that offers a different path to cost effective utilization of a large renewable resource.

The Mackinac Technology Company

Single Pane Window Retrofit System

Program: OPEN 2015

Project Term: 04/01/2016 to 03/31/2018

Project Status: ACTIVE

Project State: Michigan

Technical Categories: Building Efficiency

The Mackinac Technology Company will develop an innovative, cost effective, retrofit window insulation system that will significantly reduce heat losses. The insulation system will use a durable window film that is highly transparent to visible light (more than 90% of light can pass through), but reflects thermal radiation back into the room and reduces heat loss in winter. The film will be microporous and breathable to allow air pressures to balance across the window system. The film will be bonded to a rigid frame that can be retrofitted to an existing single-pane glass window. Mackinac's pane assembly will maintain a wrinkle-free appearance over an anticipated 20-year product lifecycle. The system will be fire resistant and lightweight (less than two pounds per square foot of window pane), which will help reduce stress on existing window panes.

Marine BioEnergy, Inc.

Biofuel Production from Kelp

Program: OPEN 2015

Project Term: 06/06/2016 to 06/05/2019

Project Status: ACTIVE

Project State:

Technical Categories: Transportation Fuels

The team led by Marine BioEnergy, Inc. will develop an open ocean cultivation system for macroalgae biomass, which can be converted to biocrude. Giant kelp is one of the fastest growing sources of biomass, and the open ocean surface water is an immense, untapped region for growing kelp. However, kelp does not grow in the open ocean because it needs to attach to a hard surface, typically less than 40 meters deep. Kelp also needs nutrients that are only available in deep water or near shore but not on the surface of the open ocean. To overcome these obstacles, the team proposes to build inexpensive robotic submarines that will tow large grids, to which the kelp is attached. These autonomous submarines will be capable of ferrying the kelp from sunlight-rich surface water during the day to nutrient-rich deep water during the night. A prerequiste for this vision will be successful demonstration of depth-cycling kelp plants from the surface to the deep ocean. Working with researchers at Scripps Institution of Oceanography, UC San Diego, Marine BioEnergy will develop and deploy first-of-kind technology to assess and apply this unique concept of kelp depth-cycling for deep water nutrient uptake to kelp production. Researchers at Pacific Northwest National Laboratory will convert this kelp to biocrude and document the quality. This technology could enable large-scale energy crop production in many regions of the open ocean, with an initial focus on the U.S. Exclusive Economic Zone off California.

University of Virginia

Ultra-Large Wind Turbine

Program: OPEN 2015

Project Term: 04/01/2016 to 03/31/2019

Project Status: ACTIVE

Project State: Virginia

Technical Categories: Distributed Generation

The team led by the University of Virginia will design the world's largest wind turbine by employing a new downwind turbine concept called Segmented Ultralight Morphing Rotor (SUMR). Increasing the size of wind turbine blades will enable a large increase in power from today's largest turbines - from an average of 5-10MW to a proposed 50MW system. The SUMR concept allows blades to deflect in the wind, much like a palm tree, to accommodate a wide range of wind speeds (up to hurricane-wind speeds) with reduced blade load, thus reducing rotor mass and fatigue. The novel blades also use segmentation to reduce production, transportation, and installation costs. This innovative design overcomes key challenges for extreme-scale turbines resulting in a cost-effective approach to advance the domestic wind energy market. The team includes world's experts at the National Renewable Energy Laboratory (NREL) and Sandia National Labs (SNL) working with world-class faculty and students at the Colorado School of Mines, University of Colorado (Boulder), University of Illinois (Urbana-Champaign), and the University of Virginia.

Princeton Optronics

High-Efficiency Data Transfer

Program: OPEN 2015

Project Term: 02/26/2016 to 08/25/2018

Project Status: ACTIVE

Project State: New Jersey

Technical Categories: Electrical Efficiency

Princeton Optronics, Inc. will develop a new device architecture for optical interconnect links, which communicate using optical fibers that carry light. The maximum speed and power consumption requirement of data communication lasers have not changed significantly over the last decade, and state-of-the-art commercial technology delivers only 30 Gigabits per second (Gb/s). Increasing this speed has been difficult because the current devices are limited by resistance and capacitance constraints. Princeton Optronics will develop a novel device architecture to improve the data transfer and reduce the power consumption per bit by a factor of 10. They will use their expertise in vertical-cavity surface-emitting lasers (VCSELs) to design and build unique quantum wells - and increase the speed and lower the power consumption. The team aims to demonstrate speeds greater than 50 Gb/s, and perhaps 250 Gb/s devices in the future.

Pajarito Powder, LLC

High-Efficiency Hydrogen Production

Program: OPEN 2015

Project Term: 05/01/2016 to 04/30/2019

Project Status: ACTIVE

Project State: New Mexico

Technical Categories: Transportation Vehicles

The team led by Pajarito Powder, LLC will develop a reversible hydrogen electrode that would enable cost-effective hydrogen production and reversible fuel cells. Both electrolyzers and fuel cells, generally operate in acidic conditions that rely on expensive precious metal catalysts to avoid corrosion. Running the electrochemical cell in alkaline conditions reduces the requirements for the oxygen electrode, but effective and inexpensive electrocatalysts for the hydrogen electrode still need to be developed. This project aims to develop a bi-functional (i.e. two way) low-cost catalyst that runs in alkaline conditions capable of oxidizing or reducing hydrogen depending on whether power is needed immediately, or needs to be stored. By integrating the electrolyzer and fuel cell into one system, the overall cost could be drastically reduced, which would open an entire suite of new applications including grid load-leveling and long-term energy storage applications. The system will be compatible with intermittent energy sources because it can operate at lower temperatures than competiting technologies, thus allowing startup times on the order of seconds.

Cummins Corporate Research & Technology

High-Efficiency Engines

Program: OPEN 2015

Project Term: 02/09/2016 to 08/08/2018

Project Status: ACTIVE

Project State: Indiana

Technical Categories: Distributed Generation

Cummins Corporate Research & Technology will develop an advanced high efficiency natural gas-fueled internal combustion engine for high-power distributed electricity generation. The team is seeking to achieve 55% brake thermal efficiency while maintaining low exhaust emissions. The enabling technology is wet compression, where fine droplets of water are sprayed directly into the engine cylinders, causing the charge temperature to drop and thereby prevent the onset of damaging engine knock at high compression ratios. Since it takes less energy to compress cooler air, the savings from reduced compression work can be passed on to increase the net engine output. Wet compression is a transformative technology that dramatically improves engine efficiency while still allowing for conventional engine manufacturing methods at existing facilities.

Proton Energy Systems

[Energy Conversion and Storage System]

Program: OPEN 2015

Project Term: 05/06/2016 to 05/05/2019

Project Status: ACTIVE

Project State: Connecticut

Technical Categories: Distributed Generation

The team led by Proton OnSite will develop a hydrogen-iron flow battery that can generate hydrogen for use and energy storage on the electric grid. This dual-purpose device can be recharged using renewable grid electricity and either store the hydrogen or run in reverse, as a flow cell battery, when electricity is needed. The team will develop low-cost catalysts to use on both electrodes and leverage their expertise in system engineering to keep the costs low. By using two highly reversible single electron reactions, the round trip efficiency could exceed 80%. By operating at much higher efficiencies than traditional electrolyzers, this technology could offer multiple value streams thereby enabling widespread adoption of distributed storage and hydrogen fueling.

Ocean Renewable Power Company

[Marine Hydrokinetic Turbine]

Program: OPEN 2015

Project Term: 04/01/2016 to 09/30/2018

Project Status: ACTIVE

Project State: Maine

Technical Categories: Distributed Generation

The Ocean Renewable Power Company (ORPC) will develop an innovative, self-deploying MHK power system, which will reduce the operating costs and improve the efficiency of MHK systems by up to 50%. ORPC's system is based on pitch control of the blades of a cross-flow turbine, in which the tidal flow passes across the turbine blades rather than in a radial fashion. This system will allow the turbine to self-propel itself to the deployment location, and lower itself to the sea floor remotely. This innovative approach will allow for lower costs of deployment and retrieval, reduced requirements for sea-bed foundation construction, as well as increased turbine efficiency. The ORPC team will design, build, and test a model scale of the MHK system to demonstrate the benefits of using a self-deploying turbine, before completing the design and cost analysis of the full-scale commercial system. Successful deployment of this system would significantly reduce the LCOE associated with MHK systems, making the technology a viable renewable resource to generate electrical power.

University of California, Santa Barbara

[Laser-Based Solid State Lighting]

Program: OPEN 2015

Project Term: 04/14/2016 to 04/13/2019

Project Status: ACTIVE

Project State: California

Technical Categories: Electrical Efficiency

The University of California, Santa Barbara will develop a gallium nitride (GaN) laser-based white light emitter with no efficiency droop at high current densities. The team's solution will address the efficiency and cost limitations of LEDs. Laser diodes do not suffer efficiency droop at high current densities, and this allows for the design of lamps using a single, small, light-emitting chip operating at high current densities. Using a single chip reduces system costs compared with LEDs because the system uses less material per chip, requires fewer chips, and employs simplified optics and a simplified heat-sink. The chip area required for LED technologies will be significantly reduced using laser-based solid state lighting. This technology will also enable highly controllable beams of light that cannot be achieved with LEDs. The goal of the project is to develop a 1,000 lumen laser-based white light emitter with the efficiency of at least 200 lm/W and a cost of $0.25/klm.

Tibbar Technologies

[Plasma-Based Electrical Transformers]

Program: OPEN 2015

Project Term: 05/02/2016 to 05/01/2018

Project Status: ACTIVE

Project State: New Mexico

Technical Categories: Distributed Generation

Tibbar Technologies will develop plasma-based AC to DC converters for a variety of applications, including DC power for commercial buildings and for High Voltage Direct Current (HVDC) electrical transmission. A plasma is created when a gas absorbs enough energy to separate the electrons from the nuclei, making it susceptible to electric and magnetic fields. In this project the team will develop a converter based principally on a single plasma component, rather than a system of capacitors and semiconductor switches. The concept is based on a recently discovered plasma configuration that utilizes helical electrodes along the perimeter of the plasma chamber to induce a current along the axis of the plasma. The current induced along the axis produces an output voltage and current at the ends of the plasma chamber, which enables efficient conversion of AC to DC or DC to DC. The project team seeks to develop a robust, economical plasma device to convert 3-phase AC to high quality DC. These devices have the potential to be half the cost and yield power densities 10x higher than state-of-the-art converters, and have the potential to significantly improve electrical use efficiencies in power transmission, distribution, micro-grids, datacenters, and in large, electrified platforms for transportation such as ships and trains.

Gas Technology Institute

[Reactor Engine]

Program: OPEN 2015

Project Term: 03/01/2016 to 02/28/2018

Project Status: ACTIVE

Project State: Illinois

Technical Categories: Manufacturing Efficiency

The team led by Gas Technology Institute (GTI) will develop a conventional automotive engine as a reactor to convert ethane into ethylene by using a new catalyst and reactor design that could enable record-breaking conversion yields. The technology proposed by GTI would use a reciprocating engine as a variable volume oxidative dehydrogenation (ODH) reactor. This means a conventional engine would be modified with a new valving mechanism that would take advantage of high flow rates and high pressure and temperature regime that already exists in an internal combustion engine. This process requires no energy input, does produce minimal CO_2 emissions, and improves yields to about 80% at one third the cost. The ODH reactor engine's relatively small size and high throughput will enable ethylene producers to add ethylene production capacity without the financial risk of building a billion-dollar steam cracking plant. This technology will reduce energy-related emissions and could enable the U.S. plastics industry to increase utilization of low-cost, domestic ethane to produce ethylene for plastics.

University of Illinois, Urbana Champaign

[Biomass Water Efficiency]

Program: OPEN 2015

Project Term: 04/01/2016 to 03/31/2019

Project Status: ACTIVE

Project State: Illinois

Technical Categories: Transportation Fuels

The University of Illinois, Urbana-Champaign team proposes to increase the water-use efficiency in sorghum production, enabling plants to produce the same yield with 40% less water. By analyzing mathematical models of crop physiology and biophysics, the Illinois team has identified multiple strategies to improve water-use efficiency. In one instance, the team will decrease water loss within plants by shifting photosynthetic activity from leaves at the top of crop canopy where it is drier to lower leaves that operate in higher humidity. To increase photosynthesis in lower leaves, the upper canopy leaves will need to be a lighter shade of green and more vertical to allow more light to penetrate the canopy.

Additionally, the team will alter the density and activity of the pores, called stomata, on the leaves that regulate CO_2 uptake and water loss for the plant. Illinois will utilize both biotechnology and advanced molecular breeding techniques to implement these strategies. These water-efficient sorghum technologies will open up more than 9.5 million acres of lower quality land in the Midwest for sorghum production without relying on irrigation. Additionally, it will increase yields across current arable, rain-fed land. These techniques could be applied to other agricultural crops, such as corn, sugarcane and Miscanthus. The development of this water-use efficiency biotechnology will advance the efficiency of biomass production, reducing dependence on foreign oil imports and decreasing CO_2 emissions.

Ceramatec, Inc.

Efficient Ammonia Production

Program: OPEN 2015

Project Term: 03/22/2016 to 03/21/2019

Project Status: ACTIVE

Project State: Utah

Technical Categories: Storage

The team led by Ceramatec, Inc. will develop a modular electrochemical process for a power-to-fuel system that can synthesize ammonia directly from nitrogen and water. The proposed synthesis approach will combine chemical and electrochemical steps to facilitate the high-energy step of breaking the nitrogen-nitrogen bond, with projected conversion efficiencies above 70%. By operating at lower temperature and pressure and reducing the air-separation requirement, this technology reduces overall system complexity, thus potentially enabling smaller-scale production at equal or lower costs. Furthermore, the smaller-scale process does not need consistent, baseload power to operate and therefore could be compatible with intermittent renewable energy sources, placing it on a path to be carbon-neutral.

Achates Power, Inc.

Efficient Engine Design

Program: OPEN 2015

Project Term: 04/01/2016 to 11/13/2018

Project Status: ACTIVE

Project State: California

Technical Categories: Transportation Vehicles

The team led by Achates Power, Inc. will develop an internal combustion engine that combines two promising engine technologies: an opposed-piston (OP) engine configuration and gasoline compression ignition (GCI). Compression ignition OP engines are inherently more efficient than existing spark-ignited 4-stroke engines (potentially up to 50% higher thermal efficiency using gasoline) while providing comparable power and torque, and showing the potential to meet future tailpipe emissions standards. GCI uses gasoline or gasoline-like fuels in a compression ignition engine to deliver thermal efficiency on par with diesel combustion. However, unlike conventional diesel engines, this technology does not require the added expense of high-pressure fuel injection equipment and sophisticated aftertreatment systems. The OP/GCI engine technology is adaptable to a range of engine configurations and can be used in all types of passenger vehicles and light trucks. By successfully combining the highly fuel efficient architecture of the OP engine with the ultra-low emissions GCI technology, the resulting engine could be transformational, significantly reducing U.S. petroleum consumption and carbon dioxide.

Oregon State University

Natural Gas to Fuels

Program: OPEN 2015

Project Term: 05/16/2016 to 05/15/2019

Project Status: ACTIVE

Project State: Oregon

Technical Categories: Transportation Fuels

The team led by Oregon State University (OSU) is developing a novel gas-to-liquid (GTL) technology that utilizes a "corona discharge" plasma to convert methane to higher value chemicals, such as ethylene or liquid fuels. A corona discharge is formed when a high voltage is applied across a gap with a shaped electrode that concentrates the electric field at a tip. At sufficiently high voltage, an electrical discharge (characterized by a faint glow - a corona) is formed, and ionizes the surrounding gas molecules, i.e. split them into positive ions and free electrons. The team will build a reactor consisting of an array of micro-structured conducting surfaces to form corona discharges that ionize methane molecules and recombine the ionized components to form longer chain hydrocarbons with higher value. The key advantages of this technology are the innovative reactor design, which will allow small-scale production, as well as the high energy and conversion efficiencies, resulting in less energy being consumed to convert methane to liquid fuels.

University of Colorado, Boulder

Heat-Reflective Window Coating

Program: OPEN 2015

Project Term: 05/05/2016 to 05/04/2019

Project Status: ACTIVE

Project State: Colorado

Technical Categories: Building Efficiency

The University of Colorado Boulder (CU-Boulder) and its partners are developing an inexpensive, polymer-based, energy-saving material that can be applied to windows as a retrofit. The team will develop a coating consisting of polymers that can rapidly self-assemble into orderly layers that will reflect infrared wavelengths but pass visible light. As such, the coating will help reduce building cooling requirements and energy use without darkening the room. The polymers can be applied as a paint, meaning that deployment could be faster, less expensive, and more widespread because homeowners can apply the window coatings themselves instead of paying for a technician. The team estimates that up to 75% of the dry film could be produced from commodity plastic, which has the potential to significantly reduce the current costs associated with manufacturing window coatings.

Texas A&M Agrilife Research

Radar for Bioenergy Crop Imaging

Program: OPEN 2015

Project Term: 04/13/2016 to 04/12/2019

Project Status: ACTIVE

Project State: Texas

Technical Categories: Transportation Fuels

Texas A&M AgriLife Research will develop ground penetrating radar (GPR) antenna arrays for 3D root and soil organic carbon imaging and quantification. Visualization of root systems with one mm resolution in soils could enable breeders to select climate-resilient bioenergy crops that provide higher yields, require fewer inputs, improve soil health, and promote carbon sequestration. Texas A&M will create a GPR system that will collect real-time measurements using a deployable robotic platform. The GPR system will collect data comparing annual energy sorghum to perennial species, which have great potential to deposit and store carbon in the soil. Texas A&M's primary focus is to complement the selection of high biomass feedstock crops by providing valuable data about the root architecture. This data could improve understanding of the soil ecosystem and ultimately allow for improved bioenergy crop productivity.

General Electric

Silicon Carbide Superjunction

Program: OPEN 2015

Project Term: 05/10/2016 to 05/09/2019

Project Status: ACTIVE

Project State: Connecticut

Technical Categories: Electrical Efficiency

The team led by GE Global Research (GE) will develop a new high-voltage, solid-state Silicon Carbide (SiC) Field-Effect Transistor (FET) charge-balanced device, also known as a "Superjunction." These devices have become the industry norm in high-voltage Silicon switching devices, because they allow for more efficient switching at higher voltages and frequencies. The team proposes to demonstrate charge balanced SiC devices for the first time. Their approach will offer scaling up to 15kV while reducing losses for power conversion applications by 10x when compared with existing silicon bipolar devices and competing SiC approaches. This will enable highly efficient, medium-voltage, multi-megawatt power conversion for conventional and renewable energy applications. The technology could dramatically reduce energy consumption and emissions for applications such as solar, wind, mining, oil and gas development, and medical devices. If these efficient devices were widely adopted the technology could save enough energy to power 5.9 million homes annually. It can also have a significant impact on medium voltage drives for high-speed motors and transportation applications, including hybrid and electric vehicles. In rail applications, the higher voltage and higher frequencies afforded by SiC devices could reduce the total energy consumption by as much as 30%.

Oak Ridge National Laboratory

Robust Metal Alloys

Program: OPEN 2015

Project Term: 04/05/2016 to 04/14/2019

Project Status: ACTIVE

Project State: Tennessee

Technical Categories: Manufacturing Efficiency

The team led by Oak Ridge National Laboratory (ORNL) will develop new cast alumina-forming austenitic alloys (AFAs), along with associated casting and welding processes for component fabrication. ORNL and its partners will prototype industrial components with at least twice the oxidation resistance compared to current cast chromia-forming steel and test it in an industrial environment. These innovations could allow various industrial and chemical processing systems and gas turbines to operate at higher temperatures to improve efficiencies and reduce downtimes, thus providing cost and energy reductions for a wide range of energy-intensive applications.

Oak Ridge National Laboratory

High-Efficiency Energy Converters

Program: OPEN 2015

Project Term: 05/01/2016 to 04/30/2019

Project Status: ACTIVE

Project State: Tennessee

Technical Categories: Distributed Generation

The team led by Oak Ridge National Laboratory will design proton-selective membranes for use in storage technologies, such as flow batteries, fuel cells, or electrolyzers for liquid-fuel storage. Current proton-selective membranes (e.g. Nafion) require hydration, but the proposed materials would be the first low-temperature membranes that conduct protons without the need for hydration. The enabling technology relies on making single-layer membranes from graphene or similar materials and supporting them for mechanical stability. The team estimates that these membranes can be manufactured at costs around one order of magnitude lower than Nafion membranes. Due to the lower system complexity, the team's innovations would enable fuel cell production at lower system-level costs.

University of Tennessee

Advanced Bioengineering for Biofuels

Program: OPEN 2015

Project Term: 02/04/2016 to 02/03/2019

Project Status: ACTIVE

Project State: Tennessee

Technical Categories: Transportation Fuels

The University of Tennessee (UT) team proposes to develop a tool that will revolutionize plant metabolic engineering by using a large scale DNA synthesis strategy. The UT team will develop synthetic chloroplast (the part of the plant cell where photosynthesis occurs) genomes, called "synplastomes." Rather than introducing or editing genes individually inside the plant cell, the UT team will synthesize a complete chloroplast genome in the laboratory that can be readily modified and then introduced into the plant. UT's synplastomes will have significant advantages over conventional biotechnology methods. UT's synplastomes are expected to result in an extremely high expression of desired genes and will lack transgene positional effects, meaning improved consistency of trait expression. To ensure broader adoption and utilization of this technology, an editable synplastome will be generated that will feature standard genome editing sites and will allow for modification by researchers using standard, cost-effective techniques. The UT team's work in synthetic biology could significantly advance the field of plant metabolic engineering and help produce a path toward more economical, sustainable bio-based products.

National Renewable Energy Laboratory

High-Efficiency PV Cells

Program: OPEN 2015

Project Term: 04/22/2016 to 04/21/2019

Project Status: ACTIVE

Project State: Colorado

Technical Categories: Distributed Generation

This project team, led by the National Renewable Energy Laboratory (NREL), will employ hydride vapor phase epitaxy (HPVE), a fast growth technique used to produce semiconductors, to lower the manufacturing cost of multijunction solar cells. Additionally the team will develop new materials to be used in the HVPE process, enabling a chemical liftoff method that allows reuse of substrates. The chemical liftoff will mitigate costs of substrates, further reducing the overall system cost. NREL's approach will leverage this improved HVPE technology to produce thin, flexible, highly efficient multijunction cells, with very high power at low cost. III-V PV has several inherent advantages over other PV materials, including higher efficiency, low temperature coefficients, and low material usage. The novel combination of HVPE growth of multijunction solar cells and substrate reuse could result in more cost-effective, higher performing multijunction solar cells, which could ultimately lower the cost and increase the efficiency of PV systems. These innovations could spur greater adoption of PV systems and reduce reliance on fossil-fuel power generation.

University of Michigan

Enhanced Engine Improvements

Program: OPEN 2015

Project Term: 07/14/2016 to 07/13/2019

Project Status: ACTIVE

Project State: Michigan

Technical Categories: Transportation Vehicles

The University of Michigan team will develop a compact micro-hybrid configuration that pairs an Electrically Assisted Variable Speed (EAVS) supercharger with an exhaust expander Waste Energy Recovery (WER) system. Together, the EAVS and WER can nearly eliminate the slow air-path dynamics associated with turbocharge inertia and high exhaust gas recirculation (EGR). The EAVS system compresses engine intake air to increase engine power and allows the engine to have valuable "breathing time." This breathing time allows for a coordinated intake boosting and exhaust vacuum, so that the combustion timing and fueling is always optimal. Meanwhile, the WER system will capture exhaust energy, store it in a low-voltage battery together with energy from regenerative braking and later reuse it to assist the engine under transient acceleration loads, helping to further increase fuel efficiency. The team's innovation could increase fuel economy in advanced vehicles by 20%.

Starfire Energy

Efficient Ammonia Production

Program: OPEN 2015

Project Term: 03/01/2016 to 02/28/2018

Project Status: ACTIVE

Project State: Colorado

Technical Categories: Transportation Fuels

The team led by Starfire Energy will develop a modular, small-scale, HB-type process for ammonia synthesis. The team's innovative approach is less energy-intensive and more economical than conventional, large-scale HB because a novel electroactive catalyst allows operation at lower temperatures and pressures. Their approach combines a high-activity precious metal catalyst and an electroactive catalyst support to form ammonia molecules, while operating at moderate pressures and using localized high-temperature reaction zones. The extreme reaction conditions in conventional HB require that the process runs continuously, as turning on and off would require bringing the reactor back up to synthesis temperature. Since Starfire's process is smaller scale, it does not require continuous energy input and therefore could be compatible with intermittent energy sources, setting it on a path to be carbon-neutral.

Pacific Northwest National Laboratory

Power-Grid Optimization

Program: OPEN 2015

Project Term: 07/19/2016 to 08/29/2019

Project Status: ACTIVE

Project State: Washington

Technical Categories: Grid

The team led by Pacific Northwest National Laboratory will develop a High-Performance Power-Grid Optimization (HIPPO) technology to reduce grid resource scheduling times to within a fraction of current speeds, which can lead to more flexible and reliable real-time operation. The team will leverage advances in optimization algorithms and deploy high-performance computing technologies to significantly improve the performance of grid scheduling. HIPPO will provide inter-algorithm parallelization and allow algorithms to share information during their solution process, with the objective of reducing computing time by efficiently using computational power. New algorithms will leverage knowledge of the underlying system, operational experience, and past solutions to improve performance and avoid previously encountered mistakes.

Case Western Reserve University

Virtual Building Energy Audits

Program: OPEN 2015

Project Term: 05/10/2016 to 05/09/2019

Project Status: ACTIVE

Project State: Ohio

Technical Categories: Building Efficiency

Case Western Reserve University will develop a data analytics approach to building-efficiency diagnosis and prognostics. Their tool, called EDIFES (Energy Diagnostics Investigator for Efficiency Savings), will not require complex or expensive computational simulation, physical audits, or building automation systems. Instead, the tool will map a building's energy signature through a rigorous analysis of multiple datastreams. Combining knowledge of specific climatic, weather, solar insolation, and utility meter data through data assembly, the team will analyze these time-series datastreams to reveal patterns and relationships that were previously ignored or neglected. EDIFES will provide a virtual energy audit combined with a predictive energy usage calculator for efficiency solutions without setting foot in a building. The team's goal is to design EDIFES in such a way that beyond time-series, whole building utility data, only minimal information will be required from the building owner for accurate virtual energy audits that identify efficiency problems and solutions and provide continuous efficiency monitoring. EDIFES will be a resource for equipment providers and contractors to illustrate replacement equipment value, a mechanism for utilities to measure the impact of energy efficiency programs, and a tool for financiers to evaluate the potential risk and opportunity of efficiency investments. EDIFES will target the light commercial building space where minimal tools are available and a high potential for savings exists.

Iowa State University

Low-Cost, Robust Battery

Program: OPEN 2015

Project Term: 06/01/2016 to 05/31/2019

Project Status: ACTIVE

Project State: Iowa

Technical Categories: Distributed Generation

The team led by Iowa State University will develop an All Solid-State Sodium Battery (ASSSB) that will have a high energy content, can easily be recycled, and rely on highly abundant and extremely low cost starting materials. Commercially available sodium-based batteries operate at elevated temperatures, which decreases the efficiency and safety of the system. The team seeks to improve all three of the main components of a sodium-based battery: the anode, cathode, and electrolyte separator. The team's anode is a porous carbon nanotube layer that will serve as a framework on which sodium metal will be deposited. The separator will be made of a novel oxy-thio-nitride glass solid electrolyte, and the cathode will be composed of a polymer in which reversible sodium insertion and removal takes place. The team will need to overcome several challenges, including reducing interfacial resistance between the organic electrode and the solid electrolyte. The proposed sodium battery can operate at room temperature, uses a benign and scalable solid-stack design for a long cycle life, and expects to achieve an energy density eqivalent to state-of-the-art Li-ion cells.

ProsumerGrid, Inc.

Distribution Operator Simulation Studio

Program: OPEN 2015

Project Term: 06/01/2016 to 11/30/2018

Project Status: ACTIVE

Project State: Georgia

Technical Categories: Grid

ProsumerGrid, Inc, with its partners, will develop a highly specialized and interactive software tool capable of simulating the operation of emerging DSOs at the physical, information, and market levels while capturing the interactions among the various market participants. The software will offer electricity industry analysts, engineers, economists, and policy makers a "design studio environment" in which various propositions of participant roles, market rules, business processes, and services exchange can be studied to achieve a robust DSO design. The software will utilize a powerful decentralized decision-making algorithm, and extend state-of-the-art grid solvers with the ability to develop DER scheduling, DSO market rules, and energy service transactions. The tool could ensure correctness and reduce risk in upcoming regulatory decisions as various states move towards the formation of DSOs.

INFINIUM, Inc.

Low-Energy Magnesium Recycling

Program: OPEN 2015

Project Term: 02/05/2016 to 02/04/2018

Project Status: ACTIVE

Project State: Massachusetts

Technical Categories: Manufacturing Efficiency

Infinium, Inc. will convert low-grade magnesium scrap into material of sufficient purity for motor vehicle components by a novel high-efficiency process using less than 1 kWh/kg magnesium product. Other magnesium purification technologies such as distillation and electrorefining use 5-10 kWh/kg, and primary production uses 40-100 kWh/kg. This is also a high-speed continuous process, with much lower labor and capital costs than other batch purification technologies. This technology could enable cost-effective recycling of magnesium, converting low-grade scrap metal into high-purity magnesium at low cost and significantly lower energy consumption, and could also enable new classes of primary production technology.

University of Michigan

Low-Cost, Robust Battery

Program: OPEN 2015

Project Term: 06/09/2016 to 07/14/2019

Project Status: ACTIVE

Project State: Michigan

Technical Categories: Transportation Storage

The team led by University of Michigan will develop a ceramic electrolyte based on a ceramic oxide that is durable, offers high conductivity (e.g., it moves Li ions easily), and can be used in cells with metallic Li electrodes. The team will develop a technique to fabricate flexible sheets of electrolyte using roll-to-roll manufacturing. The team will also develop thick, solid-composite cathodes and then will integrate them with the electrolyte and a Li anode. Finally, the team will demonstrate the production of numerous cells using the new materials and techniques, and will integrate the cells into a flexible battery stack that is compatible with roll-to-roll manufacturing techniques and exhibits high energy density (900 Wh/L). This project aims to overcome the major challenges at the interfaces of solid components, including poor Li conductivity. The resulting technology could improve energy density and enable an electric vehicle to travel farther on a single charge. The technology also provides a stronger barrier between Li-ion battery electrodes that is capable of withstanding Li-dendrite intrusion to prevent shorts, thereby reducing the chance of battery failure.

University of California, Santa Barbara

High-Efficiency Data Transfer

Program: OPEN 2015

Project Term: 04/07/2016 to 04/06/2019

Project Status: ACTIVE

Project State: California

Technical Categories: Electrical Efficiency

The University of California at Santa Barbara will develop a new technology for optical communication links. Optical interconnects transfer data by carrying light through optical fibers, and offer higher bandwidths than copper with higher efficiency and, consequently, reduced heat losses. However, short-reach optical interconnects are not widely used because of their higher costs and larger device footprints. Production costs of these interconnects could be reduced by using silicon-based fabrication technologies, but silicon is not suited for fabricating lasers, a key ingredient. In contrast III-V semiconductors, are well-suited for fabricating highly efficient lasers, but at a high cost. The team plans to combine these components to create III-V lasers, grown on a silicon substrate, harnessing both the low cost of silicon and the superior laser of the III-V semiconductor. However, growing the III-V laser material directly on silicon is difficult due to incompatibilities in their crystal structures. The team aims to overcome this challenge by implementing nanostructures called "quantum dots" as the light producing material and by growing the structure on patterned silicon substrates to help contain potential defects.

Vanderbilt University

Software for Smarter Grids

Program: OPEN 2015

Project Term: 04/04/2016 to 04/03/2019

Project Status: ACTIVE

Project State: Tennessee

Technical Categories: Grid

Vanderbilt University will develop a foundation platform for developing and deploying robust, reliable, effective and secure software applications for the Smart Grid. The Resilient Information Architecture Platform for the Smart Grid (RIAPS) provides core services for building effective and powerful smart grid applications. It offers unique services for real-time data dissemination, fault tolerance, and coordination across apps distributed over the network. The platform will allow plug-and-play architecture by providing a software layer that isolates the hardware details making software applications portable across multiple devices and enabling interoperability among heterogeneous devices and applications. Additionally, the RIAPS will be supported by a model-driven development toolchain to reduce development costs. The platform will allow apps to be upgraded and dynamically reconfigured in the field and will enable a marketplace of hardware device vendors, app developers, and end users to sell and buy products and services that will interoperate. Vanderbilt's team will develop and prototype the platform using an open source code base. The team will also construct representative open source energy management software apps that will demonstrate the effectiveness and dependability of the system, while offering a starting point for commercial implementations. The team expects the platform to become an industry standard on which Smart Grid applications can reliably run, much in the same way Android and iOS have become industry standard platforms for smartphones.

Newton Energy Group, LLC

Gas-Electric Co-Optimization

Program: OPEN 2015

Project Term: 04/11/2016 to 04/19/2018

Project Status: ACTIVE

Project State: Massachusetts

Technical Categories: Grid

The team led by Newton Energy Group, LLC will lead the Gas-Electric Co-Optimization (GECO) project to improve coordination of wholesale natural gas and power operators both at the physical and market levels. The team's approach uses mathematical methods and computational techniques that have revolutionized the field of optimal control. These methods will be applied to natural gas pipeline networks, and the final deliverable will consist of three major components. First, they will model and optimize intra-day pipeline operations represented by realistic models of gas network flow. Next, the team will develop economic theory and computation algorithms for the pricing of natural gas delivered to end users, in particular to gas-fired power plants. Finally, they will combine these two analytical components to design practical market mechanisms for efficient coordination of gas and electric systems. The goal of efficient market design is to develop a mechanism under which access to pipeline capacity will be provided on the basis of its economic value as determined by gas buyers and sellers, and not on the current allocation of physical capacity rights. The tool guarantees natural gas will be available when power plants need it, and that the power produced can be sold to consumers at a price sufficient to cover the cost of the natural gas.

Dioxide Materials, Inc.

High-Efficiency Hydrogen Production

Program: OPEN 2015

Project Term: 02/01/2016 to 01/31/2019

Project Status: ACTIVE

Project State: Illinois

Technical Categories: Grid, Storage

The team led by Dioxide Materials, Inc. will develop an alkaline water electrolyzer for an improved power-to-gas system. The team's electrochemical cells are composed of an anode, a cathode, and a membrane that allows anions to pass through, while being electrically insulating. High-conductivity anion exchange membranes are rare and often do not have the chemical or mechanical stability to withstand H2production at elevated pressures. Therefore, the project is focused on developing an anion exchange membrane that is low-cost, is manufacturable in a scaleable process, and has sufficient conductivity, chemical stability, and mechanical strength. Moreover, by operating at alkaline instead of acidic conditions, the electrochemical cells do not need to use expensive precious metal catalysts, which most systems require to prevent corrosion. Dioxide Materials, Inc. estimates that operating under alkaline conditions could lead to a 10x lower electrolyzer stack cost due to higher current densities and lower material costs (i.e. non-precious metals). The system will be compatible with intermittent energy sources because it can operate at lower temperatures than competiting technologies, thus allowing startup times on the order of seconds.

Boston Electrometallurgical Corporation

High-Efficiency Titanium Production

Program: OPEN 2015

Project Term: 05/05/2016 to 05/04/2019

Project Status: ACTIVE

Project State: Massachusetts

Technical Categories: Manufacturing Efficiency

Boston Electrometallurgical Corporation will develop and scale a one step molten oxide electrolysis process for producing Ti metal directly from the oxide. Titanium oxide is dissolved in a molten oxide, where it is directly and efficiently extracted as molten titanium metal. In this process, electrolysis is used to separate the product from the solution as a bottom layer that can then be removed from the reactor in its molten state. If successful, it could replace the multistep Kroll process with a one-step process that resembles today's aluminum production techniques. If successful, Ti ingots could be produced at cost parity with stainless steel, opening the doorway to industrial waste heat recovery applications and increasing its adoption in commercial aircraft.

University of Tennessee

Smart and Flexible Microgrid

Program: OPEN 2015

Project Term: 06/24/2016 to 12/23/2018

Project Status: ACTIVE

Project State: Tennessee

Technical Categories: Grid

The University of Tennessee at Knoxville, along with their partners, will develop a new type of microgrid design, along with its corresponding controller. Like most other microgrids, it will have solar PV-based distributed generation and be capable of grid-connected or disconnected (islanded) operations. Unlike other microgrids, this design will incorporate smart grid capabilities including intelligent switches and high-speed communication links. The included controller will accommodate and utilize these smart grid features for enhanced performance and reduced costs. The microgrid controller will be open source, offering a flexible and robust development and implementation environment. The microgrid and controller design will also be scalable for different geographic areas, load sizes, distributed generation source number and types, and even multiple microgrids within an area.

Stanford University

High-Efficiency Energy Converters

Program: OPEN 2015

Project Term: 06/01/2016 to 05/31/2018

Project Status: ACTIVE

Project State: California

Technical Categories: Distributed Generation

By leveraging advanced microfabrication processes, the team led by Stanford University will develop a scalable heat-to-electricity conversion device with higher performance at a lower manufacturing cost than is presently available to industry. The team's solid-state conversion device is based on a 20th century thermionic converter design, where an electric current is produced by heating up an electrode to eject electrons across a vacuum gap for collection by a cooler electrode. Historically, thermionic energy converters are limited by heat losses and are costly to manufacture due to the high precision used in their construction. However, by utilizing wafer-based fabrication processes to create a much smaller vacuum gap and enhanced thermal isolation structures, Stanford's thermionic converter will result in improved device performance, lower manufacturing cost, and a scalability for systems producing Watts to Megawatts of power. The team's initial focus is on the residential Combined Heat and Power (CHP) applications, but their innovative microfabricated thermionic device could also be used to improve efficiency in high-temperature solar thermal systems as well as convert waste heat from factory equipment, power plants, and vehicles to useful power.

RedWave Energy, Inc.

Electricity from Waste-Heat Harvesting

Program: OPEN 2015

Project Term: 05/26/2016 to 05/25/2019

Project Status: ACTIVE

Project State: Illinois

Technical Categories: Distributed Generation

The team led by RedWave Energy, Inc. will develop a waste heat harvesting system, called a rectenna, that converts low-temperature waste heat into electricity. Rectennas are nanoantennas that convert radiant energy to direct current (DC) electricity. The rectennas are fabricated onto sheets of flexible material in tightly packed arrays and placed near key heat sources such as the turbine's condenser, heat exchanger, and flue gas cooling stack. Heat radiates onto the nanoantennas and energizes electrons on the antennas' surface. These electrons are rectified by the system, resulting in DC power. This technology will target the waste heat in industrial processes and thermoelectric power generation.

PETRO Plants Engineered to Replace Oil (10)

The 10 projects that comprise ARPA-E's PETRO program, short for "Plants Engineered to Replace Oil," aim to develop non-food crops that directly produce transportation fuel. These crops can help supply the transportation sector with plant-derived fuels that are cost-competitive with petroleum and do not affect U.S. food supply. PETRO aims to redirect the processes for energy and carbon dioxide (CO2) capture in plants toward fuel production. This would create dedicated energy crops that serve as a domestic alternative to petroleum-based fuels and deliver more energy per acre with less processing prior to the pump.

University of Illinois, Urbana Champaign

Genetically Enhanced Sorghum and Sugarcane

Program: PETRO

Project Term: 02/15/2012 to 03/31/2017

Project Status: ACTIVE

Project State: Illinois

Technical Categories: Transportation Fuels

UIUC is working to convert sugarcane and sorghum--already 2 of the most productive crops in the world--into dedicated bio-oil crop systems. Three components will be engineered to produce new crops that have a 50% higher yield, produce easily extractable oils, and have a wider growing range across the U.S. This will be achieved by modifying the crop canopy to better distribute sunlight and increase its cold tolerance. By directly producing oil in the shoots of these plants, these biofuels could be easily extracted with the conventional crushing techniques used today to extract sugar.

North Carolina State University

Jet Fuel from Camelina

Program: PETRO

Project Term: 01/01/2012 to 12/31/2016

Project Status: ACTIVE

Project State: North Carolina

Technical Categories: Transportation Fuels

NC State will genetically modify the oil-crop plant Camelina sativa to produce high quantities of both modified oils and terpenes. These components are optimized for thermocatalytic conversion into energy-dense drop-in transportation fuels. The genetically engineered Camelina will capture more carbon than current varieties and have higher oil yields. The Camelina will be more tolerant to drought and heat, which makes it suitable for farming in warmer and drier climate zones in the US. The increased productivity of NC State's enhanced Camelina and the development of energy-effective harvesting, extraction, and conversion technology could provide an alternative non-petrochemical source of fuel.

Donald Danforth Plant Science Center

Improved Light Utilization in Camelina

Program: PETRO

Project Term: 01/01/2012 to 12/31/2016

Project Status: ACTIVE

Project State: Missouri

Technical Categories: Transportation Fuels

The Danforth Center will optimize light utilization in Camelina, a drought-resistant, cold-tolerant oilseed crop. The team is modifying how Camelina collects sunlight, engineering its topmost leaves to be lighter in color so sunlight can more easily reflect onto lower parts of the plant. A more uniform distribution of light would improve the efficiency of photosynthesis. Combined with other strategies to produce more oil in the seed, Camelina would yield more oil per plant. The team is also working to allow Camelina to absorb carbon dioxide (CO2) more efficiently, providing more carbon input for oil production. The goal is to improve light utilization and oil production to the point where Camelina produces enough fuel precursors per acre to compete with other fuels.

University of Florida

[Tappable Pine Trees]

Program: PETRO

Project Term: 01/01/2012 to 06/10/2017

Project Status: ACTIVE

Project State: Florida

Technical Categories: Transportation Fuels

The University of Florida is working to increase the amount of turpentine in harvested pine from 4% to 20% of its dry weight. While enhanced feedstocks for biofuels have generally focused on fuel production from leafy plants and grasses, the University of Florida is experimenting with enhancing fuel production in a species of pine that is currently used in the paper pulping industry. Pine trees naturally produce around 3-5% terpene content in the wood--terpenes are the energy-dense fuel molecules that are the predominant components of turpentine. The team aims to increase the terpene storage potential and production capacity while improving the terpene composition to a point at which the trees could be tapped while alive, like sugar maples. Growth and production from these trees will take years, but this pioneering technology could have significant impact in making available an economical and domestic source of aviation and diesel biofuels.

Texas A&M Agrilife Research

[Fuel from Tobacco and Arundo Donax]

Program: PETRO

Project Term: 02/15/2012 to 12/31/2016

Project Status: ACTIVE

Project State: Texas

Technical Categories: Transportation Fuels

Texas A&M Agrilife Research is addressing one of the major inefficiencies in photosynthesis, the process by which plants convert sunlight into energy. Texas A&M Agrilife Research is targeting the most wasteful step in photosynthesis by redirecting a waste byproduct into a new pathway that will create terpenes--energy-dense fuel molecules that can be converted into jet or diesel fuel. This strategy will be first applied to tobacco to demonstrate more efficient terpene production in the leaf. If successful in tobacco, the approach will be translated into the high biomass plant Arundo donax (giant cane) for fuel production.

University of California, Los Angeles

[Efficient CO2 Fixation Pathways]

Program: PETRO

Project Term: 01/01/2012 to 09/30/2015

Project Status: ALUMNI

Project State: California

Technical Categories: Transportation Fuels

UCLA is redesigning the carbon fixation pathways of plants to make them more efficient at capturing the energy in sunlight. Carbon fixation is the key process that plants use to convert carbon dioxide (CO2) from the atmosphere into higher energy molecules (such as sugars) using energy from the sun. UCLA is addressing the inefficiency of the process through an alternative biochemical pathway that uses 50% less energy than the pathway used by all land plants. In addition, instead of producing sugars, UCLA's designer pathway will produce pyruvate, the precursor of choice for a wide variety of liquid fuels. Theoretically, the new biochemical pathway will allow a plant to capture 200% as much CO2using the same amount of light. The pathways will first be tested on model photosynthetic organisms and later incorporated into other plants, thus dramatically improving the productivity of both food and fuel crops.

University of Massachusetts, Amherst

[Enhanced Carbon Concentration in Camelina]

Program: PETRO

Project Term: 01/01/2012 to 12/31/2015
Project Status: ALUMNI
Project State: Massachusetts
Technical Categories: Transportation Fuels

UMass Amherst is developing an enhanced, biofuels-producing variant of Camelina, a drought-resistant, cold-tolerant oilseed crop that can be grown in many places other plants cannot. The team is working to incorporate several genetic traits into Camelina that increases its natural ability to produce oils and add the production of energy-dense terpene molecules that can be easily converted into liquid fuels. UMass Amherst is also experimenting with translating a component common in algae to Camelina that should allow the plants to absorb higher levels of carbon dioxide (CO_2), which aids in enhancing photosynthesis and fuel conversion. The process will first be demonstrated in tobacco before being applied in Camelina.

Lawrence Berkeley National Laboratory

Oil from Tobacco Leaves

Program: PETRO
Project Term: 01/01/2012 to 03/26/2015
Project Status: ALUMNI
Project State: California
Technical Categories: Transportation Fuels

LBNL is modifying tobacco to enable it to directly produce fuel molecules in its leaves for use as a biofuel. Tobacco is a good crop for biofuels production because it is an outstanding biomass crop, has a long history of cultivation, does not compete with the national food supply, and is highly responsive to genetic manipulation. LBNL will incorporate traits for hydrocarbon biosynthesis from cyanobacteria and algae, and enhance light utilization and carbon uptake in tobacco, improving the efficiency of photosynthesis so more fuel can be produced in the leaves. The tobacco-generated biofuels can be processed for gasoline, jet fuel, or diesel alternatives. LBNL is also working to optimize methods for planting, cultivating and harvesting tobacco to increase biomass production several-fold over the level of traditional growing techniques.

Arcadia Biosciences

Vegetable Oil from Leaves and Stems

Program: PETRO
Project Term: 01/01/2012 to 09/30/2015
Project Status: ALUMNI
Project State: California
Technical Categories: Transportation Fuels

Arcadia Biosciences, in collaboration with the University of California-Davis, is developing plants that produce vegetable oil in their leaves and stems. Ordinarily, these oils are produced in seeds, but Arcadia Biosciences is turning parts of the plant that are not usually harvested into a source of concentrated energy. Vegetable oil is a concentrated source of energy that plants naturally produce and is easily separated after harvest. Arcadia Biosciences will isolate traits that control oil production in seeds and transfer them into leaves and stems so that all parts of the plants are oil-rich at harvest time. After demonstrating these traits in a fast-growing model plant, Arcadia Biosciences will incorporate them into a variety of dedicated biofuel crops that can be grown on land not typically suited for food production.

Chromatin, Inc.

Biofuels from Sorghum

Program: PETRO
Project Term: 01/01/2012 to 12/31/2015
Project Status: CANCELLED
Project State: Illinois
Technical Categories: Transportation Fuels

Chromatin will engineer sweet sorghum--a plant that naturally produces large quantities of sugar and requires little water--to accumulate the fuel precursor farnesene, a molecule that can be blended into diesel fuel. Chromatin's proprietary technology enables the introduction of a completely novel biosynthetic process into the plant to produce farnesene, enabling sorghum to accumulate up to 20% of its weight as fuel. Chromatin will also introduce a trait to improve biomass yields in sorghum. The farnesene will accumulate in the sorghum plants--similar to the way in which it currently stores sugar--and can be extracted and converted into a type of diesel fuel using low-cost, conventional methods. Sorghum can be easily grown and harvested in many climates with low input of water or fertilizer, and is already planted on an agricultural scale. The technology will be demonstrated in a model plant, guayule, before being used in sorghum.

RANGE Robust Affordable Next Generation Energy Storage Systems (22)

The projects that comprise ARPA-E's RANGE Program, short for "Robust Affordable Next Generation Energy Storage Systems," seek to develop transformational electrochemical energy storage technologies that will accelerate the widespread adoption of electric vehicles by dramatically improving their driving range, cost, and safety. RANGE focuses on four specific areas 1) aqueous batteries constructed using water to improve safety and reduce costs, 2) non-aqueous batteries that incorporate inherent protection mechanisms that ensure no harm to vehicle occupants in the event of a collision or fire, 3) solid-state batteries that use no liquids or pastes in their construction, and 4) multifunctional batteries that contribute to both vehicle structure and energy storage functions.

Stanford University

Multifunctional Battery Chassis Systems

Program: RANGE

Project Term: 02/11/2014 to 02/10/2017

Project Status: ACTIVE

Project State: California

Technical Categories: Transportation Storage

Stanford University is developing an EV battery that can be used as a structural component of the vehicle. Today's EV battery packs only serve one purpose: electrical energy storage. They do not carry structural loads during operation or absorb impact energy in the event of a collision. Stanford's new battery design would improve upon existing technologies in four key areas: 1) structural capabilities, 2) damage and state sensing systems, 3) novel battery management and thermal regulation, and 4) high-capacity battery cells. Stanford's research will result in a multifunctional battery chassis system that is safe and achieves high efficiency in terms of energy storage at low production cost. The integration of such a battery system would result in decreased overall weight of the combined vehicle and battery, for greater EV range.

University of Maryland

Multiple-Electron Aqueous Battery

Program: RANGE

Project Term: 03/18/2014 to 10/31/2016

Project Status: ACTIVE

Project State: Maryland

Technical Categories: Transportation Storage

UMD is using water-based magnesium and hydrogen chemistries to improve the energy density and reduce the cost of EV batteries. The lithium-ion batteries typically used in most EVs today require heavy components to protect the battery and ensure safety. Water-based batteries are an inherently safer alternative, but can be larger and heavier compared to lithium-ion batteries, making them inefficient for use in EVs. To address this, UMD's water-based battery will use a magnesium hydrogen chemistry that would double energy storage capacity, for a much lighter energy storage system. Furthermore, UMD's use of safe inexpensive materials could reduce the cost of battery management, improve reliability, and allow for operation across a wider range of temperatures.

Cadenza Innovation

[Low-Cost Electric Vehicle Battery Architecture]

Program: RANGE

Project Term: 02/10/2014 to 03/06/2017

Project Status: ACTIVE

Project State: Connecticut

Technical Categories: Transportation Storage

Cadenza Innovation is developing an innovative system to join and package batteries using a wide range of battery chemistries. Today's battery packs require heavy and bulky packaging that limits where they can be positioned within a vehicle. By contrast, Cadenza's design enables flexible placement of battery packs to absorb and manage impact energy in the event of a collision. Cadenza's battery will use a novel configuration that allows for double the energy density through the use of a multifunctional pack design.

University of California, San Diego

[Multifunctional Battery Systems for Electric Vehicles]

Program: RANGE

Project Term: 02/13/2014 to 02/12/2017

Project Status: ACTIVE

Project State: California

Technical Categories: Transportation Storage

The University of California, San Diego (UCSD) is developing a new battery that can be built into a vehicle frame. Conventional electric vehicle batteries are constructed independently of chassis, which results in a heavier, more inefficient vehicle. By rethinking auto frame design and incorporating the battery into the frame, vehicles can be cheaper and lighter vehicle. Since conventional batteries require potentially flammable materials, UCSD will also explore new chemistries to make this multifunctional battery safe in the event of a collision. This approach may require a complete redesign to the auto frame with consideration of adaptability to future battery technologies.

Solid Power, Inc.

[All Solid-State Lithium-Ion Battery]

Program: RANGE

Project Term: 01/01/2014 to 03/06/2017

Project Status: ACTIVE

Project State: Colorado

Technical Categories: Transportation Storage

Solid Power is developing a new low-cost, all-solid-state battery for EVs with greater energy storage capacity and a lighter, safer design compared to lithium-ion batteries. Conventional batteries are expensive, perform poorly at high temperatures and require heavy protective components to ensure safety. In contrast, Solid Power's liquid-free cells store more energy for their size and weight, but use non-flammable and non-volatile materials that are stable high temperatures. This results in improved safety in the event of a collision or fire. Additionally, Solid Power plans to use low-cost, abundant materials in the range of $10-$20/kg that could reduce battery manufacturing costs, to help drive down the cost of EVs.

Ceramatec, Inc.

[Advanced Lithium-Sulfur Batteries]

Program: RANGE

Project Term: 01/01/2014 to 01/14/2017

Project Status: ACTIVE

Project State: Utah

Technical Categories: Transportation Storage

Ceramatec is developing new batteries that make use of a non-porous, high ion conductivity ceramic membrane employing a lithium-sulfur (Li-S) battery chemistry. Porous separators found in today's batteries contain liquids that negatively impact cycle life. To address this, Ceramatec's battery includes a ceramic membrane to help to hold charge while not in use. This new design would also provide load bearing capability, improved mechanical integrity, and extend battery life. Ceramatec will build and demonstrate its innovative, low-cost, non-porous membrane in a prototype Li-S battery with a smaller size and higher storage capacity than conventional batteries. This battery pack could offer high energy density--greater than 300 Watt hours per kilogram--at a price of approximately $125-150/kWh.

Oak Ridge National Laboratory

Impact-Resistant Electrolyte

Program: RANGE

Project Term: 11/01/2013 to 10/31/2015

Project Status: ALUMNI

Project State: Tennessee

Technical Categories: Transportation Storage

ORNL is developing an electrolyte for use in EV batteries that changes from liquid to solid during collisions, eliminating the need for many of the safety components found in today's batteries. Today's batteries contain a flammable electrolyte and an expensive polymer separator to prevent electrical shorts--in an accident, the separator must prevent the battery positive and negative ends of the battery from touching each other and causing fires or other safety problems. ORNL's new electrolyte would undergo a phase change--from liquid to solid--in the event of an external force such as a collision. This phase change would produce a solid impenetrable barrier that prevents electrical shorts, eliminating the need for a separator. This would improve the safety and reduce the weight of the vehicle battery system, ultimately resulting in increased driving range.

Oak Ridge National Laboratory

Light-weight Battery with Built-in Safety Features

Program: RANGE

Project Term: 06/01/2014 to 12/31/2015

Project Status: ALUMNI

Project State: Tennessee

Technical Categories: Transportation Storage

ORNL is developing an abuse-tolerant EV battery. Abuse tolerance is a key factor for EV batteries. Robust batteries allow for a broader range of battery chemistries, including low-cost chemistries that could improve driving range and enable cost parity with gas-powered vehicles. ORNL's design would improve battery abuse tolerance at the cell level, thereby reducing the need for heavy protective battery housing. This will enable an EV system that would be lighter and more efficient, both reducing weight and cost and allowing the vehicle to drive further on each charge. ORNL will be researching a new architecture within each cell that will reduce the likelihood of a thermal damage in the event of an abuse situation. The new architecture incorporates a novel foil concept into the battery current collectors. In event of impact, crushing or penetration of the battery, the novel current collector will limit the connectivity and/or conductivity of the battery electrode assembly and hence limit the current at the site of an internal or external short. Limiting the current will avoid the local heating that can trigger thermal excitation and battery damage.

Pennsylvania State University

Structural Battery Power Panels

Program: RANGE

Project Term: 11/01/2013 to 12/31/2015

Project Status: ALUMNI

Project State: Pennsylvania

Technical Categories: Transportation Storage

Penn State is using a new fabrication process to build load-bearing lithium-ion batteries that could be used as structural components of electric vehicles. Conventional batteries remain independent of a vehicle's structure and require heavy protective components that reduce the energy to weight ratio of a vehicle. PowerPanels combine the structural components with a functional battery for an overall reduction in weight. Penn State's PowerPanels use a "jelly roll" design that winds battery components together in a configuration that is strong and stiff enough to be used as a structural component. The result of this would be a low-profile battery usable as a panel on the floor of a vehicle.

University of Maryland

[Solid-State Lithium-Ion Battery With Ceramic Electrolyte]

Program: RANGE

Project Term: 01/29/2014 to 03/31/2016

Project Status: ALUMNI

Project State: Maryland

Technical Categories: Transportation Storage

UMD is developing ceramic materials and processing methods to enable high-power, solid-state, lithium-ion batteries for use in EVs. Conventional lithium-ion batteries used in most EVs contain liquids that necessitate the use of heavy, protective components. By contrast, UMD's technology uses no liquids and offers greater abuse tolerance and reducing weight. This reduced weight leads to improved EV efficiency for greater driving range. UMD's technology also has the potential to help reduce manufacturing costs using scalable, ceramic fabrication techniques that does not require dry rooms or vacuum equipment.

Purdue University

[Impact-Tolerant Electric Vehicle Batteries]

Program: RANGE

Project Term: 12/02/2013 to 12/31/2015

Project Status: ALUMNI

Project State: Indiana

Technical Categories: Transportation Storage

Purdue University is developing an EV battery pack that can better withstand impact during a collision. In contrast to today's EV battery packs that require heavy packaging to ensure safety, Purdue's pack stores energy like a standard battery but is also designed to absorb the shock from an accident, prevents battery failure, and mitigates the risk of personal injury. Batteries housed in protective units are arranged in an interlocking configuration to create an impact energy dissipation device. Should a collision occur, the assemblies of the encased battery units rub against each other, thereby absorbing impact energy and preserving the integrity of the battery pack. Purdue will build a prototype protective casing, create a battery array of several battery units using this design, and study the dynamic behavior of battery units under impact in order to develop a novel EV battery pack.

Princeton University

[Long-Life Rechargeable Alkaline Batteries for EVs]

Program: RANGE

Project Term: 12/11/2013 to 03/31/2015

Project Status: ALUMNI

Project State: New Jersey

Technical Categories: Transportation Storage

Alkaline batteries are used in a variety of electronic devices today because of their ability to hold considerable energy, for a long time, at a low cost. In order to create alkaline batteries suitable for EVs, Princeton will use its expertise in alkaline battery systems examine a variety of suitable positive and negative electrode chemistries. Princeton will then select and experiment with those chemistries that show promise, using computational models to better understand their potential cycle life and storage capacities. Once a promising chemistry has been settled on, Princeton will build and test a prototype battery for an EV.

National Renewable Energy Laboratory

[Renewable Organics for Flow Battery]

Program: RANGE

Project Term: 01/06/2014 to 02/18/2015

Project Status: ALUMNI

Project State: Colorado

Technical Categories: Transportation Storage

NREL is developing a low-cost battery system that uses safe and inexpensive organic energy storage materials that can be pumped in and out of the system. NREL's battery, known as a "liquid-phase organic redox system," uses newly developed non-flammable compounds from biological sources to reduce cost while improving the amount of energy that can be stored. The battery's unique construction will enable a 5-minute "fast-charge" and promote long life by allowing for the rapid replacement of liquid electrodes. NREL anticipates an energy density of approximately 590 watt hours per liter with a cost of only $72 per kilowatt hour.

University of California, Los Angeles

[Long-Life, Acid-Based Battery]

Program: RANGE

Project Term: 12/09/2013 to 09/28/2017

Project Status: ALUMNI

Project State: California

Technical Categories: Transportation Storage

The University of California, Los Angeles (UCLA) is developing a new high-power, long-life, acid-based battery that addresses the cycle life issues associated with lead-acid batteries today. Lead-acid batteries are used extensively in gasoline-powered vehicles and even modern electric vehicles for initial ignition, but inevitably wear out after a limited number of complete discharge cycles. To solve this problem, UCLA will incorporate novel, newly-discovered material that allows the battery to store a greater electrical charge using a conventional battery design. This new battery would provide up to 500 times more charge and discharge cycles and up to 10 times the power of existing lead-acid batteries. UCLA's batteries will be compatible with comparable manufacturing processes for current lead-acid batteries, allowing for rapid, low-cost commercialization.

General Electric

[Water-Based Flow Battery for EVs]

Program: RANGE

Project Term: 03/28/2014 to 04/02/2015

Project Status: ALUMNI

Project State: Connecticut

Technical Categories: Transportation Storage

GE is developing an innovative, high-energy chemistry for a water-based flow battery. A flow battery is an easily rechargeable system that stores its electrode--the material that provides energy--as liquid in external tanks. Flow batteries have typically been used in grid-scale storage applications, but their flexible design architecture could enable their use in vehicles. To create a flow battery suitable for EVs, GE will test new chemistries with improved energy storage capabilities and built a working prototype. GE's water-based flow battery would be inherently safe because no combustible components would be required and any reactive liquids would be contained in separate tanks. GE estimates that its flow battery could reduce costs by up to 75% while offering a driving range of approximately 240 miles.

Bettergy Corp.

[Beyond Lithium-Ion Solid-State Battery]

Program: RANGE

Project Term: 12/01/2013 to 09/30/2015

Project Status: ALUMNI

Project State: New York

Technical Categories: Transportation Storage

Bettergy is developing an inexpensive battery that uses a novel combination of solid, non-flammable materials to hold a greater amount of energy for use in EVs. Conventional EV batteries are typically constructed using costly materials and require heavy, protective components to ensure safety. Consequently, these heavy battery systems require the car to expend more energy, leading to reduced driving range. Bettergy will research a battery design that utilizes low-cost energy storage materials to reduce costs, and solid, non-flammable components that will not leak to improve battery safety. Bettergy plans to do this while reducing the battery weight for greater efficiency so vehicles can drive further on a single charge.

University of Houston

Low-Cost Water-Based Electric Vehicle Batteries

Program: RANGE

Project Term: 11/13/2013 to 08/12/2015

Project Status: ALUMNI

Project State: Texas

Technical Categories: Transportation Storage

The University of Houston (UH) is developing a battery with a new water-based, lithium-ion chemistry that makes use of sustainable, low-cost, and high-energy organic materials. Conventional lithium-ion batteries include volatile materials and chemistries that necessitate considerable packaging to ensure safety. This additional packaging results in a heavier, bulkier battery and limits where the battery can be placed within the vehicle. In contrast, UH's organic materials are readily available, safe, and non-volatile, making them ideal for use in battery construction. UH will identify, synthesize, and optimize new organic compounds for storage that are inherently safer and require less heavy shielding to safely construct them.

EnZinc, Inc.

Rechargeable, Long-Life, Zinc-Air Battery

Program: RANGE

Project Term: 02/19/2014 to 03/27/2015

Project Status: ALUMNI

Project State: California

Technical Categories: Transportation Storage

EnZinc is developing a low-cost battery using 3D zinc microstructured sponge technology that could dramatically improve the rechargeability of zinc-based EV batteries. As a battery material, zinc is inexpensive and readily available, but presently unsuitable for long-term use in EVs. Current zinc based batteries offer limited cycle life due to the formation of tree-like internal structures (dendrites) that can short out the battery. To address this, EnZinc, in collaboration with the U.S. Naval Research Laboratory, will replace conventional zinc powder-bed anodes with a porous zinc sponge that thwarts formation of structures that lead to battery failure. EnZinc's technology will enable zinc-based batteries that accept high-power charge and discharge as required by EVs.

Arizona State University

Multifunctional Cells for Electric Vehicles

Program: RANGE

Project Term: 11/25/2013 to 12/31/2015

Project Status: ALUMNI

Project State: Arizona

Technical Categories: Transportation Storage

ASU is developing an innovative, formable battery that can be incorporated as a structural element in the vehicle. This battery would replace structural elements such as roof and side panels that previously remained passive, and incapable of storing energy. Unlike today's batteries that require significant packaging and protection, ASU's non-volatile chemistry could better withstand collision on its own because the battery would be more widely distributed throughout the vehicle so less electricity would be stored in any single area. Furthermore, ASU's battery would not use any flammable components or high-voltage modules. The chemistry minimizes conventional protection and controls while enabling it to store energy and provide structure, thus making vehicles lighter and safer.

Jet Propulsion Laboratory

Metal Hydride-Air Battery

Program: RANGE

Project Term: 04/30/2014 to 05/18/2016

Project Status: CANCELLED

Project State: California

Technical Categories: Transportation Storage

NASA's Jet Propulsion Laboratory (JPL) is developing a new metal-hydride/air battery. Current electric vehicle batteries use costly components and require packaging and shielding to ensure safety. To address this, JPL's technology will incorporate safe, inexpensive, and high-capacity materials for both the positive and negative electrodes of the battery as part of a novel design. Additionally, JPL's design will use a membrane developed to prevent water loss and CO2entry within the battery. High power performance and decreased costs will be possible with the use of a single catalyst material that operates both on charge and discharge. Since its new design is intrinsically safer, less packaging is needed, resulting in an overall reduction in weight and volume.

Illinois Institute of Technology

Nanoelectrofuel Flow Battery for Electric Vehicles

Program: RANGE

Project Term: 01/01/2014 to 12/31/2016

Project Status: CANCELLED

Project State: Illinois

Technical Categories: Transportation Storage

IIT is collaborating with Argonne National Laboratory to develop a rechargeable flow battery for EVs that uses a nanotechnology-based electrochemical liquid fuel that offers over 30 times the energy density of traditional electrolytes. Flow batteries, which store chemical energy in external tanks instead of within the battery container, are typically low in energy density and therefore not well suited for transportation. However, IIT/Argonne's flow battery uses a liquid electrolyte containing a large portion of nanoparticles to carry its charge; increases its energy density while ensuring stability and low-resistance flow within the battery. IIT/Argonne's technology could enable a whole new class of high-energy-density flow batteries. This unique battery design could be manufactured domestically using an easily scalable process.

BASF

Rare-Earth Free EV Batteries

Program: RANGE

Project Term: 02/18/2014 to 06/30/2015

Project Status: CANCELLED

Project State: New Jersey

Technical Categories: Transportation Storage

BASF is developing metal hydride alloys using new, low-cost metals for use in high-energy nickel-metal hydride (NiMH) batteries. Although NiMH batteries have been used in over 5 million vehicles with a proven record of long service life and abuse tolerance, their storage capacity is limited, which restricts driving range. BASF looks to develop a new NiMH design that will improve storage capacity and reduce fabrication costs through the use of inexpensive components. BASF will select new metals with a high energy storage capacity, then modify and optimize battery cell design. Once the ideal design has been established, BASF will evaluate methods for mass production and build a prototype 1 Kilowatt-hour battery.

REACT Rare Earth Alternatives in Critical Technologies (14)

The projects that comprise ARPA-E's REACT program, short for "Rare Earth Alternatives in Critical Technologies", are developing cost-effective alternatives to rare earths, the naturally occurring minerals with unique magnetic properties that are used in electric vehicle (EV) motors and wind generators. The REACT projects will identify low-cost and abundant replacement materials for rare earths while encouraging existing technologies to use them more efficiently. These alternatives would facilitate the widespread use of EVs and wind power, drastically reducing the amount of greenhouse gases released into the atmosphere.

Northeastern University

Iron-Nickel-Based Supermagnets

Program: REACT

Project Term: 02/24/2012 to 12/31/2013

Project Status: ALUMNI

Project State: Massachusetts

Technical Categories: Resource Efficiency

Northeastern University is developing bulk quantities of rare-earth-free permanent magnets with an iron-nickel crystal structure for use in the electric motors of renewable power generators and EVs. These materials could offer magnetic properties that are equivalent to today's best commercial magnets, but with a significant cost reduction and diminished environmental impact. This iron-nickel crystal structure, which is only found naturally in meteorites and developed over billions of years in space, will be artificially synthesized by the Northeastern University team. Its material structure will be replicated with the assistance of alloying elements introduced to help it achieve superior magnetic properties. The ultimate goal of this project is to demonstrate bulk magnetic properties that can be fabricated at the industrial scale.

QM Power, Inc.

Efficient, High-Torque Electric Vehicle Motor

Program: REACT

Project Term: 01/01/2012 to 02/28/2015

Project Status: ALUMNI

Project State: Missouri

Technical Categories: Resource Efficiency

QM Power is developing a new type of electric motor with the potential to efficiently power future generations of EVs without the use of rare-earth-based magnets. Many of today's EV motors use rare earth magnets to efficiently provide torque to the wheels. QM Power's motors would contain magnets that use no rare earth minerals, are light and compact, and can deliver more power with greater efficiency and at reduced cost. Key innovations in this project include a new motor design with iron-based magnetic materials, a new motor control technique, and advanced manufacturing techniques that substantially reduce the cost of the motor. The ultimate goal of this project is to create a cost-effective EV motor that offers the rough peak equivalent of 270 horsepower.

Brookhaven National Laboratory

Improved Superconducting Wire for Wind Generators

Program: REACT

Project Term: 01/01/2012 to 03/31/2016

Project Status: ALUMNI

Project State: New York

Technical Categories: Resource Efficiency

Brookhaven National Laboratory is developing a low-cost superconducting wire that could be used in high-power wind generators. Superconducting wire currently transports 600 times more electric current than a similarly sized copper wire, but is significantly more expensive. Brookhaven National Laboratory will develop a high-performance superconducting wire that can handle significantly more electrical current, and will demonstrate an advanced manufacturing process that has the potential to yield a several-fold reduction in wire costs while using a using negligible amount of rare earth material. This design has the potential to make a wind turbine generator lighter, more powerful, and more efficient, particularly for offshore applications.

Virginia Commonwealth University

Carbon-Based Magnets

Program: REACT

Project Term: 01/01/2012 to 12/31/2013

Project Status: ALUMNI

Project State: Virginia

Technical Categories: Resource Efficiency

VCU is developing a new magnet for use in renewable power generators and EV motors that requires no rare earth minerals. Rare earths are difficult and expensive to process, but they make electric motors and generators smaller, lighter, and more efficient. VCU would replace the rare earth minerals in EV motor magnets with a low-cost and abundant carbon-based compound that resembles a fine black powder. This new magnet could demonstrate the same level of performance as the best commercial magnets available today at a significantly lower cost. The ultimate goal of this project is to demonstrate this new magnet in a prototype electric motor.

University of Alabama

Rare-Earth-Free Nanostructure Magnets

Program: REACT

Project Term: 02/08/2012 to 09/30/2013

Project Status: ALUMNI

Project State: Alabama

Technical Categories: Resource Efficiency

The University of Alabama is developing new iron- and manganese-based composite materials for use in the electric motors of EVs and renewable power generators that will demonstrate magnetic properties superior to today's best rare-earth-based magnets. Rare earths are difficult and expensive to refine. EVs and renewable power generators typically use rare earths to make their electric motors smaller and more powerful. The University of Alabama has the potential to improve upon the performance of current state-of-the-art rare-earth-based magnets using low-cost and more abundant materials such as manganese and iron. The ultimate goal of this project is to demonstrate improved performance in a full-size prototype magnet at reduced cost.

Pacific Northwest National Laboratory

Manganese-Based Magnets

Program: REACT

Project Term: 01/01/2012 to 09/30/2015

Project Status: ALUMNI

Project State: Washington

Technical Categories: Resource Efficiency

PNNL is working to reduce the cost of wind turbines and EVs by developing a manganese-based nano-composite magnet that could serve as an inexpensive alternative to rare-earth-based magnets. The manganese composite, made from low-cost and abundant materials, could exceed the performance of today's most powerful commercial magnets at temperature higher than 200°C. Members of PNNL's research team will leverage comprehensive computer high-performance supercomputer modeling and materials testing to meet this objective. Manganese-based magnets could withstand higher temperatures than their rare earth predecessors and potentially reduce the need for any expensive, bulky engine cooling systems for the motor and generator. This would further contribute to cost savings for both EVs and wind turbines.

Argonne National Laboratory

Exchange-Spring Magnets

Program: REACT

Project Term: 01/01/2012 to 09/30/2015

Project Status: ALUMNI

Project State: Illinois

Technical Categories: Resource Efficiency

ANL is developing a cost-effective exchange-spring magnet to use in the electric motors of wind generators and EVs that uses no rare earth materials. This ANL exchange-spring magnet combines a hard magnetic outer shell with a soft magnetic inner core--coupling these together increases the performance (energy density and operating temperature). The hard and soft magnet composite particles would be created at the molecular level, followed by consolidation in a magnetic field. This process allows the particles to be oriented to maximize the magnetic properties of low-cost and abundant metals, eliminating the need for expensive imported rare earths. The ultimate goal of this project is to demonstrate this new type of magnet in a prototype electric motor.

Dartmouth College

Manganese-Aluminum-Based Magnets

Program: REACT

Project Term: 01/01/2012 to 03/30/2013

Project Status: ALUMNI

Project State: New Hampshire

Technical Categories: Resource Efficiency

Dartmouth is developing specialized alloys with magnetic properties superior to the rare earths used in today's best magnets. EVs and renewable power generators typically use rare earths to turn the axles in their electric motors due to the magnetic strength of these minerals. However, rare earths are difficult and expensive to refine. Dartmouth will swap rare earths for a manganese-aluminum alloy that could demonstrate better performance and cost significantly less. The ultimate goal of this project is to develop an easily scalable process that enables the widespread use of low-cost and abundant materials for the magnets used in EVs and renewable power generators.

University of Houston

Low-Cost Superconducting Wire for Wind Generators

Program: REACT

Project Term: 01/01/2012 to 06/30/2015

Project Status: ALUMNI

Project State: Texas

Technical Categories: Resource Efficiency

The University of Houston is developing a low-cost, high-current superconducting wire that could be used in high-power wind generators. Superconducting wire currently transports 600 times more electric current than a similarly sized copper wire, but is significantly more expensive. The University of Houston's innovation is based on engineering nanoscale defects in the superconducting film. This could quadruple the current relative to today's superconducting wires, supporting the same amount of current using 25% of the material. This would make wind generators lighter, more powerful and more efficient. The design could result in a several-fold reduction in wire costs and enable their commercial viability of high-power wind generators for use in offshore applications.

Baldor Electric Company

Rare-Earth-Free Traction Motor

Program: REACT

Project Term: 01/31/2012 to 02/15/2015

Project Status: ALUMNI

Project State: South Carolina

Technical Categories: Resource Efficiency

Baldor is developing a new type of traction motor with the potential to efficiently power future generations of EVs. Unlike today's large, bulky EV motors which use expensive, imported rare-earth-based magnets, Baldor's motor could be light, compact, contain no rare earth materials, and have the potential to deliver more torque at a substantially lower cost. Key innovations in this project include the use of a unique motor design, incorporation of an improved cooling system, and the development of advanced materials manufacturing techniques. These innovations could significantly reduce the cost of an electric motor.

Case Western Reserve University

[Iron-Nitride Alloy Magnets]

Program: REACT

Project Term: 01/01/2012 to 06/30/2015

Project Status: ALUMNI

Project State: Ohio

Technical Categories: Resource Efficiency

Case Western is developing a highly magnetic iron-nitride alloy to use in the magnets that power electric motors found in EVs and renewable power generators. This would reduce the overall price of the motor by eliminating the expensive imported rare earth minerals typically found in today's best commercial magnets. The iron-nitride powder is sourced from abundant and inexpensive materials found in the U.S. The ultimate goal of this project is to demonstrate this new magnet system, which contains no rare earths, in a prototype electric motor. This could significantly reduce the amount of greenhouse gases emitted in the U.S. each year by encouraging the use of clean alternatives to oil and coal.

Ames National Laboratory

[Cerium-Based Magnets]

Program: REACT

Project Term: 01/01/2012 to 05/31/2015

Project Status: ALUMNI

Project State: Iowa

Technical Categories: Resource Efficiency

Ames Laboratory is developing a new class of permanent magnets based on the more commonly available element cerium for use in both EVs and renewable power generators. Cerium is 4 times more abundant and significantly less expensive than the rare earth element neodymium, which is frequently used in today's most powerful magnets. Ames Laboratory will combine other metal elements with cerium to create a new magnet that can remain stable at the high temperatures typically found in electric motors. This new magnetic material will ultimately be demonstrated in a prototype electric motor, representing a cost-effective and efficient alternative to neodymium-based motors.

University of Texas, Dallas

[Double-Stator Motor Design]

Program: REACT

Project Term: 06/07/2012 to 02/15/2015

Project Status: ALUMNI

Project State: Texas

Technical Categories: Resource Efficiency

UT Dallas is developing a unique electric motor with the potential to efficiently power future classes of EVs and renewable power generators. Unlike many of today's best electric motors--which contain permanent magnets that use expensive, imported rare earths--UT Dallas' motor completely eliminates the use of rare earth materials. Additionally, the motor contains two stators. The stator is the stationary part of the motor that uses electromagnetism to help its rotor spin and generate power. The double-stator design has the potential to generate very high power densities at substantially lower cost than existing motors. In addition, this design can operate under higher temperatures and in more rugged environments. This project will focus on manufacturing and testing of a 100 kW motor with emphasis on low cost manufacturing for future use in EVs and renewable power generators.

University of Minnesota

Iron-Nitride-Based Magnets

Program: REACT

Project Term: 01/01/2012 to 09/30/2015

Project Status: ALUMNI

Project State: Minnesota

Technical Categories: Resource Efficiency

The University of Minnesota is developing an early stage prototype of an iron-nitride permanent magnet material for EVs and renewable power generators. This new material, comprised entirely of low-cost and abundant resources, has the potential to demonstrate the highest energy potential of any magnet to date. This project will provide the basis for an entirely new class of rare-earth-free magnets capable of generating power without costly and scarce rare earth materials. The ultimate goal of this project is to demonstrate a prototype with magnetic properties exceeding state-of-the-art commercial magnets.

REBELS Reliable Electricity Based on ELectrochemical Systems (13)

Fuel cell technologies have been touted for decades due to their high chemical-to-electrical conversion efficiencies and potential for near-zero greenhouse gas emissions. Fuel cell technologies for power generation have not achieved widespread adoption, however, due primarily to their high cost relative to more established combustion technologies. There is a critical need to develop fuel cell technologies that can enable distributed power generation at low cost and high performance. The projects that comprise ARPA-E's Reliable Electricity Based on ELectrochemical Systems (REBELS) program include transformational fuel cell devices that operate in an intermediate temperature range in an attempt to create new pathways to achieve an installed cost to the end-user of less than $1,500/kW at moderate production volumes and create new fuel cell functionality that will help increase grid stability and integration of renewable energy technologies such as wind and solar.

Georgia Tech Research Corporation

Fuel Cell Tailored for Efficient Utilization of Methane

Program: REBELS

Project Term: 10/01/2014 to 09/30/2017

Project Status: ACTIVE

Project State: Georgia

Technical Categories: Distributed Generation, Storage

Georgia Tech is developing a fuel cell that operates at temperatures less than 500°C by integrating nanostructured materials into all cell components. This is a departure from traditional fuel cells that operate at much lower or much higher temperatures. By developing multifunctional anodes that can efficiently reform and directly process methane, this fuel cell will allow for efficient use of methane. Additionally, the Georgia Tech team will develop nanocomposite electrolytes to reduce cell temperature without sacrificing system performance. These technological advances will enable an efficient, intermediate-temperature fuel cell for distributed generation applications.

Redox Power Systems, LLC

Low-Temperature Solid Oxide Fuel Cells

Program: REBELS

Project Term: 10/01/2014 to 09/30/2017

Project Status: ACTIVE

Project State: Maryland

Technical Categories: Distributed Generation, Storage

Redox Power Systems is developing a fuel cell with a mid-temperature operating target of 400°C while maintaining high power density and enabling faster cycling. Current fuel cell systems are expensive and bulky, which limits their commercialization and widespread adoption for distributed generation and other applications. Such state-of-the-art systems consist of fuel cells that either use a mixture of ceramic oxide materials that require high temperatures (~800°C) for grid-scale applications or are polymer-based technology with prohibitive low temperature operation for vehicle technologies. By combining advanced materials that have traditionally been unstable alone, Redox will create a new two-layer electrolyte configuration incorporating nano-enabled electrodes and stable ceramic anodes. The use of these materials will increase system power density and will have a startup time of less than 10 minutes, making them more responsive to demand. Redox is also developing a new fuel processor system optimized to work with their low-temperature solid oxide fuel cells. This new material configuration also allows the operating temperature to be reduced when incorporated into commercially fabricated fuel cells. These advances will enable Redox to produce a lower cost distributed generation product, as well as to enter new markets such as embedded power for datacenters.

United Technologies Research Center

[Intermediate Temperature Solid Oxide Fuel Cell Stack]

Program: REBELS

Project Term: 10/01/2014 to 09/30/2017

Project Status: ACTIVE

Project State: Connecticut

Technical Categories: Distributed Generation, Storage

UTRC is developing an intermediate-temperature fuel cell for residential applications that will combine a building's heating and power systems into one unit. Existing fuel cell technologies usually focus on operating low temperatures for vehicle technologies or at high temperatures for grid-scale applications. By creating a metal-supported proton conducting fuel cell with a natural gas fuel processor, UTRC could lower the operating system temperatures to under 500 °C. The use of metal offers faster start-up times and the possibility of lower manufacturing costs and additional automation options, while the proton conducting electrolyte offers the potential for higher ionic conductivity at lower temperatures than regular oxygen conducting solid oxide electrolyte materials. An intermediate temperature electrolyte will be used to achieve a lower operating temperature, while a redesigned cell architecture will increase the efficiency and lower the cost of UTRC's overall system.

Argonne National Laboratory

[Electricity and Liquid Fuels from Natural Gas]

Program: REBELS

Project Term: 10/01/2014 to 11/15/2016

Project Status: ACTIVE

Project State: Illinois

Technical Categories: Distributed Generation, Storage

ANL is developing a new hybrid fuel cell technology that could generate both electricity and liquid fuels from natural gas. Existing fuel cell technologies typically convert chemical energy from hydrogen into electricity during a chemical reaction with oxygen or some other agent. In addition to generating electricity from hydrogen, ANL's fuel cell would produce ethylene--a liquid fuel precursor--from natural gas. In this design, a methane-coupling catalyst is added to the anode side of a fuel cell that, when fed with natural gas, creates a chemical reaction that produces ethylene and utilizes leftover hydrogen, which is then passed through a proton-conducting membrane to generate electricity. Removing hydrogen from the reaction site leads to increased conversion of natural gas to ethylene.

University of California, Los Angeles

[Fuel Cells with Dynamic Response Capability]

Program: REBELS

Project Term: 11/01/2014 to 10/31/2016

Project Status: ACTIVE

Project State: California

Technical Categories: Distributed Generation, Storage

UCLA is developing a low-cost, intermediate-temperature fuel cell that will also function like a battery to increase load-following capability. The fuel cell will use new metal-oxide electrode materials--inspired by the proton channels found in biological systems--that offer superior energy storage capacity and cycling stability, making it ideal for distributed generation systems. UCLA's new materials also have high catalytic activity, which will lower the cost of the overall system. Success of this project will enable a rapid commercialization of multi-functional fuel cells for broad applications where reliable distributed generations are needed.

SAFCell, Inc.

Solid Acid Fuel Cell Stack

Program: REBELS

Project Term: 10/01/2014 to 03/31/2017

Project Status: ACTIVE

Project State: California

Technical Categories: Distributed Generation, Storage

SAFCell is developing solid acid fuel cells (SAFCs) that operate at 250 °C and will be nearly free of precious metal catalysts. Current fuel cells either rely on ultra-pure hydrogen as a fuel and operate at low temperatures for vehicles technologies, or run on natural gas, but operate only at high temperatures for grid-scale applications. SAFCell's fuel cell is utilizing a new solid acid electrolyte material to operate efficiently at intermediate temperatures and on multiple fuels. Additionally, the team will dramatically lower system costs by reducing precious metals, such as platinum, from the electrodes and developing new catalysts based on carbon nanotubes and metal organic frameworks. The proposed SAFC stack design will lead to the creation of low cost fuel cells that can withstand common fuel impurities, making them ideal for distributed generation applications.

University of South Carolina

Bi-functional Ceramic Fuel Cell Energy System

Program: REBELS

Project Term: 10/01/2014 to 09/30/2017

Project Status: ACTIVE

Project State: South Carolina

Technical Categories: Distributed Generation, Storage

The University of South Carolina is developing an intermediate-temperature, ceramic-based fuel cell that will both generate and store electrical power with high efficiencies. Reducing operating temperatures for fuel cells is critical to enabling distributed power generation. The device will incorporate a newly discovered ceramic electrolyte and nanostructured electrodes that enable it to operate at temperatures lower than 500ºC, far below the temperatures associated with fuel cells for grid-scale power generation. The fuel cell's unique design includes an iron-based layer that stores electrical charge like a battery, enabling a faster response to changes in power demand.

Colorado School of Mines

Fuel-Flexible Protonic Ceramic Fuel Cell Stack

Program: REBELS

Project Term: 10/01/2014 to 01/31/2017

Project Status: ACTIVE

Project State: Colorado

Technical Categories: Distributed Generation, Storage

The Colorado School of Mines (Mines) is developing a mixed proton and oxygen ion conducting electrolyte that will allow a fuel cell to operate at temperatures less than 500°C. By using a proton and oxygen ion electrolyte, the fuel cell stack is able to reduce coking - which clogs anodes with carbon deposits - and enhance the process of turning hydrocarbon fuels into hydrogen. Today's ceramic fuel cells are based on oxygen-ion conducting electrolytes and operate at high temperatures. Mines' advanced mixed proton and oxygen-ion conducting fuel cells will operate on lower temperatures, and have the capacity to run on hydrogen, ethanol, methanol, or methane, representing a drastic improvement over using only oxygen-ion conducting electrolytes. Additionally, the fuel cell will leverage a recently developed ceramic processing technique that decreases fuel cell manufacturing cost and complexity. Additionally, their technology will reduce the number of manufacturing steps from 15 to 3, drastically reducing the cost of distributed generation applications.

Oak Ridge National Laboratory

[Nanocomposite Electrodes for a Solid Acid Fuel Cell Stack]()

Program: REBELS

Project Term: 10/01/2014 to 10/07/2017

Project Status: ACTIVE

Project State: Tennessee

Technical Categories: Distributed Generation, Storage

Oak Ridge National Laboratory (ORNL) is redesigning a fuel cell electrode that operates at 250ºC. Today's solid acid fuel cells (SAFCs) contain relatively inefficient cathodes, which require expensive platinum catalysts for the chemical reactions to take place. ORNL's fuel cell will contain highly porous carbon nanostructures that increase the amount of surface area of the cell's electrolyte, and substantially reduce the amount of catalyst required by the cell. By using nanostructured electrodes, ORNL can increase the performance of SAFC cathodes at a fraction of the cost of existing technologies. The ORNL team will also modify existing fuel processors to operate efficiently at reduced temperatures; those processors will work in conjunction with the fuel cell to lower costs at the system level. ORNL's innovations will enable efficient distributed electricity generation from domestic fuel sources using less expensive catalysts.

Materials & Systems Research, Inc.

[Electrogenerative Cells for Flexible Cogeneration of Power and Liquid Fuel]()

Program: REBELS

Project Term: 11/01/2014 to 10/31/2017

Project Status: ACTIVE

Project State: Utah

Technical Categories: Distributed Generation, Storage

MSRI is developing an intermediate-temperature fuel cell capable of electrochemically converting natural gas into electricity or liquid fuel in a single step. Existing solid-oxide fuel cells (SOFCs) convert the chemical energy of hydrocarbons--such as hydrogen or methane--into electricity at higher efficiencies than traditional power generators, but are expensive to manufacture and operate at extremely high temperatures, introducing durability and cost concerns over time. Existing processes for converting methane to liquid transportation fuels are also capital intensive. MSRI's technology would convert natural gas into liquid fuel using efficient catalysts and a cost-effective fabrication process that can be readily scaled up for mass production. MSRI's technology will provide low-cost power or liquid fuel while operating in a temperature range of 400-500ºC, enabling better durability than today's high-temperature fuel cells.

Palo Alto Research Center

[Reformer-less Fuel Cell]()

Program: REBELS

Project Term: 10/01/2014 to 03/15/2016

Project Status: CANCELLED

Project State: California

Technical Categories: Distributed Generation, Storage

Palo Alto Research Center (PARC) is developing an intermediate-temperature fuel cell that is capable of utilizing a wide variety of carbon-based input fuels such as methane, butane, propane, or coal without reformation. Current fuel cell technologies require the use of a reformer - which turns hydrocarbon fuels into hydrogen and can generate heat and produce gases. PARC's design will include a novel electrolyte membrane system that doesn't have a methane-to-hydrogen reformer, and transports oxygen in a form that allows it to react directly with almost any fuel. This new membrane system eliminates the need for a separate fuel processing system all while reducing overall costs. PARC's fuel cell will also operate at relatively low temperatures of 200-300ºC which allows it to use less expensive materials and maintain durability. With the use of these materials, the fuel cell system avoids the long-term durability problems associated with existing higher-temperature fuel cells, all while reducing overall costs.

SiEnergy Systems

Hybrid Fuel Cell-Battery System

Program: REBELS

Project Term: 09/17/2014 to 11/20/2015

Project Status: CANCELLED

Project State: Massachusetts

Technical Categories: Distributed Generation, Storage

SiEnergy Systems is developing a hybrid electrochemical system that uses a multi-functional electrode to allow the cell to perform as both a fuel cell and a battery, a capability that does not exist today. A fuel cell can convert chemical energy stored in domestically abundant natural gas to electrical energy at high efficiency, but adoption of these technologies has been slow due to high cost and limited functionality. SiEnergy's design would expand the functional capability of a fuel cell to two modes: fuel cell mode and battery mode. In fuel cell mode, non-precious metal catalysts are integrated at the cell's anode to react directly with hydrocarbons such as the methane found in natural gas. In battery mode, the system will provide storage capability that offers faster response to changes in power demand compared to a standard fuel cell. SiEnergy's technology will operate at relatively low temperatures of 300-500ºC, which makes the system more durable than existing high-temperature fuel cells.

FuelCell Energy, Inc.

Liquid Fuels and Electricity from Intermediate-Temperature Fuel Cells

Program: REBELS

Project Term: 10/01/2014 to 09/30/2017

Project Status: CANCELLED

Project State: Connecticut

Technical Categories: Distributed Generation, Storage

FuelCell Energy will develop an intermediate-temperature fuel cell that will directly convert methane to methanol and other liquid fuels using advanced metal catalysts. Existing fuel cell technologies typically convert chemical energy from hydrogen into electricity during a chemical reaction with oxygen or some other agent. FuelCell Energy's cell would create liquid fuel from natural gas. Their advanced catalysts are optimized to improve the yield and selectivity of methane-to-methanol reactions; this efficiency provides the ability to run a fuel cell on methane instead of hydrogen. In addition, FuelCell Energy will utilize a new reactive spray deposition technique that can be employed to manufacture their fuel cell in a continuous process. The combination of these advanced catalysts and advanced manufacturing techniques will reduce overall system-level costs.

REMOTE Reducing Emissions using Methanotrophic Organisms for Transportation Energy (15)

The projects that comprise ARPA-E's REMOTE program, short for "Reducing Emissions using Methanotrophic Organisms for Transportation Energy," seek to enable highly efficient biological conversion of methane to liquid fuels for small-scale deployment. Specifically REMOTE focuses on improving the energy efficiency and carbon yield of biological routes from methane to a useable form for fuel synthesis while also examining high-productivity methane conversion processes and bioreactor technologies.

University of Delaware

Methanol to Liquid Fuel

Program: REMOTE

Project Term: 01/13/2014 to 01/12/2017

Project Status: ACTIVE

Project State: Delaware

Technical Categories: Transportation Fuels

The University of Delaware is engineering new metabolic pathways to convert methane into liquid fuel. Delaware's technology targets high-efficiency activation of methane to methanol without the consumption of additional energy, followed by conversion to butanol. The two-stage technology is envisioned to recapture carbon dioxide --with no carbon dioxide emissions. The team will use metabolic engineering and synthetic biology techniques to enable methanol utilization in organisms that are not natively about to do so. This modification will allow the new organism to grow on methanol, and utilize the available energy to produce butanol. Butanol is a high-energy fuel, with chemical and physical properties that are compatible with the current gasoline-based technologies for transportation.

MOgene Green Chemicals, LLC

Sunlight-Assisted Methane Conversion

Program: REMOTE

Project Term: 01/01/2014 to 12/31/2016

Project Status: ACTIVE

Project State: Missouri

Technical Categories: Transportation Fuels

MOgene Green Chemicals will engineer a photosynthetic organism for methane conversion that can use energy from both methane and sunlight. The first step in aerobic biological activation of methane requires oxygen and the introduction of energy in the form of heat. Organisms that use methane typically do so through a process that creates carbon dioxide, a greenhouse gas, losing energy-rich carbon molecules in the process. To address this, MOgene will engineer a "phototrophic" organism to convert methane that is capable of deriving additional energy from sunlight. This will allow the organism to naturally provide oxygen needed for methane conversion while recapturing any carbon dioxide that would have been released in the process. Consequently, MOgene's technology would be a more efficient and cost-effective way to activate methane, while producing n-butanol, a liquid fuel precursor.

Massachusetts Institute of Technology

Single-Step Methane to Liquid Fuels

Program: REMOTE

Project Term: 02/03/2014 to 02/02/2017

Project Status: ACTIVE

Project State: Massachusetts

Technical Categories: Transportation Fuels

The Bioinformatics and Metabolic Engineering Lab at the Massachusetts Institute of Technology (MIT) led by Prof. Greg Stephanopoulos will develop a comprehensive process to directly convert methane into a usable transportation fuel in a single step. MIT's unique technologies integrate methane activation with fuel synthesis, two distinct processes required to convert methane that are typically performed separately. Today, activating methane prior to converting it to useful fuel is a high-temperature, energy-intensive process. MIT's unique approach would use nitrate instead of oxygen to oxidize the methane, which could increase the energy efficiency of methane activation and ultimately convert it to fuel. Further, MIT will investigate the use of zeolite catalysts that have the potential to activate methane and convert it to methanol at very high efficiencies.

University of California, Los Angeles

Synthetic Pathway for Methanol Conversion

Program: REMOTE

Project Term: 01/01/2014 to 12/31/2016

Project Status: ACTIVE

Project State: California

Technical Categories: Transportation Fuels

The University of California Los Angeles (UCLA) will develop a high-efficiency, synthetic metabolic pathway that transforms methanol into n-butanol, a liquid fuel that can be used as a direct substitute for gasoline due to its high energy density. In nature, the process by which organisms that feed on methane convert it into fuel is inefficient, resulting in a substantial loss of carbon in the process. UCLA's synthetic metabolic pathway would oxidize the methanol into formaldehyde, convert the formaldehyde into an essential metabolite known as acetyl-CoA, and then condense the acetyl-CoA into n-butanol. In the end, UCLA's pathway would transform 4 parts methanol into 3 parts water and 1 part n-butanol while achieving 100% carbon conversion. UCLA will also attempt to move this synthetic metabolic pathway into organisms capable of biological methane activation to create a complete methane to n-butanol microbial production system.

Lawrence Berkeley National Laboratory

Enzymes for Methane Conversion

Program: REMOTE

Project Term: 01/01/2014 to 12/31/2016

Project Status: ACTIVE

Project State: California

Technical Categories: Transportation Fuels

Lawrence Berkeley National Laboratory (LBNL) is genetically engineering a bacterium called Methylococcus in order to produce an enzyme that binds methane with a common fuel precursor to create a liquid fuel. This process relies on methylation, a reaction that requires no oxygen or energy inputs but has never been applied to methane conversion." First, LBNL will construct a unique enzyme called a "PEP methylase" from an existing enzyme. The team will then bioengineer new metabolic pathways for assimilating methane and conversion to liquid fuels.

University of Michigan

Methane-to-Methanol

Program: REMOTE

Project Term: 01/23/2014 to 01/22/2017

Project Status: ACTIVE

Project State: Michigan

Technical Categories: Transportation Fuels

The University of Michigan (UM) team will develop a biological approach to activate methane, the first step in creating a liquid fuel from natural gas. Current approaches to methane activation require the addition of oxygen and energy in the form of heat, which is inefficient and costly. UM's multidisciplinary team will engineer a methane-generating microorganism that can activate methane without the need for these additional inputs. UM will use computer models to understand the processes on a molecular level and predict the structure of new enzymes and chemical interactions. Once modeled and engineered, UM's optimized organism and process would provide a way to produce butanol, a drop-in liquid fuel.

University of California, Davis

Ethylene-to-Butanol

Program: REMOTE

Project Term: 01/01/2014 to 12/31/2016

Project Status: ACTIVE

Project State: California

Technical Categories: Transportation Fuels

The University of California Davis (UCD) will engineer new biological pathways for bacteria to convert ethylene to a liquid fuel. Currently, ethylene is readily available and used by the chemicals and plastics industries to produce a wide range of useful products, but it cannot be cost-effectively converted to a liquid fuel like butanol, an alcohol that can be used directly as part of a fuel blend. UCD is addressing this problem with synthetic biology and protein engineering. The team will engineer ethylene assimilation pathways into a host organism and use that organism to convert ethylene into n-butanol, an important platform chemical with broad applications in many chemical and fuel markets. This technology could provide a transformative route from methane to liquid biofuels that is more efficient than ones found in nature.

LanzaTech, Inc.

Bioreactor with Improved Methane Transfer

Program: REMOTE

Project Term: 01/29/2014 to 01/28/2017

Project Status: ACTIVE

Project State: Illinois

Technical Categories: Transportation Fuels

LanzaTech will combine methane fermentation expertise, experimental bioreactor characterization, as well as advanced simulation and modeling to develop a novel gas fermentation system that can significantly improve gas to liquid mass transfer, or the rate at which methane gas is delivered to a biocatalyst. This unique bioreactor concept seeks to efficiently transfer methane to microbial biocatalysts by reducing the energy demand required for high transfer rates. Although methane is a flammable gas, the new technology also maintains the safe operation necessary for a small-scale conversion process. This bioreactor design would significantly reduce capital and operating costs, enabling small-scale deployment of fuel production from remote natural gas sources. LanzaTech's new gas fermentation system could help produce liquid fuel at a cost of less than $2 per gallon of gasoline equivalent.

GreenLight Biosciences, Inc.

Cell-Free Bioconversion of Natural Gas

Program: REMOTE

Project Term: 02/03/2014 to 02/02/2017

Project Status: ACTIVE

Project State: Massachusetts

Technical Categories: Transportation Fuels

GreenLight Biosciences is developing a cell-free bioreactor that can convert large quantities of methane to fuel in one step. This technology integrates biological and chemical processes into a single process by separating and concentrating the biocatalysts from the host microorganisms. This unique "cell-free" approach is anticipated to improve the productivity of the reactor without increasing cost. GreenLight's system can be erected onsite without the need for massive, costly equipment. The process uses natural gas and wellhead pressure to generate the power needed to run the facility. Any carbon dioxide that is released in the process is captured, condensed and pumped back into the well to maintain reservoir pressure and reduce emissions. This technology could enable a scalable, mobile facility that can be transported to remote natural gas wells as needed.

Oregon State University

Bioreactor Using Ultra-Thin Plates

Program: REMOTE

Project Term: 01/01/2014 to 05/01/2017

Project Status: ACTIVE

Project State: Oregon

Technical Categories: Transportation Fuels

OSU will develop a small-scale bioreactor that can enable high-rate, low cost bioconversion of methane to liquid fuel. Current systems to convert methane using microorganisms can be slow and inefficient due to the low rate at which methane gas and nutrients are transferred to biocatalysts as well as the build-up of toxins that affect the health of biocatalysts. Using an ultra-thin, stacked "Bio-Lamina-Plate" system OSU will attempt to improve the overall rate at which methane is transferred to the biocatalysts. This new reactor design also helps to improve the rate at which oxygen is provided and products are removed from the system. The reactor design improves the amount of surface exposed relative to the volume of biofilm and provides better heat transfer to improve overall reactor efficiency. Unlike reactors build using stainless steel, OSU's reactor may use low-cost materials such as plastic and glass, as well as simple fabrication techniques to reduce the bioreactor manufacturing costs.

Pennsylvania State University

[Methane-to-Acetate]

Program: REMOTE

Project Term: 01/01/2014 to 12/31/2016

Project Status: ACTIVE

Project State: Pennsylvania

Technical Categories: Transportation Fuels

Penn State is engineering a type of bacteria known as Methanosarcina acetivorans to produce acetate from methane gas. Current approaches to methane conversion are energy-intensive and result in substantial waste of carbon dioxide. Penn State will engineer a pathway for converting methane to a chemical called acetate by reversing the natural pathway for acetate to methanol conversion. This new approach is advantageous because it consumes carbon dioxide, produces energy-rich carbon-carbon bonds, and conserves electrons to make the molecules produced reactive and easy to combine with other molecules. The acetate generated can be used to form polymers that can be further processed into liquid fuels.

Calysta Energy, Inc.

[Bioreactor Designs for Rapid Fermentation]

Program: REMOTE

Project Term: 01/06/2014 to 01/05/2015

Project Status: ALUMNI

Project State: California

Technical Categories: Transportation Fuels

Calysta Energy will develop a new bioreactor technology to enable the efficient biological conversion of methane into liquid fuels. While reasonably efficient, Gas-to-liquid (GTL) conversion is difficult to accomplish without costly and complex infrastructure. Biocatalysts are anticipated to reduce the cost of GTL conversion. Calysta will address this by using computational fluid dynamics to model best existing high mass transfer bioreactor designs and overcome existing limitations. Calysta will make the newly developed technology available to the broader research community, which could help other research groups to quickly test and commercialize their methane conversion processes.

ARZEDA Corp.

[Metalloenzymes for Methane Activation]

Program: REMOTE

Project Term: 01/01/2014 to 09/30/2015

Project Status: ALUMNI

Project State: Washington

Technical Categories: Transportation Fuels

The team from Arzeda will use computational enzyme design tools and their knowledge of biological engineering and chemistry to create new synthetic enzymes to activate methane. Organisms that are capable of using methane as an energy and carbon source are typically difficult to engineer. To address this challenge, Arzeda will develop technologies essential to creating modular enzymes that can be used in other organisms. The team will combine computation enzyme design with experimental methods to improve enzyme activity and help direct methane more effectively into metabolism for fuel production. Arzeda's new enzymes could transform the way methane is activated, and would be more efficient than current chemical and biological approaches.

Northwestern University

[New Synthetic Catalysts for Methane Activation]

Program: REMOTE

Project Term: 02/12/2014 to 11/15/2015

Project Status: ALUMNI

Project State: Illinois

Technical Categories: Transportation Fuels

Northwestern University and partners will leverage computational protein design to engineer and repurpose a natural catalyst to convert methane gas to liquid fuel. Current industrial processes to convert methane to liquid fuels are costly, or inefficient and wasteful. To address this, Northwestern University will alter natural catalysts to create versatile new protein catalysts that convert methane to methanol which can more easily integrate into fuel production pathways. Northwestern will also engineer an additional protein catalysts to couple, or join, two molecules of methane together, a process critical towards producing longer chain "hydrocarbons" similar to those found in gasoline. Northwestern University's simplified catalysts will provide a better alternative to existing methane converting enzymes and can be incorporated into multiple types of processes.

Coskata, Inc.

Methanol Fermentation in Clostridium Bacteria

Program: REMOTE

Project Term: 01/15/2014 to 06/13/2014

Project Status: CANCELLED

Project State: Illinois

Technical Categories: Transportation Fuels

Coskata is engineering methanol fermentation into an anaerobic microorganism to enable a low-cost biological approach for liquid fuel production. Currently, the most well-known processes available to convert methane into fuel are expensive and energy-intensive. Coskata is constructing strains of the anaerobic bacteria to efficiently and cost-effectively convert activated methane to butanol, an alcohol that can be used directly as part of a fuel blend. Coskata's process involves molecular genetics to introduce and control specific genes, and to inactivate undesired pathways, together with fermentation optimization of constructed strains. Further, the team will work to increase the tolerance of these strains to high concentrations of butanol, an essential element of the technology.

SHIELD Single-Pane Highly Insulating Efficient Lucid Designs (1)

The SHIELD Program, short for "Single-Pane Highly Insulating Efficient Lucid Designs," aims to develop innovative materials that will improve the energy efficiency of existing single-pane windows in commercial and residential buildings. Technologies created through the SHIELD program seek to cut in half the amount of heat lost through single-pane windows in cold weather. These materials would improve insulation, reduce cold weather condensation, and enhance occupant comfort. The technologies could also produce secondary benefits, such as improved soundproofing, that will make retrofits more desirable to building occupants and owners. The program will focus on three technical categories: products that can be applied onto existing windowpanes; manufactured windowpanes that can be installed into the existing window sash that holds the windowpane in place; and other early-stage, highly innovative technologies that can enable products in the first two technical categories.

NanoSD, Inc.

More information on NanoSD's project is coming soon!

Program: SHIELD

Project Term: 10/01/2016 to 09/30/2020

Project Status: ACTIVE

Project State: California

Technical Categories: Building Efficiency

Solar ADEPT Solar Agile Delivery of Electrical Power Technology (7)

The projects that make up ARPA-E's Solar ADEPT program, short for "Solar Agile Delivery of Electrical Power Technology," aim to improve the performance of photovoltaic (PV) solar energy systems, which convert the sun's rays into electricity. Solar ADEPT projects are integrating advanced electrical components into PV systems to make the process of converting solar energy to electricity more efficient.

Cree, Inc.

Utility-Scale Solar Power Converter

Program: Solar ADEPT

Project Term: 01/25/2012 to 04/30/2017

Project Status: ACTIVE

Project State: North Carolina

Technical Categories: Distributed Generation

Cree is developing a compact, lightweight power conversion device that is capable of taking utility-scale solar power and outputting it directly into the electric utility grid at distribution voltage levels--eliminating the need for large transformers. Transformers "step up" the voltage of the power that is generated by a solar power system so it can be efficiently transported through transmission lines and eventually "stepped down" to usable voltages before it enters homes and businesses. Power companies step up the voltage because less electricity is lost along transmission lines when the voltage is high and current is low. Cree's new power conversion devices will eliminate these heavy transformers and connect a utility-scale solar power system directly to the grid. Cree's modular devices are designed to ensure reliability--if one device fails it can be bypassed and the system can continue to run.

University of Colorado, Boulder

Integrated Solar Power Converters

Program: Solar ADEPT

Project Term: 02/09/2012 to 08/31/2015

Project Status: ALUMNI

Project State: Colorado

Technical Categories: Distributed Generation

CU-Boulder is developing advanced power conversion components that can be integrated into individual solar panels to improve energy yields. The solar energy that is absorbed and collected by a solar panel is converted into useable energy for the grid through an electronic component called an inverter. Many large, conventional solar energy systems use one, central inverter to convert energy. CU-Boulder is integrating smaller, microconverters into individual solar panels to improve the efficiency of energy collection. The university's microconverters rely on electrical components that direct energy at high speeds and ensure that minimal energy is lost during the conversion process--improving the overall efficiency of the power conversion process. CU-Boulder is designing its power conversion devices for use on any type of solar panel.

SolarBridge Technologies, Inc.

Efficient Power Converters for PV Arrays

Program: Solar ADEPT

Project Term: 02/23/2012 to 06/22/2015

Project Status: ALUMNI

Project State: Texas

Technical Categories: Distributed Generation

SolarBridge is developing a new power conversion technique to improve the energy output of PV power plants. This new technique is specifically aimed at large plants where many solar panels are connected together. SolarBridge is correcting for the inefficiencies that occur when two solar panels that encounter different amounts of sun are connected together. In most conventional PV system, the weakest panel limits the energy production of the entire system. That's because all of the energy collected by the PV system feeds into a single collection point where a central inverter then converts it into useable energy for the grid. SolarBridge has found a more efficient and cost-effective way to convert solar energy, correcting these power differences before they reach the grid.

Ideal Power, Inc.

Lightweight PV Inverters

Program: Solar ADEPT

Project Term: 01/30/2012 to 05/29/2015
Project Status: ALUMNI
Project State: Texas
Technical Categories: Distributed Generation

PV inverters convert DC power generated by modules into usable AC power. IPC's initial 30kW 94lb. PV inverter reduces the weight of comparable 30kW PV inverters by 90%--reducing the cost of materials, manufacturing, shipping, and installation. With ARPA-E support, new bi-directional silicon power switches will be developed, commercialized, and utilized in IPC's next-generation PV inverter. With these components, IPC will produce 100kW inverters that weight less than 100lb., reducing the weight of conventional 3,000lb. 100kW inverters by more than 95%. The new power switches will cut IPC's $/W manufacturing cost in half, as well as further reduce indirect shipping and installation costs.

Transphorm, Inc.

Efficient Switches for Solar Power Conversion

Program: Solar ADEPT
Project Term: 02/13/2012 to 03/31/2015
Project Status: ALUMNI
Project State: California
Technical Categories: Distributed Generation

Transphorm is developing power switches for new types of inverters that improve the efficiency and reliability of converting energy from solar panels into useable electricity for the grid. Transistors act as fast switches and control the electrical energy that flows in an electrical circuit. Turning a transistor off opens the circuit and stops the flow of electrical current; turning it on closes the circuit and allows electrical current to flow. In this way a transistor can be used to convert DC from a solar panel into AC for use in a home. Transphorm's transistors will enable a single semiconductor device to switch electrical currents at high-voltage in both directions--making the inverter more compact and reliable. Transphorm is using Gallium Nitride (GaN) as a semiconductor material in its transistors instead of silicon, which is used in most conventional transistors, because GaN transistors have lower losses at higher voltages and switching

Carnegie Mellon University

Magnet Technology for Power Converters

Program: Solar ADEPT
Project Term: 02/27/2012 to 03/28/2015
Project Status: ALUMNI
Project State: Pennsylvania
Technical Categories: Distributed Generation

CMU is developing a new nanoscale magnetic material that will reduce the size, weight, and cost of utility-scale PV solar power conversion systems that connect directly to the grid. Power converters are required to turn the energy that solar power systems create into useable energy for the grid. The power conversion systems made with CMU's nanoscale magnetic material have the potential to be 150 times lighter and significantly smaller than conventional power conversion systems that produce similar amounts of power.

SiCLAB, Rutgers University, NJ

New Switches for Utility Scale Inverters

Program: Solar ADEPT
Project Term: 12/23/2011 to 01/20/2013
Project Status: CANCELLED
Project State: New Jersey
Technical Categories: Distributed Generation

The SiCLAB is developing a new power switch for utility-scale PV inverters that would improve the performance and significantly reduce the size, weight, and energy loss of PV systems. A power switch controls the electrical energy flowing through an inverter, which takes the electrical current from a PV solar panel and converts it into the type and amount of electricity that is compatible with the electric grid. SiCLAB is using silicon carbide (SiC) semiconductors in its new power switches, which are more efficient than the silicon semiconductors used to conduct electricity in most conventional power switches today. Switches with SiC semiconductors can operate at much higher temperatures, as well as higher voltage and power levels than silicon switches. SiC-based power switches are also smaller than those made with silicon alone, so they result in much smaller and lighter electrical devices. In addition to their use in utility-scale PV inverters, SiCLAB's new power switches can also be used in wind turbines, railways, and other smart grid applications.

SWITCHES Strategies for Wide Bandgap, Inexpensive Transistors for Controlling High-Efficiency Systems (14)

The projects in ARPA-E's SWITCHES program, which is short for "Strategies for Wide-Bandgap, Inexpensive Transistors for Controlling High-Efficiency Systems," are focused on developing next-generation power switching devices that could dramatically improve energy efficiency in a wide range of applications, including new lighting technologies, computer power supplies, industrial motor drives, and automobiles. SWITCHES projects aim to find innovative new wide-bandgap semiconductor materials, device architectures, and device fabrication processes that will enable increased switching frequency, enhanced temperature control, and reduced power losses, at substantially lower cost relative to today's solutions. More specifically, SWITCHES projects are advancing bulk gallium nitride (GaN) power semiconductor devices, the manufacture of silicon carbide (SiC) devices using a foundry model, and the design of synthetic diamond-based transistors. A number of SWITCHES projects are small businesses being funded through ARPA-E's Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) program.

Michigan State University

Diamond Semiconductor Devices

Program: SWITCHES

Project Term: 02/19/2014 to 07/18/2017

Project Status: ACTIVE

Project State: Michigan

Technical Categories: Electrical Efficiency

Michigan State University (MSU) will develop high-voltage diamond semiconductor devices for use in high-power electronics. Diamond is an excellent conductor of electricity when boron or phosphorus is added--or doped--into its crystal structures. It can also withstand much higher temperatures with higher performance levels than silicon, which is used in the majority of today's semiconductors. However, current techniques for growing doped diamond and depositing it on electronic devices are difficult and expensive. MSU is overcoming these challenges by using an innovative, low-cost, lattice-etching method on doped diamond surfaces, which will facilitate improved conductivity in diamond semiconductor devices.

Kyma Technologies, Inc.

GaN Substrate Technology

Program: SWITCHES

Project Term: 03/10/2014 to 03/09/2018

Project Status: ACTIVE

Project State: North Carolina

Technical Categories: Electrical Efficiency

Kyma will develop a cost-effective technique to grow high-quality gallium nitride (GaN) seeds into GaN crystal boules, which are used as the starting material for a number of semiconductor devices. Currently, growing boules from GaN seeds is a slow, expensive, and inconsistent process, so it yields expensive electronic devices of varying quality. Kyma will select the highest quality GaN seeds and use a proprietary hydride vapor phase epitaxy growth process to rapidly grow the seeds into boules while preserving the seed's structural quality and improving its purity.

HRL Laboratories, LLC

Vertical GaN Transistor

Program: SWITCHES

Project Term: 03/07/2014 to 03/06/2017

Project Status: ACTIVE

Project State: California

Technical Categories: Electrical Efficiency

HRL will develop a high-performance, low-cost, vertical gallium nitride (GaN) transistor that could displace the silicon transistor technologies used in most high-power switching applications today. GaN transistors can operate at higher temperatures, voltages, and currents than their silicon counterparts, but they are expensive to manufacture. HRL will combine innovations in semiconductor material growth, device fabrication, and circuit design to create its high-performance GaN vertical transistor at a competitive manufacturing cost.

University of California, Santa Barbara

Vertical GaN Devices

Program: SWITCHES

Project Term: 03/10/2014 to 03/09/2017

Project Status: ACTIVE

Project State: California

Technical Categories: Electrical Efficiency

The University of California, Santa Barbara (UCSB) will develop new vertical gallium nitride (GaN) semiconductor technologies that will significantly enhance the performance and reduce the cost of high-power electronics. UCSB will markedly reduce the size of its vertical GaN semiconductor devices compared to today's commercially available, lateral GaN-on-silicon-based devices. Despite their reduced size, UCSB's vertical GaN devices will exhibit improved performance and significantly lower power losses when switching and converting power than lateral GaN devices. UCSB will also simplify fabrication processes to keep costs down.

SixPoint Materials, Inc.

Vertical GaN Substrates

Program: SWITCHES

Project Term: 03/10/2014 to 03/09/2017

Project Status: ACTIVE

Project State: California

Technical Categories: Electrical Efficiency

SixPoint Materials will create low-cost, high-quality vertical gallium nitride (GaN) substrates for use in high-power electronic devices. In its two-phase project, SixPoint Materials will first focus on developing a high-quality GaN substrate and then on expanding the substrate's size. Substrates are thin wafers of semiconducting material used to power devices like transistors and integrated circuits. SixPoint Materials will use a two-phase production approach that employs both hydride vapor phase epitaxy technology and ammonothermal growth techniques to create its high-quality, low-cost GaN substrates.

Columbia University

Spalling GaN Transistors

Program: SWITCHES

Project Term: 04/01/2014 to 07/31/2017

Project Status: ACTIVE

Project State: New York

Technical Categories: Electrical Efficiency

Columbia University will create high-performance, low-cost, vertical gallium nitride (GaN) devices using a technique called spalling, which involves exfoliating a working circuit and transferring it to another material. Columbia and its project partners will spall and bond entire transistors from high-performance GaN wafers to lower cost silicon substrates. Substrates are thin wafers of semiconducting material needed to power devices like transistors and integrated circuits. GaN substrates operate much more efficiently than silicon substrates, particularly at high voltages, but the high cost of GaN is a barrier to its widespread use. The spalling technique developed by Columbia will allow GaN substrates to be reused, lowering their manufacturing cost.

Cornell University

GaN Power Transistor

Program: SWITCHES

Project Term: 08/01/2015 to 10/16/2017

Project Status: ACTIVE

Project State: New York

Technical Categories: Electrical Efficiency

Cornell University will develop an innovative, high-efficiency, gallium nitride (GaN) power switch. Cornell's design is significantly smaller and operates at much higher performance levels than conventional silicon power switches, making it ideal for use in a variety of power electronics applications. Cornell will also reuse expensive GaN materials and utilize conventional low-cost production methods to keep costs down.

Arizona State University

Diamond Power Transistors

Program: SWITCHES

Project Term: 02/20/2014 to 11/20/2017

Project Status: ACTIVE

Project State: Arizona

Technical Categories: Electrical Efficiency

Arizona State University (ASU) will develop a process to produce low-cost, vertical, diamond semiconductor devices for use in high-power electronics. Diamond is an excellent conductor of electricity when boron or phosphorus is added--or doped--into its crystal structures. In fact, diamond can withstand much higher temperatures with higher performance levels than silicon, which is used in the majority of today's semiconductor devices. However, growing uniformly doped diamond crystals is difficult and expensive. ASU's innovative diamond-growing process could create greater doping uniformity, helping to significantly lower the cost of diamond semiconductor devices.

MicroLink Devices

High-Power Transistor Fabrication

Program: SWITCHES

Project Term: 03/10/2014 to 12/09/2017

Project Status: ACTIVE

Project State: Illinois

Technical Categories: Electrical Efficiency

MicroLink Devices will engineer affordable, high-performance transistors for power conversion. Currently, high-performance power transistors are prohibitively expensive because they are grown on expensive gallium nitride (GaN) semiconductor wafers. In conventional manufacturing processes, this expensive wafer is permanently attached to the transistor, so the wafer can only be used once. MicroLink Devices will develop an innovative method to remove the transistor structure from the wafer without damaging any components, enabling wafer reuse and significantly reducing costs.

iBeam Materials, Inc.

GaN LEDs on Flexible Metal Foils

Program: SWITCHES

Project Term: 03/10/2014 to 10/01/2017

Project Status: ACTIVE
Project State: New Mexico
Technical Categories: Electrical Efficiency

iBeam Materials is developing a scalable manufacturing method to produce low-cost gallium nitride (GaN) LED devices for use in solid-state lighting. iBeam Materials uses an ion-beam crystal-aligning process to create single-crystal-like templates on arbitrary substrates thereby eliminating the need for small rigid single-crystal substrates. This process is inexpensive, high-output, and allows for large-area deposition in particular on flexible metal foils. In using flexible substrates, in contrast to rigid single-crystal wafers, the ion-aligning process also enables roll-to-roll (R2R) processing of crystalline films. R2R processing in turn simplifies manufacturing scale-up by reducing equipment footprint and associated labor costs By fabricating the LED directly on a metal substrate, one "pre-packages" the LED with the reflector and the heat sink built-in. This significantly reduces cost, simplifies packaging and allows a pick-and-place (P&P) technology to be replaced with printing of LEDs.

Avogy, Inc.

Vertical GaN Transistors

Program: SWITCHES
Project Term: 01/01/2014 to 03/31/2017
Project Status: ACTIVE
Project State: California
Technical Categories: Electrical Efficiency

Avogy will develop a vertical transistor with a gallium nitride (GaN) semiconductor that is 30 times smaller than conventional silicon transistors but can conduct significantly more electricity. Avogy's GaN transistor will function effectively in high-power electronics because it can withstand higher electric fields and operate at higher temperatures than comparable silicon transistors. Avogy's vertical device architecture can also enable higher current devices. With such a small and efficient device, Avogy projects it will achieve functional cost parity with conventional silicon transistors within three years, while offering game-changing performance improvements.

Monolith Semiconductor, Inc.

Advanced Manufacturing for SiC MOSFETS

Program: SWITCHES
Project Term: 01/01/2014 to 12/31/2016
Project Status: ACTIVE
Project State: Texas
Technical Categories: Electrical Efficiency

Monolith Semiconductor will utilize advanced device designs and existing low-cost, high-volume manufacturing processes to create high-performance silicon carbide (SiC) devices for power conversion. SiC devices provide much better performance and efficiency than their silicon counterparts, which are used in the majority of today's semiconductors. However, SiC devices cost significantly more. Monolith will develop a high-volume SiC production process that utilizes existing silicon manufacturing facilities to help drive down the cost of SiC devices.

Soraa, Inc.

Low-Cost GaN Substrates

Program: SWITCHES
Project Term: 02/17/2014 to 05/17/2015
Project Status: ALUMNI
Project State: California
Technical Categories: Electrical Efficiency

Soraa will develop a cost-effective technique to manufacture high-quality, high-performance gallium nitride (GaN) crystal substrates that have fewer defects by several orders of magnitude than conventional GaN substrates and cost about 10 times less. Substrates are thin wafers of semiconducting material needed to power devices like transistors and integrated circuits. Most GaN-based electronics today suffer from very high defect levels and, in turn, reduced performance. In addition to reducing defects, Soraa will also develop methods capable of producing large-area GaN substrates--3 to 4 times larger in diameter than conventional GaN substrates--that can handle high-power switching applications.

Fairfield Crystal Technology, LLC

GaN Crystal Substrates

Program: SWITCHES

Project Term: 03/05/2014 to 06/22/2015

Project Status: ALUMNI

Project State: Connecticut

Technical Categories: Electrical Efficiency

Fairfield Crystal Technology will develop a new technique to accelerate the growth of gallium nitride (GaN) single-crystal boules. A boule is a large crystal that is cut into wafers and polished to provide a surface, or substrate, suitable for fabricating a semiconductor device. Fairfield Crystal Technology's unique boule-growth technique will rapidly produce superior-quality GaN crystal boules--overcoming the quality and growth-rate barriers typically associated with conventional growth techniques, including the current state-of-the-art hydride vapor phase epitaxy technique, and helping to significantly reduce manufacturing costs.

TERRA Transportation Energy Resources from Renewable Agriculture (6)

The TERRA program is facilitating improvement of advanced biofuel crops, specifically energy sorghum, by developing and integrating cutting-edge remote sensing platforms, complex data analytics tools, and high-throughput plant breeding technologies. Project teams are constructing automated systems to accurately measure and analyze crop growth in the field, thoroughly characterizing genetic potential and creating algorithms for selecting the best plants to reproduce. These innovations will accelerate domestic production of sustainable, renewable, and affordable liquid transportation fuels. The program will also generate the world's largest public reference database of sorghum plant characteristics and genetic composition that will facilitate research and development efforts across public and private sector institutions and in other important agricultural crops.

Pacific Northwest National Laboratory

The Consortium for Advanced Sorghum Phenomics (CASP)

Program: TERRA

Project Term: 09/15/2015 to 12/14/2017

Project Status: ACTIVE

Project State: Washington

Technical Categories: Transportation Fuels

Pacific Northwest National Laboratory (PNNL), along with its partners, will use aerial and ground-based platforms to identify traits required for greater production yield and resistance to drought and salinity stresses to accelerate sorghum breeding for biofuel production. The project will combine plant analysis in both outdoor field and indoor greenhouse environments as each provides unique advantages; and will use robotics and imaging platforms for increased speed and accuracy of data collection. Traditionally aboveground biomass is measured by harvesting, drying, and weighing the plant material. As an alternative approach, the team will develop non-destructive high-throughput methods to measure biomass over time. Drought tolerance will be measured by mapping water stress and using sensors to compare the difference between the canopy temperature and air temperature. The overall goal of the project is to understand the traits related to increasing biomass yield and drought/salinity stress, and to predict those traits in the early stages of plant development, before those traits become apparent using current methods.

Texas A&M Agrilife Research

Automated TERRA Phenotyping System

Program: TERRA

Project Term: 10/01/2015 to 12/31/2017
Project Status: ACTIVE
Project State: Texas
Technical Categories: Transportation Fuels

Texas A&M University, along with Carnegie Melon University (CMU), will develop a rugged robotic system to measure characteristics of sorghum in the field. Traditionally this type of data collection is performed manually and often can only be collected when the crop is harvested. The team from CMU will create an automated gantry system with a plunging sensor arm to characterize individual plants in the field. The sensor arm of the gantry system allows the team to collect data not only from above, but to descend into the canopy and take measurements within. The team will utilize machine learning algorithms to interpret the field data and correlate them to plant phenotypes, molecular markers, and genes of interest linked to the field phenotypes. TAMU will incorporate this technology into its world class sorghum breeding program to increase the rate of genetic improvement.

Donald Danforth Plant Science Center

A Reference Phenotyping System for Energy Sorghum

Program: TERRA
Project Term: 09/15/2015 to 09/14/2019
Project Status: ACTIVE
Project State: Missouri
Technical Categories: Transportation Fuels

The Donald Danforth Plant Science Center, in collaboration with partners from seven institutions, proposes an integrated open-sourced phenotyping system for energy sorghum. Phenotyping is the assessment of observable plant traits, and is critical for breeding improvements. The team will develop a central repository for high quality phenotyping datasets, and make this resource available to other TERRA project groups and the wider community to stimulate further innovations. The team will collect data with their complete system that will include a number of components. First, the team will install, operate, and maintain a reference phenotyping field system that employs a bridge-like overhead structure with a moveable platform supporting sensing equipment, called the Scanalyzer, at the Maricopa Agricultural Center (MAC) at the University of Arizona. The Scanalyzer's advanced sensors will be used for automated high-throughput phenotyping to gather data from the energy sorghum in the field. Second, the project will combine field- and controlled-environment phenotyping. The controlled-environment facilities allow the team to more precisely manipulate environmental conditions and resolve complex dynamic interactions observed in the field. Third, plant and environment data gathered will be used to create computational solutions and predictive algorithms to improve the ability to predict phenotypes; increasing the ability to identify traits for improved biomass yield earlier in a plant's development. Collected data will also be used in the fourth component of the project, advancing our understanding of phenotype-to-genotype trait associations, determining which genes control observable traits in the sorghum. Some traits are largely determined by genes and others are largely determined by environmental factors; work in this project will help elucidate the differences. All of these components generate an incredible amount of data. An "Open Data" policy is central to the philosophy of the Danforth project. To ensure that this data is useful, the team will convene a standards committee selected in collaboration with the TERRA program to standardize phenotyping efforts between institutions. This sharing of standards, data, and open-source code will reduce redundancy, lower costs for researchers, allow for long-term curation, and unlock potential new innovations from entrepreneurs outside the TERRA community.

Purdue University

Automated Sorghum Phenotyping and Trait Development Platform

Program: TERRA
Project Term: 08/24/2015 to 08/23/2018
Project Status: ACTIVE
Project State: Indiana
Technical Categories: Transportation Fuels

Purdue University, along with IBM Research and international partners from the Commonwealth Scientific and Industrial Research Organisation (CSIRO, Australia) will utilize remote sensing platforms to collect data and develop models for automated phenotyping and predictive plant growth. The team will create a system that combines data streams from ground and airborne mobile platforms for high-throughput automated field phenotyping. The team's custom "phenomobile" will be a mobile, ground-based platform that will carry a sensor package capable of measuring numerous plant traits in a large number of research plots in a single day. In addition, the team will use unmanned aerial vehicles (UAVs) equipped with advanced sensors configured to optimize the collection of diverse phenotypic data and complement the data collected from the phenomobile. Advanced image and signal processing methods will be utilized to extract phenotypic information and develop predictive models for plant growth and development. IBM Research will contribute high-performance computing platforms and advanced machine learning approaches to associate these measurements with genomic information to identify genes controlling sorghum performance. International partners from CSIRO will lend their expertise in crop modelling and phenotyping to the effort.

Clemson University

Breeding High Yielding Bioenergy Sorghum

Program: TERRA

Project Term: 09/30/2015 to 09/29/2018

Project Status: ACTIVE

Project State: South Carolina

Technical Categories: Transportation Fuels

Clemson University is partnering with Carnegie Mellon University (CMU), the Donald Danforth Plant Science Center, and Near Earth Autonomy to develop and operate an advanced plant phenotyping system, incorporating modeling and rapid prediction of plant performance to drive improved yield and compositional gains for energy sorghum. The team will plant and phenotype one of the largest sets of plant types in the TERRA program. Researchers will design and build two phenotyping platforms - an aerial sensor platform and a ground-based platform. The aerial platform, developed by Near Earth Autonomy, is a fast moving, autonomous helicopter outfitted with sensors that will collect image data from above. The ground platforms are customized robots from CMU that will drive between crop rows below the plant canopy and collect data using two distinct sensor suites. The first will use sophisticated cameras and imaging algorithms to develop detailed 3D models of individual plants and their canopy structure. The second will have the unique ability to directly contact the plant in order to systematically measure physical characteristics that were previously measured manually with labor-intensive, low-throughput methods. The team will use machine learning techniques to analyze the data gathered from the phenotyping systems and translate this into predictive algorithms for accelerated breeding of improved biofuel plants.

University of Illinois, Urbana Champaign

TERRA MEPP (Mobile Energy-crop Phenotyping Platform)

Program: TERRA

Project Term: 10/01/2015 to 12/31/2017

Project Status: ACTIVE

Project State: Illinois

Technical Categories: Transportation Fuels

The University of Illinois with partners, Cornell University and Signetron Inc., will develop a small semi-autonomous, ground-based vehicle called TERRA-MEPP (Mobile Energy-Crop Phenotyping Platform). The platform performs high-throughput field-based data collection for bioenergy crops, providing on-the-go measurements of the physical structure of individual plants. TERRA-MEPP will use visual, thermal, and multi-spectral sensors to collect data and create 3-D reconstructions of individual plants. Newly developed software will interpret the data and a model-based data synthesis system will enable breeders to select the most promising sorghum lines for bioenergy production much sooner than currently possible, dramatically increasing the rate of genetic advancements in biomass.

TRANSNET Traveler Response Architecture using Novel Signaling for Network Efficiency in Transportation (5)

The projects in ARPA-E's Traveler Response Architecture using Novel Signaling for Network Efficiency in Transportation (TRANSNET) program aim to minimize energy consumption in personal transportation, without having to improve current infrastructure or vehicle efficiency. TRANSNET project teams are developing new network control architectures, coupled with incentive strategies, to encourage individual travelers to take specific energy-relevant actions. These actions could, for example, contribute to reductions in miles traveled and increased occupancy rates for all modes. Project teams will design two interacting computer models: a system model that dynamically simulates the entire transportation network, including roadways, public transit, and other modes of travel, and calculates energy use at an individual level; and a control architecture, which quantifies the impacts of incentives and signals on real-time energy reductions. Operating together, these modules will measure changes to energy use in response to controls. If successful, these systems will allow the optimization of control strategies, which could increase the efficiency in a transportation network.

University of Maryland

Traveler Information and Incentive Technology

Program: TRANSNET

Project Term: 11/23/2015 to 05/22/2018

Project Status: ACTIVE

Project State: Maryland

Technical Categories: Transportation Network

The National Transportation Center at the University of Maryland (UMD) and its partners will develop a technology capable of delivering personalized, real-time travel information to users and incentivizing travelers to adopt more energy-efficient travel plans. The project team will use data from UMD's existing regional integrated transportation information system (RITIS) as well as other available resources to design its system model. This system model will integrate information on individual traveler behavior to simulate the effects of traffic and individual traveler choices on energy use in the Washington/Baltimore metro area. For its control architecture, UMD researchers will apply behavioral research to predict travelers' responses and identify appropriate, personalized incentives to encourage drivers to alter routes, departure times, and driving styles, or to take mass transit or ride-sharing services. The control architecture will incentivize users with monetary and non-monetary rewards, including social influence strategies that leverage social media to generate competition or rewards among social network users.

National Renewable Energy Laboratory

The Connected Traveler: A Framework to Reduce Energy Use in Transportation

Program: TRANSNET

Project Term: 01/20/2016 to 07/19/2018

Project Status: ACTIVE

Project State: Colorado

Technical Categories: Transportation Network

The National Renewable Energy Laboratory (NREL) and its partners will create a network architecture that approaches sustainable transportation as a dynamic system of travelers and decision points, rather than one of vehicles and roads, in order to create personalized energy-saving opportunities. The project will use currently available demographic and transportation data from an urban U.S. city as a test bed for energy reduction. To incentivize travelers to pursue energy-efficient routes, the control architecture will develop algorithms to understand a traveler's preferences, tailor recommendations to the user, and identify personal incentives that will enable transportation system energy benefits. The Connected Traveler framework will provide local transportation authorities and individual travelers with a tool to identify personal travel decisions that balance quality of service with energy efficiency.

Palo Alto Research Center

Collaborative Optimization and Planning for Transportation Energy Reduction (COPTER)

Program: TRANSNET

Project Term: 12/28/2015 to 06/27/2018

Project Status: ACTIVE

Project State: California

Technical Categories: Transportation Network

The Palo Alto Research Center (PARC) will develop its COPTER system to identify the energy-efficient routes most likely to be adopted by a traveler. PARC's system model will use currently available data from navigation tools, public transit, and intelligent transportation systems to simulate the Los Angeles transportation network and its energy use. For its control architecture, PARC will leverage its expertise in behavioral modeling and use machine-learning algorithms to predict the near-time travel needs of users, their constraints, and how likely they are to respond to suggested travel options. The system would send users recommendations for energy-efficient trips before departure, and could provide real-time guidance to users if adjustments in a trip need to be made to account for traffic or other unexpected interruptions. Unlike existing platforms, PARC's technology will be able to optimize for multiple travelers at the same time, organized by their most likely corridors of travel. This would prevent travelers from all pursuing the same alternative, which could cause additional traffic, and would also create dynamic ride-sharing options. By improving travelers' quality of service, PARC believes no further incentives are needed to encourage users to adopt the suggestions pushed to their smartphone.

Massachusetts Institute of Technology

Mobility Electronic Market for Optimized Travel (MeMOT)

Program: TRANSNET

Project Term: 12/11/2015 to 06/10/2018

Project Status: ACTIVE

Project State: Massachusetts

Technical Categories: Transportation Network

Massachusetts Institute of Technology (MIT) will develop and test its "Mobility Electronic Market for Optimized Travel" (MeMOT), a system that could incentivize travelers to pursue specific routes, modes of travel, departure times, vehicle types, and driving styles in order to reduce energy use. MeMOT relies on an app-based travel incentive tool designed to influence users' travel choices by offering them real-time information and rewards. MIT researchers will use an open-source simulation platform, SimMobility, and an energy model, TripEnergy, to test MeMOT. The system model, which will simulate the Greater Boston area, will be able to dynamically measure energy use as changes to the network and travelers' behavior occur. The team's system model will be linked with a control architecture that will evaluate energy savings and traveler satisfaction with different incentive structures. The control architecture will present users with personalized options via a smartphone app, and it will include a reward points system to incentivize users to adopt energy-efficient travel options. Reward points, or tokens, could be redeemed for prizes or discounts at participating vendors, or could be transferred amongst users in a social network.

Georgia Tech Research Corporation

Network Performance Monitoring and Distributed Simulation

Program: TRANSNET

Project Term: 01/06/2016 to 07/05/2018

Project Status: ACTIVE

Project State: Georgia

Technical Categories: Transportation Network

Researchers with the Georgia Institute of Technology (Georgia Tech) will combine real-time analysis of transportation network data with distributed simulation modeling to provide drivers with information and incentives to reduce energy consumption. The team's system model will use three sources of data to simulate the transportation network of the Atlanta metro area. The Georgia Department of Transportation's intelligent transportation system (ITS) data repository, hosted at Georgia Tech, will provide 20-second, lane-specific operations data while team partner, AirSage, will provide highway speeds and origin-destination patterns obtained from cellular networks. The team will also use real-time speed data collected from 40,000 volunteers using a smartphone application. The researchers will use pattern recognition algorithms to identify traffic accidents and recurrent congestion, predict traffic congestion severity, and user responses to congested conditions. Using this information, the team will develop a control architecture that will signal drivers with options to alter departure times, take specific routes, and/or use alternate modes of transportation to reduce energy use. The team anticipates that users will adopt the suggested guidance because the suggestions identified will not increase the time or cost of the trip, and could ultimately save users money in fuel costs.

3. What statutory authority has been given to the Department with respect to cybersecurity?

Response: Authority given to DOE with respect to cybersecurity can be divided into three groups:

(1) internal cybersecurity: authority includes primarily the Federal Information Security Modernization Act and to a lesser extent, the Federal Information Technology Acquisition Reform Act.

(2) external cybersecurity engagement: statutory authority includes the Atomic Energy Act, the Fixing America's Surface Transportation (FAST) Act, and the Cybersecurity Information Sharing Act.

Under the FAST Act, the DOE Office of Electricity Delivery and Energy Reliability (OE) represents DOE in its role as the Sector Specific Agency for cybersecurity for the energy sector. In this role, the Secretary coordinates with the Department of Homeland Security (DHS) and other relevant Federal departments and agencies and collaborates with critical electric infrastructure owners and operators (and as appropriate, independent regulatory agencies, state, local, tribal and territorial entities) to serve as a day-to-day Federal interface to effect dynamic prioritization and coordination of sector-specific activities and to carry out incident management responsibilities consistent with applicable laws, regulations and other appropriate policies or directives. The role also involves providing, supporting or facilitating technical assistance and consultations for the energy sector to identify vulnerabilities and to help mitigate incidents, as appropriate, as well as to support annual DHS sector-specific reporting requirements.

EO 13636 Section 8(b) also provides additional guidance and authority for DOE to engage with the private sector. DOE, in consultation with DHS and other interested agencies, can engage with the energy sector in cybersecurity for the purpose of coordinating with Energy Sector Coordinating Councils to review the Cybersecurity Framework and, if necessary, develop implementation guidance or supplemental materials to address energy sector-specific risks and operating environments.

(3) limited emergency authority to take emergency actions and compel certain actions in the private sector, including actions relating to cybersecurity, which can be accomplished under limited circumstances via various statutes including: the Federal Power Act, the Atomic Energy Act, the Federal Energy Administration Act, the Department of Energy Organization Act, the Defense Production Act as well as the Robert T. Stafford Disaster Relief and Emergency Assistance Act.

In addition to these authorities, the DOE National Laboratories support and promote cybersecurity throughout the government and the private sector, utilizing Cooperative Research and Development Agreements (CRADA), Strategic Partnership Projects, and the DOE Intelligence Community element's Strategic Intelligence Partnership Program.

Finally, as part of the Intelligence Community, DOE has authorities related to cybersecurity based on Executive Orders 12333 and 13587. Concerning critical infrastructure, Presidential Policy Directive-21, assigns lead responsibilities to the Department for the energy sector.

4. What is the Department's role with respect to the development of offshore wind?

Response:

<u>Background</u>

There are over 12 GW of commercial scale offshore wind deployed in the global market, all of which is bottom fixed technology. With the recent installation of the Block Island Wind Farm (RI), which has secured a long-term power purchase agreement at 22.5₵/kWh, there are now 30 MW of offshore wind deployed in the U.S. While the Block Island project is an important initial example for the U.S. offshore wind industry, it is important to note that the U.S. has over 2,000 GW of offshore wind resource potential; two times the current installed capacity of U.S. electricity generation. Our offshore resource is uniquely located near 50% of the U.S. population where 70% of our energy is consumed, potentially minimizing the need for large transmission expansion. The unique U.S. offshore wind conditions (hurricanes, deep water depths, environmental, and human use concerns) will require a portfolio of technology solutions that are not available in the global market.

<u>DOE's Unique Role</u>

Since currently deployed off-shore designs are too costly for widespread adoption in unique U.S. conditions (e.g., deeper waters, etc.) without major subsidies, DOE's role is to catalyze innovation leading to cost-competitive designs. The cost of offshore wind today is high[1], and technology innovation is critical unlocking its potential and ultimately bringing down its cost. Since 2011, DOE has made a series of investments in infrastructure, foundational offshore wind R&D, addressing market barriers, and our forthcoming offshore wind advanced technology demonstration projects[2], which will demonstrate innovative commercial scale technologies that have not been deployed today. DOE has also established the required interagency coordination for this emerging market. Moving forward, the DOE will continue to bring together industry, academia, and researchers to leverage existing industries (i.e. Oil and Gas, Maritime), and invest in the new solutions needed in offshore wind components, systems, manufacturing, supply chain and infrastructure, in order to enable U.S. competitiveness in the electric sector, and capitalize on our large resource potential. As seen in our land-based wind industry,

[1] See DOE Quadrennial Technology Review (DOE 2015), p. 121.
[2] See U.S. Offshore Wind Issue Paper developed for Agency Review Team (Transition Book 1: Corporate Overview)

a robust domestic offshore wind industry can create tens of thousands of good paying U.S. jobs.

5. Can you offer more information about the EV Everywhere Grand Challenge?

Response: The EV Everywhere Grand Challenge, announced in March 2012, set a goal to *"enable plug-in electric vehicles (PEVs) that are as affordable and convenient for the American family as gasoline-powered vehicles by 2022."*

DOE has managed an R&D portfolio of vehicle technologies, which has included electrification-related technologies for more than a decade. The EV Everywhere Grand Challenge built upon this existing and ongoing R&D work at DOE, and particularly, substantial progress that was being made to reduce the cost of battery technology.

The EV Everywhere Grand Challenge provided an overarching goal at the vehicle-level, which serves as a useful framework to communicate DOE's goals and progress that have been historically tracked as individual technologies. For example, achieving the EV Everywhere Grand Challenge's affordability goal requires reaching an advanced battery cost of $125/kWh. DOE-funded research has reduced the cost of advanced batteries from more than $1000/kWh (2008) to $245/kWh (2016), and it is on track to achieve a 2022 research goal of $125/kWh.

In addition to DOE's core R&D work, EV Everywhere added a focus on increasing consumer awareness and adoption of plug-in electric vehicles. The EV Everywhere Grand Challenge heightened the focus and visibility of plug-in electric vehicles by building partnerships with utilities and stakeholders and raising consumer and business awareness of plug-in electric vehicles. Overall, the EV Everywhere Grand Challenge supported goals to:

- Enhance energy security by reducing dependence on foreign oil;
- Improve US industry competitiveness and create jobs through American innovation;
- Reduce fuel costs for American families and businesses; and
- Reduce tailpipe emissions.

The Workplace Charging Challenge is part of the effort and aims to increase the number of workplaces that offer EV charging for their employees (the workplace is the second most common location for consumers' desire for charging after their home).

EV Everywhere also works with utilities, cities, states, and industry to understand and support recharging infrastructure needs as plug-in electric vehicle adoption grows.

The funding for EV Everywhere activities was $6 million in fiscal year 2016. Other R&D funding for batteries and other technologies will also help plug-in electric vehicles become cost-competitive with today's traditional gasoline-powered vehicles).

The following link provides more detailed information:

EV Everywhere Grand Challenge and Resources
(http://energy.gov/eere/eveverywhere/ev-everywhere-all-electric-and-plug-hybrid-electric-cars)

6. EIA is an independent agency in DOE. How has EIA ensured its independence in your data and analysis over the past 8 years? In what instances do you think EIA's independence was most challenged?

Response: EIA's role as a source of independent and impartial energy information, as provided for in the language of the DOE Organization Act, has been highly valued and is well-understood throughout the Department, the Executive Branch, and the Congress. The early leadership of the agency, including both Administrators and senior career officials, established the framework for independence in EIA's activities that the agency continues to follow. While interested parties naturally have viewpoints that they share with us and might hope would be reflected in EIA's work, the agency has not experienced any real challenges to its ability to provide impartial and independent information over the past two Administrations.

Key procedures applied to both data and analysis include the following:

- EIA testimony, data, and analyses are developed independently and are not subject to intra- or interagency clearance.
- EIA operates independently from DOE in developing and issuing press releases and *Today in Energy* stories that characterize our data and analyses.
- EIA adheres to fair release policies for both data and analysis. For analyses completed in response to Congressional committee requests, EIA provides embargoed copies to both majority and minority offices at the same time a few days prior to public release, with the understanding that the report will be immediately released if anyone characterizes, cites, or circulates an embargoed report prior to its scheduled public release by the agency.

With respect to EIA's data, EIA's Office of Survey Development and Statistical Integration is responsible for maintaining the statistical validity of EIA survey results and tabulation methodologies. SDSI reviews survey frames, statistical procedures, estimation methodologies, data protection, and publication procedures to assure that EIA data is being collected, handled, and presented in accordance with statistical standards.

For analysis products, EIA's Office of Energy Analysis protects the independence of its assumptions and analysis in several ways.

- EIA uses energy models that are documented, vetted with experts in various public meetings and conferences.
- EIA holds public workshops involving a diverse set of energy experts in their respective fields. For example, in preparation of the Annual Energy Outlook (AEO), EIA meets with experts representing the oil and gas sector, coal, nuclear, electricity, renewables, buildings, industrial, and macro economy.

- The EIA models and input files are publicly available, enabling interested parties to verify what we have done and prepare their own scenarios.

One of the greatest potential challenges to EIA's ability to provide independent and impartial information involves requests that ask EIA to address issues beyond its mandate and expertise or adopt assumptions targeted to produce a predetermined outcome. Unconditional acceptance of all assumptions, scenarios, and subject matter proposed in a request could induce significant bias in the analytic results and create the impression that EIA has reached conclusions that the agency cannot own. In such cases, EIA attempts to address the parts of the request within its expertise and mandate while seeking to maintain unbiased and robust assumptions.

Another potential challenge may arise when other entities are engaged in analyses similar to those being undertaken by EIA, and want early access to unpublished results. In order to avoid the pre-release of findings or the possibility that pressure will be applied to alter EIA's own analysis, EIA does not provide early access.

7. Part of EIA's charter is to do analyses based on Congressional and Departmental requests. Has EIA denied or not responded to any of these requests over the last ten years?

   Response: Requests for EIA analysis have varied in frequency and complexity over the past ten years. EIA has endeavored to address as many of these requests as resources have allowed.

   Many requests can be addressed using readily available data or with modest changes in EIA's model assumptions or modeling techniques. Other requests may necessitate much greater efforts in modeling or data acquisition. Some requests have been addressed in the context of a subsequent Annual Energy Outlook to allow time for expertise to be developed and models to be adapted.

8. EIA customarily has or had set dates for completions of studies and reports. In general, have those dates been adhered to?

Response: Almost all of EIA's data and analytical products are regularly published on schedule. However, some of the energy consumption surveys, which cover residential, commercial, and manufacturing energy use, have been delayed due to data quality or budgetary issues. Some longer-term analyses, including both the Annual Energy Outlook and International Energy Outlook, have been delayed for analytic reasons.

EIA does not release data or analytic reports that do not meet its quality standards.

9. In the Annual Energy Outlook 2016, EIA assumed that the Clean Power Plan should be in the reference case despite the fact that the reference case is based on existing laws and regulations. Why did EIA make that assumption, which seems to be atypical of past forecasts?

Response: As discussed in the "Legislation and Regulations[1]" section of the 2016 Annual Energy Outlook (AEO2016), the final Clean Power Plan (CPP) rule was published in October 2015, with the performance standards for existing power plants scheduled to take effect starting in 2022. However, in February 2016 the Supreme Court issued a stay on enforcement of the CPP for existing power plants pending the resolution of legal challenges. At the time the stay was issued, no lower court had considered the merits of the legal challenges to the rule, and there was no enforceable judgment either affirming or vacating the CPP.

Given this situation, EIA decided that it was appropriate to present cases with and without the CPP, and to give great prominence to the "no CPP" case. In fact, given the importance of this matter, EIA's early release of AEO2016 on May 7, 2016, deliberately considered cases both with and without the CPP, rather than presenting just one case as was typical for previous EIA early releases. This approach also provided the earliest possible response to a Congressional request for an analysis of the final CPP rule.

In previous AEO editions, EIA also needed to consider the impact of court rulings on environmental regulations that substantially affected energy markets. However, in these instances, unlike the case of the CPP, EIA had the benefit of a lower-court ruling explicitly upholding or overturning the regulation in question.

Specific results for AEO2016 cases both with and without the CPP are available at the following location:
https://www.eia.gov/outlooks/archive/aeo16/er/tables_ref.cfm

[1] http://www.eia.gov/outlooks/aeo/section_legs_regs.cfm

10. EIA's assessments of levelized costs for renewable technologies do not contain back-up costs for the fossil fuel technologies that are brought on-line to replace the generation when those technologies are down. Is this is a correct representation of the true levelized costs?

Response: EIA has long recognized that due to their unique operating characteristics electric generating plants which rely on wind and solar resources cannot be thought of as having a comparable value to the grid as generators that typically serve base-load, load-following, or peaking duty cycles. Generating technologies such as coal-fired steam or nuclear steam plants, combined cycle plants, and simple cycle combustion turbines or internal combustion engines provide both energy and capacity services to meet daily and seasonal fluctuations in demand.

Wind and solar plants provide minimal contribution to system capacity needs and only provide energy based on resource availability (i.e. under windy or sunny conditions), rather than on customer demand. Because these characteristics manifest themselves generally in terms of system value rather than technology cost, in 2014 EIA began publishing the levelized avoided cost of electricity (LACE) alongside its estimates of levelized cost of electricity (LCOE) so that users can compare the cost of a new electric generating resource against the value that it provides to the system. The value provided to the system includes both time-of-day/seasonal energy value and value (or lack-thereof) of meeting system reserve requirements. We have determined that this approach more accurately represents the economic trade-offs for each generating resource rather than trying to represent these value differences as simply the differences between the cost of different technologies. EIA has undertaken considerable effort to emphasize the importance of this concept in its public presentations and on its website. In particular, a report entitled *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2016* is available at http://www.eia.gov/outlooks/aeo/electricity_generation.cfm

There are two general types of reliability reserves that are typically discussed in the context of wind and solar generating capacity: planning reserves and operating reserves. Planning reserves are usually measured in terms of a reserve margin or the fraction of installed capacity in excess of expected peak demand. Extensive literature from a variety of technical experts in grid reliability confirm that while wind and solar may not significantly contribute to planning reserve capacity, they do not have a "negative" contribution that would, all else being equal, require additional "firm" capacity additions to maintain adequate reserve margins.

Operating reserves are usually subdivided into "spinning", "non-spinning" and other very specific duties or ancillary services. Capital investment is not typically required for operating reserves, since the planning reserve calculation ensures sufficient installed capacity to meet system needs. Spinning reserves are typically provided by operating some amount of capacity at partial loading, so that it can quickly respond to dispatcher commands for more (or less) output in the event of an unexpected change in system operating conditions. Non-dispatchable generation such as wind or solar may have some impact on operating reserve requirements, although these are typically determined by the largest single-point failure contingency on the grid, such as the sudden loss of the largest operating generator or a key transmission corridor. Renewable resources such as wind and solar are fundamentally dispersed in nature and vary in output in a manner that is both gradual and predictable over the operational time-frame of interest (sub-hourly). Therefore, any given unit or plant (or collection of plants) is unlikely to determine the spinning reserve requirement for a balancing authority.

11. Has EIA done analysis that shows that additional back-up generation is not needed? How does EIA's analysis compare with other analyses on this issue?

Response: EIA has done limited original analysis of the contribution of wind and solar to reliability reserves, as it is not funded or staffed to conduct technical, engineering assessments of grid operations. Rather, EIA has relied on the literature in the field to inform its modeling approach. The original work performed by EIA in this area is generally documented in the Renewable Fuels Module[1] documentation to the National Energy Modeling System (NEMS).

While much of this work was conducted over 10 years ago, subsequent literature published on this topic generally supports the approach used in NEMS of setting reserve margin requirements and de-rating the contribution of wind and solar capacity towards meeting these requirements based on the operating characteristics of the resources and the grid within each region. Most current electricity markets or grid operators have the general design of dispatching for energy, with a separate market (or requirement) to ensure reliability. While each market or operator has their own approach to evaluating the contribution of wind and solar to system reliability, the requirements are to ensure system reliability to meet demand, not to ensure the reliability of any individual generator (renewable or conventional).

EIA is not aware of any current or proposed system in the U.S. that has a requirement for additional capacity to be added in conjunction with or as a "back-up" to wind or solar plants, and the literature does not support the need for such a requirement, as long as system reliability needs are communicated to market entrants and reliability contributions are properly accounted for by system operators.

---

[1] http://www.eia.gov/outlooks/aeo/nems/documentation/index.cfm

12. Renewable and solar technologies are expected to need additional transmission costs above what fossil technologies need. How has EIA represented this in the AEO forecasts? What is the magnitude of those transmission costs?

Response: EIA has long represented costs above system average costs to access the overwhelming majority of wind resources in the United States. Specifically, EIA represents a stylized "wind supply curve" for each region of the country to reflect the quality of the available wind resource, using a cost multiplier of 1, 1.1, 1.25, 1.5, and 2 times the base cost for a wind generator. While these cost multipliers are assumed to represent a variety of additional costs associated with accessing the very geographically constrained wind resources, the primary factor contributing to them is the need for additional transmission.

In the AEO2016, we find marginal wind resources in several regions being supplied from the 1.1 multiplier or higher step, even for near-term builds. This represents about a $170/kW addition to the cost for a wind resource operating at the 1.1 multiplier step. While plenty of wind resource is still available close to transmission and accessible to load, accessing the best wind resources may require significant new spur-line or backbone transmission investment. Looking at the recent build-out of wind in the United States, EIA does see evidence of both of these factors. Some analysts have estimated typical spur-line distances of new wind at around 10 miles, and states such as Texas, Minnesota, and California have all considered and/or implemented broad transmission upgrades specifically to accommodate wind resources.

EIA does not currently represent additional transmission costs to access solar resources. While solar resource quality varies both across and within regions, it is not fundamentally constrained to a limited geography, and retains substantial flexibility for even relatively high-quality resources to be sited close to transmission and close to demand. In some cases, remote desert sites are economically attractive to build solar plants because the additional transmission expense is more than offset by low land costs and the ability to build at-scale. However, numerous solar installations are built in locations with easy access to transmission, and a substantial fraction of installed solar capacity has been built directly at demand centers (that is, on customer roof-tops or adjacent property). While much of the roof-top solar market may be supported by favorable utility rate structures, there is little evidence that utility solar installations have been or will be substantially constrained by access to transmission.

13. There are studies that show that your high resource and technology case for oil and gas represents the shale gas and oil renaissance far better than your reference case. Why has EIA not put those assumptions in your reference case?

Response: Production paths are dependent on a host of assumptions including oil and gas prices, demand, cost, drilling activity levels, technology progress, and other economic factors. For example, recent changes in price have fundamentally altered assumptions of expected drilling and production rates into the future.

EIA generally updates its resources and technology assumptions for all of its cases as new information becomes available. EIA's Reference case evolves each year and the current Reference case assumptions have been significantly influenced by the rapid growth in production due to technology and resource developments over the past several years that were reflected in high resource and technology cases in earlier editions of the *Annual Energy Outlook* (AEO). The current Reference case envisions significantly higher production than those published when EIA first introduced alternative resource and technology cases into the AEO.

The AEO 2016 Reference case projections of oil and natural gas production are consistent with private sector forecasts such as IHS Energy, Energy Ventures Analysis (EVA), ICF, BP, and ExxonMobil (AEO2016 pages CP-10 – CP-13).

The high resource/technology case continues to play an important role in EIA's AEO by explicitly recognizing that estimates of shale gas and tight oil resources vary widely and change over time as new information is gained through drilling, production, and technology experimentation. Additionally, technological improvements and innovations may allow development of unidentified crude oil and natural gas resources beyond those included in the Reference case.

While EIA's Reference cases from 5 to 10 years ago do not represent the extent of the recent revolution in shale gas and tight oil, EIA has a good track record of recognizing the potential for significant production from new types of oil and natural gas resources. Notably, EIA takes the initiative to step beyond USGS resource assessments when we felt that they were too low, as in the case of the Marcellus shale several years ago. EIA was also among the first to highlight to potential of tight oil plays such as the Bakken – see for example *Technology-Based Oil and Natural Gas Plays: Shale Shock! Could There Be Billions in the Bakken?* published in 2006 and available at: https://www.eia.gov/pub/oil_gas/natural_gas/feature_articles/2006/ngshock/ngshock.pdf

14. Can you describe the number of personnel hired into management positions at EIA from outside EIA and compare it to the number of personnel hired into management positions at EIA who were currently serving at EIA?

Response: EIA's on-board career management team (not including the Presidentially-appointed and Senate-confirmed Administrator) consists of 54 individuals serving in the following roles: Deputy Administrator, Assistant Administrator, Office Director, and Team Leader. Nineteen of these 54 people were hired from outside EIA and 35 were already serving at EIA when hired into their present positions. There are currently 9 management vacancies.

15. How does EIA ensure quality in its data and analyses?

Response: EIA uses best practices at every stage of the production cycle to ensure high quality data are produced and published. Newly proposed surveys (and changes to existing ones) are cognitively tested with selected respondents to confirm understanding of the questions and availability of data. Once finalized, EIA obtains survey clearance from the Office of Information and Regulatory Affairs (OIRA) no less frequently than every three years. As part of this clearance, EIA explains the value of the information to stakeholders, specifies the collection methods and any relevant sampling or estimation techniques, and estimates the burden on respondents. EIA's experience is that oversight by OIRA relates exclusively that agency's responsibility to assure that government surveys are in the public interest and do not impose too large a burden on respondents rather than any policy issues.

Once cleared and deployed, EIA applies data quality checks through every step of the cycle from initial submission through publication. Many EIA data collection systems apply checks which encourage corrections before respondents submit data. If data passes these initial edit checks, the submitted data are reviewed for outliers and for trends and totals that differ from expected values. Respondents may be contacted and asked to verify data that appears to be anomalous. Finally, draft publications and data files are reviewed before release to the public.

Prior to publication, business-sensitive data are checked for compliance with non-disclosure algorithms, and where necessary, sensitive or protected data values are suppressed. Data are published with estimates of statistical quality (relative standard errors, coefficients of variation) to provide users with objective quality measures.

With respect to maintaining the quality of EIA's analysis, the Office of Energy Analysis employs several strategies:

- EIA regularly meets with its stakeholders. It holds public workshops to discuss assumptions and modeling methodologies and posts the results of these meetings to the EIA website.
- It documents its models and makes the documentation and models available to the public.
- EIA procures expert information from competitively sourced experts as input to both its modeling assumption and modeling methodologies.
- It promotes transparency by publishing all of the results of its analysis and associated model assumptions and code to its website, creating tools to summarize easily the content of large amounts of data.
- EIA holds internal review meetings for all of its analytic reports.

- It participates in fora, such as the Energy Modeling Forum, International Energy Workshop, and International Association of Energy Economists on a regular basis, making presentations to highlight EIA's analysis.
- Quality assurance staff verify that the information that is published in EIA reports is consistent with the underlying analytic model results and data.

EIA conducts an annual customer feedback survey to gauge customer satisfaction with EIA data and products. In the most recent survey, 90% of respondents reported they were either very satisfied or satisfied with the quality of EIA information.

16. Where does EIA think most improvement is needed in its data and analyses?

Response: The most challenging areas for EIA moving forward are modernization of EIA's data systems to modern software platforms and the development of EIA's tools to analyze energy developments in key world regions that directly affect U.S. energy markets.

EIA is modernizing its data collection systems by standardizing business processes, employing common, maintainable IT systems and platforms, and incorporating smarter ways of using third-party data. In this way, EIA can better fulfill its role as the nation's provider of energy information while also serving as a model of operational efficiency. EIA is also working to make its data more relevant and timely by exploring near real-time information opportunities and bringing that information to the public. As energy markets continue to change rapidly, EIA is increasing its outreach to stakeholders and customers to ensure that the information portfolio is as relevant and useful as possible.

The Office of Energy Analysis (OEA) believes that EIA can best improve its analysis by focusing on four areas:

- By developing and expanding its *international* energy analysis knowledge, tools, and products. It can do this through enhancing its international data analysis activities to improve the international data system portal and the information derived from it for use in the International Energy Outlook (IEO) and World Energy Projection System. In addition, it should continue to develop new international energy modules to support international energy analysis. The module representing the transportation sector was completed and used for the last IEO. OEA is currently working on a global hydrocarbon supply module and an international electricity module. These projects are extremely important; however, they have been delayed somewhat due to competing demand for limited resources.
- By increasing the output of timely, policy-relevant *analyses* of domestic and international energy markets, staying ahead of emerging issues.
- By improving the *usability* of systems and tools to more *efficiently* enable staff and *reduce* barriers to performance for new hires. One such way would be to invest in NEMS automation efforts to reduce analyst resource commitment to repetitive tasks, such as benchmarking, data updates, etc. Another example would be the move to more current software platforms, such as Python and AIMMS, with which recent graduates are more familiar and are easier to maintain.

  By providing more analysis of current energy issues. A good example of this kind of analysis is the Drilling Productivity Report that provides near-term insights into production from new wells, the status of drilled but uncompleted wells, and other related factors reflecting very recent events that affect markets but for which historical EIA data has not yet been collected or processed.

17. We note that EIA added distributed solar estimations to your electricity data reports. Those numbers are not part of your supply/demand balance on a Btu basis. Why has that not been updated accordingly?

Response: EIA first introduced its distributed solar estimates in the November 2015 issue of the Electric Power Monthly (containing data for September 2015). EIA began publishing total consumption data series that include the distributed solar estimates in August 2016. Currently, the *Monthly Energy Review* incorporates tables showing renewable energy totals with utility scale and distributed solar energy components (Table 10.1, total renewable energy production and consumption; and Table 10.5, solar energy consumption). These renewable components are also included in the total energy tables (Table 1.1, Primary Energy Overview; Table 1.3, Primary Energy Consumption by Source). It should also be noted that for many years distributed solar has been included as a part of total energy reported for both historical and projection years in the *Annual Energy Outlook.*

18. How many vacancies does EIA have in management and staff positions? What plans, if any, does EIA have to fill those positions before January 20?

Response: EIA currently has 47 total vacancies; 9 of these are management and 38 are staff positions. DOE's centralization of all Human Capital support functions over the past year has introduced new challenges to an already time-consuming hiring process. EIA has a strategy for all of these vacancies and is in the final stages of hiring for 11 of the highest-priority positions (4 management and 7 staff positions). EIA is seeking to fill these positions as expeditiously as possible.

19. Is the EIA budget sufficient to ensure quality in data and analyses? If not, where does it fall short?

Response: At the FY2016 appropriation level of $122 million, EIA was able to ensure the quality of its *current* data and analyses, but could not keep up with all of the key changes in energy markets. The FY2017 request of $131 million would allow the agency to better address energy market developments. Because energy markets are very dynamic, maintaining a high quality energy information program requires EIA to constantly assess and upgrade its data coverage, analysis tools and products, and information dissemination programs to ensure that the agency's diverse user groups are provided a full range of accurate, timely, energy data and thoughtful analysis. Budget requirements are expected to increase commensurate with the complexity and diversity of evolving needs.

With the full FY2017 request of $131 million, EIA plans to address known issues and gaps that exist in its current energy data and analysis programs. Priority areas for attention include: providing detailed petroleum data and analysis for U.S. regional areas smaller than the five large Petroleum Administration for Defense Districts (PADDs) that provide our current regionalization framework; enhancing commercial building energy efficiency data, collecting transportation energy consumption data, expanding international analysis with a focus on North America and key economies in Asia to gain deeper insight into their interaction with and effects on U.S. energy markets, and validating EIA estimates of household electricity use shares by purpose.

20. Does EIA have cost comparisons of sources of electricity generation at the national level?

Response: EIA publishes a number of annual reports that address the cost-competitiveness of different sources of electricity generation, at both the regional and national level. For historical data, the Electric Power Annual[1] includes data reported to the Federal Energy Regulatory Commission on the fuel and operating cost of nuclear, fossil steam, hydroelectric, and combustion turbine plants.

EIA also publishes input assumptions to the Annual Energy Outlook along with our current estimates for the capital and operations and maintenance (O&M) cost of new capacity for different types of generating resources. The resources considered include nuclear, coal, combined cycle natural gas, simple cycle natural gas, wind, photovoltaic, hydroelectric, and other technologies. The most recent input assumptions are summarized in the Assumptions to the Annual Energy Outlook and presented in the report *Cost and Performance Characteristics of New Generating Technologies, Annual Energy Outlook 2016* at the following location: http://www.eia.gov/outlooks/aeo/assumptions/pdf/table_8.2.pdf

Finally, EIA also publishes a report on the levelized cost of electricity (LCOE) and levelized avoided cost of electricity (LACE) for new electric generating resources as estimated in the Annual Energy Outlook. Because different technologies tend to serve different purposes and operate with different duty cycles, EIA does not believe that this LCOE/LACE report should be used to directly compare the cost of one technology against another, but rather to compare the cost of any given technology (as measured by LCOE) to its own value (as measured by LACE). For example, it is not appropriate to compare the cost of generation from a new nuclear plant to the cost of generation from a combustion turbine, since the former would generally provide baseload power and the latter would generally be built to provide peaking power or reliability services. Similarly, wind or solar do not generally provide significant capacity services to the grid, are not readily characterized as either “baseload”, “load following”, or “peaker” plants, and thus cannot be directly compared with plants that provide those services. These technologies are more accurately compared with the time-of-day/seasonal value of energy and limited capacity services that they actually do provide. The most recent *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2016* report is posted at: http://www.eia.gov/outlooks/aeo/electricity_generation.cfm

[1] https://www.eia.gov/electricity/annual/pdf/epa.pdf

In presenting the values for LCOE and LACE, the report also distinguishes between generating technologies that are dispatchable and those that are non-dispatchable.

21. What is the plan for funding cleanup of Portsmouth and Paducah when the current uranium inventory designated for barter in exchange for cleanup services, is no longer available (excluding reinstating the UED&D fee on commercial nuclear industry or utilizing the USEC fund)?

Response: Once barter is no longer available and if there is no fee assessed on the commercial nuclear industry and the USEC Fund is not available, cleanup of Portsmouth and Paducah (UED&D) would need to be funded through direct appropriations out of the general Treasury. The UED&D Fund has a balance of $2.5 Billion (B) (as of the end of FY 2016) and we have projected that it would be exhausted by 2022. This would leave us $19.2B short to fund the full estimated cost of cleanup. Absent reauthorization of the Fund, completion of UED&D would then need to be derived from direct appropriations.[1]

BACKGROUND

The Department is simultaneously working off the overall cleanup liability at all the GDPs in parallel; full-scale Decontamination & Decommissioning (D&D) of the Gaseous Diffusion Plant (GDP) facilities will generally occur in the following sequence if funding is available:

- East Tennessee Technology Park (ETTP) D&D started in 1994 and is estimated to be completed no later than 2024;
- Portsmouth D&D started in 2009 and is projected to be completed by FY 2044;
- Paducah stabilization and deactivation has begun and D&D will follow, consistent with site priorities. The current estimated date for completion is FY 2040. (Paducah was returned to the Department from USEC in 2014.)

An unresolved issue is how to fund the remaining D&D of the Gaseous Diffusion Plants (GDPs) at Oak Ridge, Portsmouth, and Paducah, recognizing that each of the three GDPs is at a different phase of D&D and recognizing the UED&D Fund established by Energy Policy Act of 1992 (EPACT) to fund GDP D&D is only expected to cover about half of the estimated cost of cleanup.[2] Appropriations for cleanup at Portsmouth have been supplemented by barter of DOE's inventory of natural uranium, which has declined in value by a factor of two (2) over the last year, and based on amounts bartered annually is estimated to be exhausted in the 2018 timeframe. According to the most recent Report to Congress on the UED&D Fund, the estimated to-go costs are about $1.4B at ETTP; $11.1B to $11.9B at Portsmouth; and from $9.5B to $10.5B at Paducah.

---

[1] UE Decontamination and Decommissioning Report to Congress, February 2016.

[2] The shortfall occurred because the estimated cleanup cost increased, the Fund accrued less interest because of lower-than-expected interest rates, and the projected investment period was shortened because of earlier-than-expected shutdown.

History of Funding

The cleanup of the former GDPs is funded by non-defense funds in a standalone appropriation account, which is separate from the Department's other appropriations for cleanup activities. The funds are appropriated out of the UED&D Fund, which was established by EPACT. From 1992 to 2007 EPACT authorized deposit into the Fund of a specific amount of funds, which were derived from collections from domestic industry and transfer of Congressional appropriations into the Fund (annual appropriations out of the Fund are not affected by the expiration of the authority to collect industry contributions or transfer Congressional appropriations). As mentioned in the UED&D transition paper, attempts to reauthorize collections from industry, with or without renewed Government contributions, have been proposed in multiple Budget Requests since 2007, but those proposals have not been supported by Congress.

22. What is the right funding level for EM to make meaningful progress across the complex and meet milestone and regulatory requirements?

Response: In FY 2017, EM requires $7.9 Billion in order to meet its enforceable cleanup milestones.

BACKGROUND

- Executive Order 12088 requires DOE to request of OMB sufficient funds to meet all enforceable cleanup milestones. 12088 compliance includes activities that are necessary to comply with any legally-enforceable requirement for which DOE is directly responsible and that is established by a federal or state environmental statute, regulation, or permit; a court order; an administrative consent order; Records of Decision; Action memoranda, or any other form of enforceable cleanup agreement, including settlement agreements.
- Currently, DOE's cleanup mission is governed by approximately 40 cleanup agreements which collectively impose approximately 60-200 enforceable milestones a year across the complex. These agreements establish the mechanisms and timelines for bringing a site into compliance with applicable environmental laws. They also potentially subject DOE to substantial fines and other penalties for each milestone that DOE fails to meet.
- Enforceable milestones take various forms, such as removing the radioactive and hazardous wastes from underground storage tanks, decontaminating and decommissioning old production facilities, and submitting cleanup plans and reports to regulators.
- Budget levels provided for FY 2017 can affect out-year milestones. Consequently, inadequate funding for specific activities in FY 2017 will have impacts on subsequent activities which, in turn, affect DOE's ability to meet enforceable agreement milestones.
  While not strictly governed by Executive Order 12088, additional requirements drive the need to fund other critical activities. Examples of other drivers include DOE Orders for Nuclear Safety or radioactive waste handling and Defense Nuclear Facility Safety Board recommendations.

23. What is the greatest opportunity for reduction in life cycle cost/return on investment?

Response:

- With a current EM to-go cost estimated at $212.7 billion through 2075, it is important that EM pursue opportunities to reduce life-cycle costs.(b)(5)
  (b) (5)

- One example of how acceleration of cleanup can reduce life cycle costs is the cleanup underway at the East Tennessee Technology Park (ETTP), where the last process building (K-27) was demolished this year, under cost and ahead of schedule.
  (b) (5)

- An example of how accelerating the cleanup of an entire site reduced the life cycle costs was the closure of the Rocky Flats Site in 2006. What was once estimated as a $37 billion cleanup over 70 years was completed in six years, at a cost of $7 billion.
  (b) (5)

There are also other actions EM pursues to reduce life cycle costs, among them, development and application of new cleanup technologies.

24. Describe your alternatives to the ever increasing WTP cost and schedule, whether technical or programmatic?

Response:

- (b) (5)

- A number of alternatives exist that could provide for other treatment approaches for the low-activity waste portion of the Hanford tank waste mission to help supplement the capabilities of WTP. These alternatives are identified and their potential environmental impacts analyzed in the *Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland Washington* (DOE/EIS-0391). (b) (5)

  (b) (5)

- The Tri-Party Agreement among the State of Washington, the U.S. Environmental Protection Agency, and DOE that governs the cleanup at Hanford includes milestones for DOE to establish and implement a to-be-determined technical approach for Supplemental LAW[1], assuming a new facility will be needed to optimize the throughput to the HLW facility. (b) (5)

  (b) (5)

---

[1] A supplementary LAW capability will be needed to complete the tank waste treatment mission. The Tri-Party Agreement requires the Department to propose a supplemental immobilization technology if it intends to pursue an alternative other than a second LAW (vitrification) facility.

(b) (5)

- (b) (5)
- (b) (5)

25. With respect to EM, what program milestones will be reached in each of the next four years?

Response: EM will establish its overarching programmatic milestones for a 5-year planning horizon over the next 90 days, informed by the FY-2018 budget request and the 5-Year Budget Planning Process underway in EM. For the last two years, EM has implemented a rigorous 5-Year Planning process that includes input from all of the field offices and sites, with analysis and verification by EM. The effort is aimed at developing budgets that enable meaningful and reasonable progress in cleanup, based on regulatory milestones, as well as other considerations such as protection and disposition of fissile materials under EM's stewardship. (b) (5)
(b) (5)

Attachment

(b) (5)

(b) (5)

(b) (5)

(b) (5)

(b) (5)

26. Are there plans to add staff to EM? What are your staffing priorities?

Response:

- (b) (5)

- (b) (5)

28. Did DOE or any of its contractors run the integrated assessment models (IAMs)? Did DOE pick the discount rates to be used with the IAMs? What was DOE's opinion on the proper discount rates used with the IAMs? What was DOE's opinion on the proper equilibrium climate sensitivity?

Response: Neither DOE nor its contractors ran the integrated assessment models. DOE did not pick the discount rates to be used with IAMS; rather, the discount rates were determined by a White House-led Interagency Working Group and were based on the range of discount rates in the expert literature. Detailed information on the process is included in the attached 2016 Social Coast of Carbon Technical Support Documentation. Similarly, the equilibrium climate sensitivity used by the working group is based on the expert literature. Detailed information on the equilibrium climate sensitivity that the Interagency Working Group is using is discussed in the attached 2010 Technical Support Documentation.

Technical Support Document: -
Social Cost of Carbon for Regulatory Impact Analysis -
Under Executive Order 12866 -

Interagency Working Group on Social Cost of Carbon, United States Government

With participation by

Council of Economic Advisers
Council on Environmental Quality
Department of Agriculture
Department of Commerce
Department of Energy
Department of Transportation
Environmental Protection Agency
National Economic Council
Office of Energy and Climate Change
Office of Management and Budget
Office of Science and Technology Policy
Department of the Treasury

February 2010

Executive Summary

Under Executive Order 12866, agencies are required, to the extent permitted by law, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the "social cost of carbon" (SCC) estimates presented here is to allow agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions. The estimates are presented with an acknowledgement of the many uncertainties involved and with a clear understanding that they should be updated over time to reflect increasing knowledge of the science and economics of climate impacts.

The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change.

This document presents a summary of the interagency process that developed these SCC estimates. Technical experts from numerous agencies met on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key model inputs and assumptions. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions grounded in the existing scientific and economic literatures. In this way, key uncertainties and model differences transparently and consistently inform the range of SCC estimates used in the rulemaking process.

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC from three integrated assessment models, at discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th percentile SCC estimate across all three models at a 3 percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution.

Social Cost of CO_2, 2010 – 2050 (in 2007 dollars)

Discount Rate Year	5% Avg	3% Avg	2.5% Avg	3% 95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

I. Monetizing Carbon Dioxide Emissions

The "social cost of carbon" (SCC) is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services. We report estimates of the social cost of carbon in dollars per metric ton of carbon dioxide throughout this document.[1]

When attempting to assess the incremental economic impacts of carbon dioxide emissions, the analyst faces a number of serious challenges. A recent report from the National Academies of Science (NRC 2009) points out that any assessment will suffer from uncertainty, speculation, and lack of information about (1) future emissions of greenhouse gases, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages. As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional.

Despite the serious limits of both quantification and monetization, SCC estimates can be useful in estimating the social benefits of reducing carbon dioxide emissions. Under Executive Order 12866, agencies are required, to the extent permitted by law, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the SCC estimates presented here is to make it possible for agencies to incorporate the social benefits from reducing carbon dioxide emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions. Most federal regulatory actions can be expected to have marginal impacts on global emissions.

For such policies, the benefits from reduced (or costs from increased) emissions in any future year can be estimated by multiplying the change in emissions in that year by the SCC value appropriate for that year. The net present value of the benefits can then be calculated by multiplying each of these future benefits by an appropriate discount factor and summing across all affected years. This approach assumes that the marginal damages from increased emissions are constant for small departures from the baseline emissions path, an approximation that is reasonable for policies that have effects on emissions that are small relative to cumulative global carbon dioxide emissions. For policies that have a large (non-marginal) impact on global cumulative emissions, there is a separate question of whether the SCC is an appropriate tool for calculating the benefits of reduced emissions; we do not attempt to answer that question here.

An interagency group convened on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key inputs and assumptions in order to generate SCC estimates. Agencies that actively participated in the interagency process include the Environmental Protection

[1] In this document, we present all values of the SCC as the cost per metric ton of CO_2 emissions. Alternatively, one could report the SCC as the cost per metric ton of carbon emissions. The multiplier for translating between mass of CO_2 and the mass of carbon is 3.67 (the molecular weight of CO_2 divided by the molecular weight of carbon = 44/12 = 3.67).

Agency, and the Departments of Agriculture, Commerce, Energy, Transportation, and Treasury. This process was convened by the Council of Economic Advisers and the Office of Management and Budget, with active participation and regular input from the Council on Environmental Quality, National Economic Council, Office of Energy and Climate Change, and Office of Science and Technology Policy. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions that are grounded in the existing literature. In this way, key uncertainties and model differences can more transparently and consistently inform the range of SCC estimates used in the rulemaking process.

The interagency group selected four SCC estimates for use in regulatory analyses. For 2010, these estimates are $5, $21, $35, and $65 (in 2007 dollars). The first three estimates are based on the average SCC across models and socio-economic and emissions scenarios at the 5, 3, and 2.5 percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95^{th} percentile at a 3 percent discount rate. The central value is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. These SCC estimates also grow over time. For instance, the central value increases to $24 per ton of CO_2 in 2015 and $26 per ton of CO_2 in 2020. See Appendix A for the full range of annual SCC estimates from 2010 to 2050.

It is important to emphasize that the interagency process is committed to updating these estimates as the science and economic understanding of climate change and its impacts on society improves over time. Specifically, we have set a preliminary goal of revisiting the SCC values within two years or at such time as substantially updated models become available, and to continue to support research in this area. In the meantime, we will continue to explore the issues raised in this document and consider public comments as part of the ongoing interagency process.

II. Social Cost of Carbon Values Used in Past Regulatory Analyses

To date, economic analyses for Federal regulations have used a wide range of values to estimate the benefits associated with reducing carbon dioxide emissions. In the final model year 2011 CAFE rule, the Department of Transportation (DOT) used both a "domestic" SCC value of $2 per ton of CO_2 and a "global" SCC value of $33 per ton of CO_2 for 2007 emission reductions (in 2007 dollars), increasing both values at 2.4 percent per year. It also included a sensitivity analysis at $80 per ton of CO_2. A domestic SCC value is meant to reflect the value of damages in the United States resulting from a unit change in carbon dioxide emissions, while a global SCC value is meant to reflect the value of damages worldwide.

A 2008 regulation proposed by DOT assumed a domestic SCC value of $7 per ton CO_2 (in 2006 dollars) for 2011 emission reductions (with a range of $0-$14 for sensitivity analysis), also increasing at 2.4 percent per year. A regulation finalized by DOE in October of 2008 used a domestic SCC range of $0 to $20 per ton CO_2 for 2007 emission reductions (in 2007 dollars). In addition, EPA's 2008 Advance Notice of Proposed Rulemaking for Greenhouse Gases identified what it described as "very preliminary" SCC estimates subject to revision. EPA's global mean values were $68 and $40 per ton CO_2 for discount rates of approximately 2 percent and 3 percent, respectively (in 2006 dollars for 2007 emissions).

In 2009, an interagency process was initiated to offer a preliminary assessment of how best to quantify the benefits from reducing carbon dioxide emissions. To ensure consistency in how benefits are evaluated across agencies, the Administration sought to develop a transparent and defensible method, specifically designed for the rulemaking process, to quantify avoided climate change damages from reduced CO_2 emissions. The interagency group did not undertake any original analysis. Instead, it combined SCC estimates from the existing literature to use as interim values until a more comprehensive analysis could be conducted.

The outcome of the preliminary assessment by the interagency group was a set of five interim values: global SCC estimates for 2007 (in 2006 dollars) of \$55, \$33, \$19, \$10, and \$5 per ton of CO_2. The \$33 and \$5 values represented model-weighted means of the published estimates produced from the most recently available versions of three integrated assessment models—DICE, PAGE, and FUND—at approximately 3 and 5 percent discount rates. The \$55 and \$10 values were derived by adjusting the published estimates for uncertainty in the discount rate (using factors developed by Newell and Pizer (2003)) at 3 and 5 percent discount rates, respectively. The \$19 value was chosen as a central value between the \$5 and \$33 per ton estimates. All of these values were assumed to increase at 3 percent annually to represent growth in incremental damages over time as the magnitude of climate change increases.

These interim values represent the first sustained interagency effort within the U.S. government to develop an SCC for use in regulatory analysis. The results of this preliminary effort were presented in several proposed and final rules and were offered for public comment in connection with proposed rules, including the joint EPA-DOT fuel economy and CO_2 tailpipe emission proposed rules.

III. Approach and Key Assumptions

Since the release of the interim values, interagency group has reconvened on a regular basis to generate improved SCC estimates. Specifically, the group has considered public comments and further explored the technical literature in relevant fields. This section details the several choices and assumptions that underlie the resulting estimates of the SCC.

It is important to recognize that a number of key uncertainties remain, and that current SCC estimates should be treated as provisional and revisable since they will evolve with improved scientific and economic understanding. The interagency group also recognizes that the existing models are imperfect and incomplete. The National Academy of Science (2009) points out that there is tension between the goal of producing quantified estimates of the economic damages from an incremental ton of carbon and the limits of existing efforts to model these effects. Throughout this document, we highlight a number of concerns and problems that should be addressed by the research community, including research programs housed in many of the agencies participating in the interagency process to estimate the SCC.

The U.S. Government will periodically review and reconsider estimates of the SCC used for cost-benefit analyses to reflect increasing knowledge of the science and economics of climate impacts, as well as improvements in modeling. In this context, statements recognizing the limitations of the analysis and calling for further research take on exceptional significance. The interagency group offers the new SCC values with all due humility about the uncertainties embedded in them and with a sincere promise to continue work to improve them.

A. Integrated Assessment Models

We rely on three integrated assessment models (IAMs) commonly used to estimate the SCC: the FUND, DICE, and PAGE models.[2] These models are frequently cited in the peer-reviewed literature and used in the IPCC assessment. Each model is given equal weight in the SCC values developed through this process, bearing in mind their different limitations (discussed below).

These models are useful because they combine climate processes, economic growth, and feedbacks between the climate and the global economy into a single modeling framework. At the same time, they gain this advantage at the expense of a more detailed representation of the underlying climatic and economic systems. DICE, PAGE, and FUND all take stylized, reduced-form approaches (see NRC 2009 for a more detailed discussion; see Nordhaus 2008 on the possible advantages of this approach). Other IAMs may better reflect the complexity of the science in their modeling frameworks but do not link physical impacts to economic damages. There is currently a limited amount of research linking climate impacts to economic damages, which makes this exercise even more difficult. Underlying the three IAMs selected for this exercise are a number of simplifying assumptions and judgments reflecting the various modelers' best attempts to synthesize the available scientific and economic research characterizing these relationships.

The three IAMs translate emissions into changes in atmospheric greenhouse concentrations, atmospheric concentrations into changes in temperature, and changes in temperature into economic damages. The emissions projections used in the models are based on specified socio-economic (GDP and population) pathways. These emissions are translated into concentrations using the carbon cycle built into each model, and concentrations are translated into warming based on each model's simplified representation of the climate and a key parameter, climate sensitivity. Each model uses a different approach to translate warming into damages. Finally, transforming the stream of economic damages over time into a single value requires judgments about how to discount them.

Each model takes a slightly different approach to model how changes in emissions result in changes in economic damages. In PAGE, for example, the consumption-equivalent damages in each period are calculated as a fraction of GDP, depending on the temperature in that period relative to the pre-industrial average temperature in each region. In FUND, damages in each period also depend on the rate of temperature change from the prior period. In DICE, temperature affects both consumption and investment. We describe each model in greater detail here. In a later section, we discuss key gaps in how the models account for various scientific and economic processes (e.g. the probability of catastrophe, and the ability to adapt to climate change and the physical changes it causes).

---

[2] The DICE (Dynamic Integrated Climate and Economy) model by William Nordhaus evolved from a series of energy models and was first presented in 1990 (Nordhaus and Boyer 2000, Nordhaus 2008). The PAGE (Policy Analysis of the Greenhouse Effect) model was developed by Chris Hope in 1991 for use by European decision-makers in assessing the marginal impact of carbon emissions (Hope 2006, Hope 2008). The FUND (Climate Framework for Uncertainty, Negotiation, and Distribution) model, developed by Richard Tol in the early 1990s, originally to study international capital transfers in climate policy. is now widely used to study climate impacts (e.g., Tol 2002a, Tol 2002b, Anthoff et al. 2009, Tol 2009).

The parameters and assumptions embedded in the three models vary widely. A key objective of the interagency process was to enable a consistent exploration of the three models while respecting the different approaches to quantifying damages taken by the key modelers in the field. An extensive review of the literature was conducted to select three sets of input parameters for these models: climate sensitivity, socio-economic and emissions trajectories, and discount rates. A probability distribution for climate sensitivity was specified as an input into all three models. In addition, the interagency group used a range of scenarios for the socio-economic parameters and a range of values for the discount rate. All other model features were left unchanged, relying on the model developers' best estimates and judgments. In DICE, these parameters are handled deterministically and represented by fixed constants; in PAGE, most parameters are represented by probability distributions. FUND was also run in a mode in which parameters were treated probabilistically.

The sensitivity of the results to other aspects of the models (e.g. the carbon cycle or damage function) is also important to explore in the context of future revisions to the SCC but has not been incorporated into these estimates. Areas for future research are highlighted at the end of this document.

The DICE Model

The DICE model is an optimal growth model based on a global production function with an extra stock variable (atmospheric carbon dioxide concentrations). Emission reductions are treated as analogous to investment in "natural capital." By investing in natural capital today through reductions in emissions—implying reduced consumption—harmful effects of climate change can be avoided and future consumption thereby increased.

For purposes of estimating the SCC, carbon dioxide emissions are a function of global GDP and the carbon intensity of economic output, with the latter declining over time due to technological progress. The DICE damage function links global average temperature to the overall impact on the world economy. It varies quadratically with temperature change to capture the more rapid increase in damages expected to occur under more extreme climate change, and is calibrated to include the effects of warming on the production of market and nonmarket goods and services. It incorporates impacts on agriculture, coastal areas (due to sea level rise), "other vulnerable market sectors" (based primarily on changes in energy use), human health (based on climate-related diseases, such as malaria and dengue fever, and pollution), non-market amenities (based on outdoor recreation), and human settlements and ecosystems. The DICE damage function also includes the expected value of damages associated with low probability, high impact "catastrophic" climate change. This last component is calibrated based on a survey of experts (Nordhaus 1994). The expected value of these impacts is then added to the other market and non-market impacts mentioned above.

No structural components of the DICE model represent adaptation explicitly, though it is included implicitly through the choice of studies used to calibrate the aggregate damage function. For example, its agricultural impact estimates assume that farmers can adjust land use decisions in response to changing climate conditions, and its health impact estimates assume improvements in healthcare over time. In addition, the small impacts on forestry, water systems, construction, fisheries, and outdoor recreation imply optimistic and costless adaptation in these sectors (Nordhaus and Boyer, 2000; Warren et al., 2006). Costs of resettlement due to sea level rise are incorporated into damage estimates, but their magnitude is not clearly reported. Mastrandrea's (2009) review concludes that "in general, DICE assumes very effective adaptation, and largely ignores adaptation costs."

Note that the damage function in DICE has a somewhat different meaning from the damage functions in FUND and PAGE. Because GDP is endogenous in DICE and because damages in a given year reduce investment in that year, damages propagate forward in time and reduce GDP in future years. In contrast, GDP is exogenous in FUND and PAGE, so damages in any given year do not propagate forward.[3]

The PAGE Model

PAGE2002 (version 1.4epm) treats GDP growth as exogenous. It divides impacts into economic, non-economic, and catastrophic categories and calculates these impacts separately for eight geographic regions. Damages in each region are expressed as a fraction of output, where the fraction lost depends on the temperature change in each region. Damages are expressed as power functions of temperature change. The exponents of the damage function are the same in all regions but are treated as uncertain, with values ranging from 1 to 3 (instead of being fixed at 2 as in DICE).

PAGE2002 includes the consequences of catastrophic events in a separate damage sub-function. Unlike DICE, PAGE2002 models these events probabilistically. The probability of a "discontinuity" (i.e., a catastrophic event) is assumed to increase with temperature above a specified threshold. The threshold temperature, the rate at which the probability of experiencing a discontinuity increases above the threshold, and the magnitude of the resulting catastrophe are all modeled probabilistically.

Adaptation is explicitly included in PAGE. Impacts are assumed to occur for temperature increases above some tolerable level (2°C for developed countries and 0°C for developing countries for economic impacts, and 0°C for all regions for non-economic impacts), but adaptation is assumed to reduce these impacts. Default values in PAGE2002 assume that the developed countries can ultimately eliminate up to 90 percent of all economic impacts beyond the tolerable 2°C increase and that developing countries can eventually eliminate 50 percent of their economic impacts. All regions are assumed to be able to mitigate 25 percent of the non-economic impacts through adaptation (Hope 2006).

The FUND Model

Like PAGE, the FUND model treats GDP growth as exogenous. It includes separately calibrated damage functions for eight market and nonmarket sectors: agriculture, forestry, water, energy (based on heating and cooling demand), sea level rise (based on the value of land lost and the cost of protection),

[3] Using the default assumptions in DICE 2007, this effect generates an approximately 25 percent increase in the SCC relative to damages calculated by fixing GDP. In DICE2007, the time path of GDP is endogenous. Specifically, the path of GDP depends on the rate of saving and level of abatement in each period chosen by the optimizing representative agent in the model. We made two modifications to DICE to make it consistent with EMF GDP trajectories (see next section): we assumed a fixed rate of savings of 20%, and we re-calibrated the exogenous path of total factor productivity so that DICE would produce GDP projections in the absence of warming that exactly matched the EMF scenarios.

ecosystems, human health (diarrhea, vector-borne diseases, and cardiovascular and respiratory mortality), and extreme weather. Each impact sector has a different functional form, and is calculated separately for sixteen geographic regions. In some impact sectors, the fraction of output lost or gained due to climate change depends not only on the absolute temperature change but also on the rate of temperature change and level of regional income.[4] In the forestry and agricultural sectors, economic damages also depend on CO_2 concentrations.

Tol (2009) discusses impacts not included in FUND, noting that many are likely to have a relatively small effect on damage estimates (both positive and negative). However, he characterizes several omitted impacts as "big unknowns": for instance, extreme climate scenarios, biodiversity loss, and effects on economic development and political violence. With regard to potentially catastrophic events, he notes, "Exactly what would cause these sorts of changes or what effects they would have are not well-understood, although the chance of any one of them happening seems low. But they do have the potential to happen relatively quickly, and if they did, the costs could be substantial. Only a few studies of climate change have examined these issues."

Adaptation is included both implicitly and explicitly in FUND. Explicit adaptation is seen in the agriculture and sea level rise sectors. Implicit adaptation is included in sectors such as energy and human health, where wealthier populations are assumed to be less vulnerable to climate impacts. For example, the damages to agriculture are the sum of three effects: (1) those due to the rate of temperature change (damages are always positive); (2) those due to the level of temperature change (damages can be positive or negative depending on region and temperature); and (3) those from CO_2 fertilization (damages are generally negative but diminishing to zero).

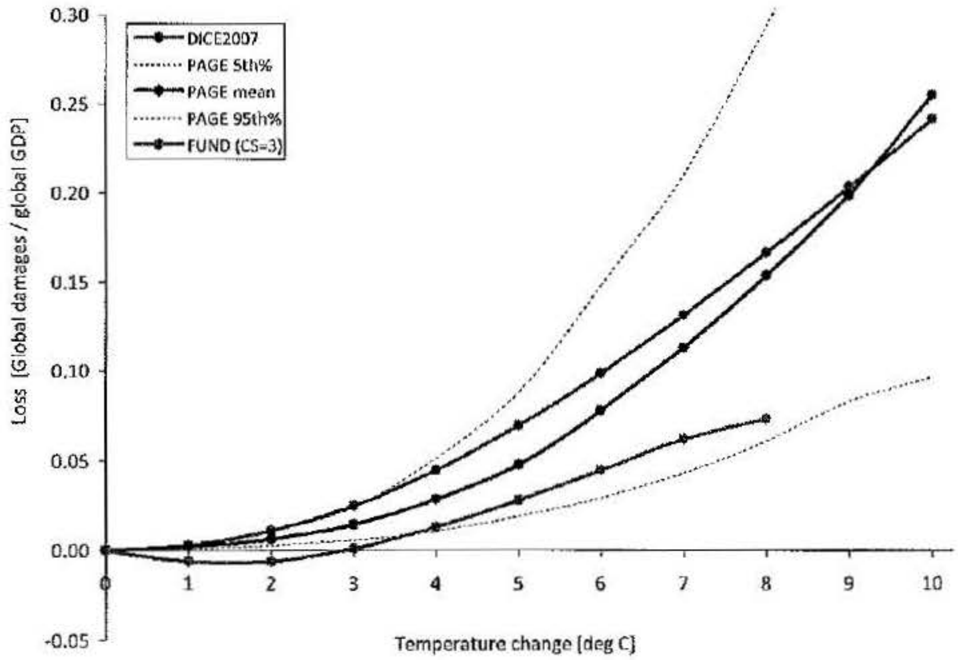
Adaptation is incorporated into FUND by allowing damages to be smaller if climate change happens more slowly. The combined effect of CO_2 fertilization in the agricultural sector, positive impacts to some regions from higher temperatures, and sufficiently slow increases in temperature across these sectors can result in negative economic damages from climate change.

Damage Functions

To generate revised SCC values, we rely on the IAM modelers' current best judgments of how to represent the effects of climate change (represented by the increase in global-average surface temperature) on the consumption-equivalent value of both market and non-market goods (represented as a fraction of global GDP). We recognize that these representations are incomplete and highly uncertain. But given the paucity of data linking the physical impacts to economic damages, we were not able to identify a better way to translate changes in climate into net economic damages, short of launching our own research program.

[4] In the deterministic version of FUND, the majority of damages are attributable to increased air conditioning demand, while reduced cold stress in Europe, North America, and Central and East Asia results in health benefits in those regions at low to moderate levels of warming (Warren et al., 2006).

Figure 1A: Annual Consumption Loss as a Fraction of Global GDP in 2100 Due to an Increase in Annual - Global Temperature in the DICE, FUND, and PAGE models[5]



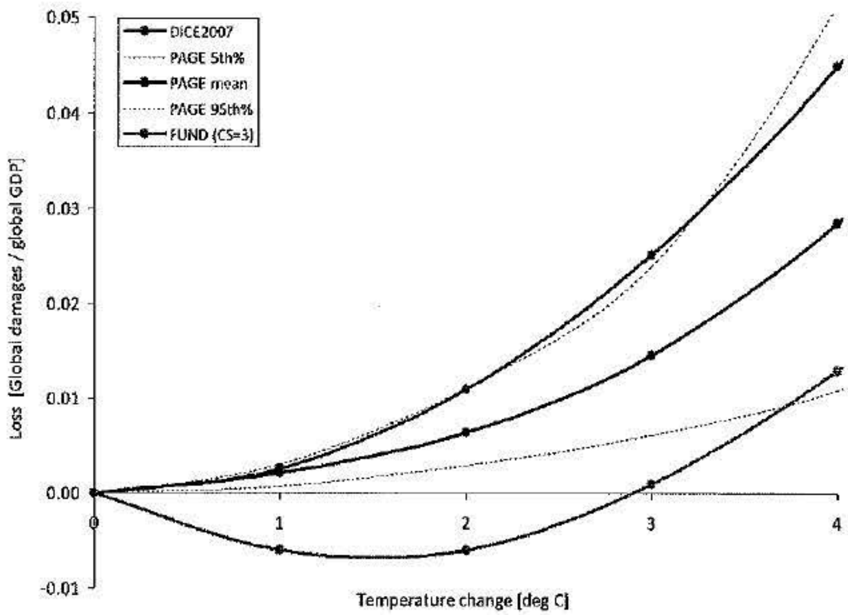
The damage functions for the three IAMs are presented in Figures 1A and 1B, using the modeler's default scenarios and mean input assumptions. There are significant differences between the three models both at lower (figure 1B) and higher (figure 1A) increases in global-average temperature.

The lack of agreement among the models at lower temperature increases is underscored by the fact that the damages from FUND are well below the 5th percentile estimated by PAGE, while the damages estimated by DICE are roughly equal to the 95th percentile estimated by PAGE. This is significant because at higher discount rates we expect that a greater proportion of the SCC value is due to damages in years with lower temperature increases. For example, when the discount rate is 2.5 percent, about 45 percent of the 2010 SCC value in DICE is due to damages that occur in years when the temperature is less than or equal to 3 °C. This increases to approximately 55 percent and 80 percent at discount rates of 3 and 5 percent, respectively.

These differences underscore the need for a thorough review of damage functions—in particular, how the models incorporate adaptation, technological change, and catastrophic damages. Gaps in the literature make modifying these aspects of the models challenging, which highlights the need for additional research. As knowledge improves, the Federal government is committed to exploring how these (and other) models can be modified to incorporate more accurate estimates of damages.

[5] The x-axis represents increases in annual, rather than equilibrium, temperature, while the y-axis represents the annual stream of benefits as a share of global GDP. Each specific combination of climate sensitivity, socio-economic, and emissions parameters will produce a different realization of damages for each IAM. The damage functions represented in Figures 1A and 1B are the outcome of default assumptions. For instance, under alternate assumptions, the damages from FUND may cross from negative to positive at less than or greater than 3 °C.

Figure 1B: Annual Consumption Loss for Lower Temperature Changes in DICE, FUND, and PAGE -



B. Global versus Domestic Measures of SCC

Because of the distinctive nature of the climate change problem, we center our current attention on a global measure of SCC. This approach is the same as that taken for the interim values, but it otherwise represents a departure from past practices, which tended to put greater emphasis on a domestic measure of SCC (limited to impacts of climate change experienced within U.S. borders). As a matter of law, consideration of both global and domestic values is generally permissible; the relevant statutory provisions are usually ambiguous and allow selection of either measure.[6]

Global SCC

Under current OMB guidance contained in Circular A-4, analysis of economically significant proposed and final regulations from the domestic perspective is required, while analysis from the international perspective is optional. However, the climate change problem is highly unusual in at least two respects. First, it involves a global externality: emissions of most greenhouse gases contribute to damages around the world even when they are emitted in the United States. Consequently, to address the global nature of the problem, the SCC must incorporate the full (global) damages caused by GHG emissions. Second, climate change presents a problem that the United States alone cannot solve. Even if the United States were to reduce its greenhouse gas emissions to zero, that step would be far from enough to avoid substantial climate change. Other countries would also need to take action to reduce emissions if

[6] It is true that federal statutes are presumed not to have extraterritorial effect, in part to ensure that the laws of the United States respect the interests of foreign sovereigns. But use of a global measure for the SCC does not give extraterritorial effect to federal law and hence does not intrude on such interests.

significant changes in the global climate are to be avoided. Emphasizing the need for a global solution to a global problem, the United States has been actively involved in seeking international agreements to reduce emissions and in encouraging other nations, including emerging major economies, to take significant steps to reduce emissions. When these considerations are taken as a whole, the interagency group concluded that a global measure of the benefits from reducing U.S. emissions is preferable.

When quantifying the damages associated with a change in emissions, a number of analysts (e.g., Anthoff, et al. 2009a) employ "equity weighting" to aggregate changes in consumption across regions. This weighting takes into account the relative reductions in wealth in different regions of the world. A per-capita loss of $500 in GDP, for instance, is weighted more heavily in a country with a per-capita GDP of $2,000 than in one with a per-capita GDP of $40,000. The main argument for this approach is that a loss of $500 in a poor country causes a greater reduction in utility or welfare than does the same loss in a wealthy nation. Notwithstanding the theoretical claims on behalf of equity weighting, the interagency group concluded that this approach would not be appropriate for estimating a SCC value used in domestic regulatory analysis.[7] For this reason, the group concluded that using the global (rather than domestic) value, without equity weighting, is the appropriate approach.

Domestic SCC

As an empirical matter, the development of a domestic SCC is greatly complicated by the relatively few region- or country-specific estimates of the SCC in the literature. One potential source of estimates comes from the FUND model. The resulting estimates suggest that the ratio of domestic to global benefits of emission reductions varies with key parameter assumptions. For example, with a 2.5 or 3 percent discount rate, the U.S. benefit is about 7-10 percent of the global benefit, on average, across the scenarios analyzed. Alternatively, if the fraction of GDP lost due to climate change is assumed to be similar across countries, the domestic benefit would be proportional to the U.S. share of global GDP, which is currently about 23 percent.[8]

On the basis of this evidence, the interagency workgroup determined that a range of values from 7 to 23 percent should be used to adjust the global SCC to calculate domestic effects. Reported domestic values should use this range. It is recognized that these values are approximate, provisional, and highly speculative. There is no a priori reason why domestic benefits should be a constant fraction of net global damages over time. Further, FUND does not account for how damages in other regions could affect the United States (e.g., global migration, economic and political destabilization). If more accurate methods for calculating the domestic SCC become available, the Federal government will examine these to determine whether to update its approach.

---

[7] It is plausible that a loss of $X inflicts more serious harm on a poor nation than on a wealthy one, but development of the appropriate "equity weight" is challenging. Emissions reductions also impose costs, and hence a full account would have to consider that a given cost of emissions reductions imposes a greater utility or welfare loss on a poor nation than on a wealthy one. Even if equity weighting—for both the costs and benefits of emissions reductions—is appropriate when considering the utility or welfare effects of international action, the interagency group concluded that it should not be used in developing an SCC for use in regulatory policy at this time.

[8] Based on 2008 GDP (in current US dollars) from the *World Bank Development Indicators Report*.

C. Valuing Non-CO_2 Emissions

While CO_2 is the most prevalent greenhouse gas emitted into the atmosphere, the U.S. included five other greenhouse gases in its recent endangerment finding: methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. The climate impact of these gases is commonly discussed in terms of their 100-year global warming potential (GWP). GWP measures the ability of different gases to trap heat in the atmosphere (i.e., radiative forcing per unit of mass) over a particular timeframe relative to CO_2. However, because these gases differ in both radiative forcing and atmospheric lifetimes, their relative damages are not constant over time. For example, because methane has a short lifetime, its impacts occur primarily in the near term and thus are not discounted as heavily as those caused by longer-lived gases. Impacts other than temperature change also vary across gases in ways that are not captured by GWP. For instance, CO_2 emissions, unlike methane and other greenhouse gases, contribute to ocean acidification. Likewise, damages from methane emissions are not offset by the positive effect of CO_2 fertilization. Thus, transforming gases into CO_2-equivalents using GWP, and then multiplying the carbon-equivalents by the SCC, would not result in accurate estimates of the social costs of non-CO_2 gases.

In light of these limitations, and the significant contributions of non-CO_2 emissions to climate change, further research is required to link non-CO_2 emissions to economic impacts. Such work would feed into efforts to develop a monetized value of reductions in non-CO_2 greenhouse gas emissions. As part of ongoing work to further improve the SCC estimates, the interagency group hopes to develop methods to value these other greenhouse gases. The goal is to develop these estimates by the time we issue revised SCC estimates for carbon dioxide emissions.

D. Equilibrium Climate Sensitivity

Equilibrium climate sensitivity (ECS) is a key input parameter for the DICE, PAGE, and FUND models.[9] It is defined as the long-term increase in the annual global-average surface temperature from a doubling of atmospheric CO_2 concentration relative to pre-industrial levels (or stabilization at a concentration of approximately 550 parts per million (ppm)). Uncertainties in this important parameter have received substantial attention in the peer-reviewed literature.

The most authoritative statement about equilibrium climate sensitivity appears in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC):

> *Basing our assessment on a combination of several independent lines of evidence...including observed climate change and the strength of known feedbacks simulated in [global climate models], we conclude that the global mean equilibrium warming for doubling CO_2, or 'equilibrium climate*

[9] The equilibrium climate sensitivity includes the response of the climate system to increased greenhouse gas concentrations over the short to medium term (up to 100-200 years), but it does not include long-term feedback effects due to possible large-scale changes in ice sheets or the biosphere, which occur on a time scale of many hundreds to thousands of years (e.g. Hansen et al. 2007).

sensitivity', is likely to lie in the range 2 °C to 4.5 °C, with a most likely value of about 3 °C. Equilibrium climate sensitivity is very likely larger than 1.5 °C. [10]

For fundamental physical reasons as well as data limitations, values substantially higher than 4.5 °C still cannot be excluded, but agreement with observations and proxy data is generally worse for those high values than for values in the 2 °C to 4.5 °C range. (Meehl et al., 2007, p 799)

After consulting with several lead authors of this chapter of the IPCC report, the interagency workgroup selected four candidate probability distributions and calibrated them to be consistent with the above statement: Roe and Baker (2007), log-normal, gamma, and Weibull. Table 1 included below gives summary statistics for the four calibrated distributions.

Table 1: Summary Statistics for Four Calibrated Climate Sensitivity Distributions

	Roe & Baker	Log-normal	Gamma	Weibull
Pr(ECS < 1.5°C)	0.013	0.050	0.070	0.102
Pr(2°C < ECS < 4.5°C)	0.667	0.667	0.667	0.667
5th percentile	1.72	1.49	1.37	1.13
10th percentile	1.91	1.74	1.65	1.48
Mode	2.34	2.52	2.65	2.90
Median (50th percentile)	3.00	3.00	3.00	3.00
Mean	3.50	3.28	3.19	3.07
90th percentile	5.86	5.14	4.93	4.69
95th percentile	7.14	5.97	5.59	5.17

Each distribution was calibrated by applying three constraints from the IPCC:

(1) a median equal to 3°C, to reflect the judgment of "a most likely value of about 3 °C";[11]
(2) two-thirds probability that the equilibrium climate sensitivity lies between 2 and 4.5 °C; and
(3) zero probability that it is less than 0°C or greater than 10°C (see Hegerl et al. 2006, p. 721).

We selected the calibrated Roe and Baker distribution from the four candidates for two reasons. First, the Roe and Baker distribution is the only one of the four that is based on a theoretical understanding of the response of the climate system to increased greenhouse gas concentrations (Roe and Baker 2007,

[10] This is in accord with the judgment that it "is likely to lie in the range 2 °C to 4.5 °C" and the IPCC definition of "likely" as greater than 66 percent probability (Le Treut et al.2007). "Very likely" indicates a greater than 90 percent probability.

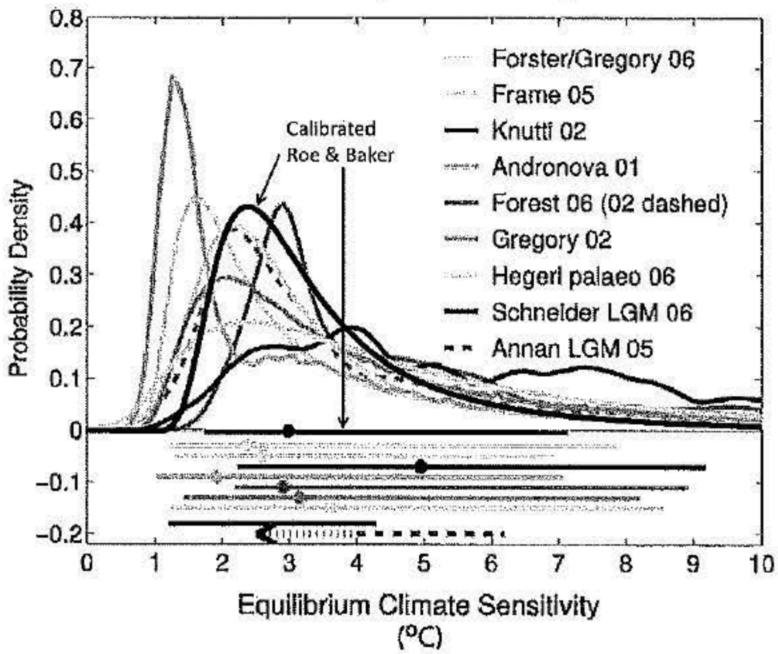
[11] Strictly speaking, "most likely" refers to the mode of a distribution rather than the median, but common usage would allow the mode, median, or mean to serve as candidates for the central or "most likely" value and the IPCC report is not specific on this point. For the distributions we considered, the median was between the mode and the mean. For the Roe and Baker distribution, setting the median equal to 3°C, rather than the mode or mean, gave a 95th percentile that is more consistent with IPCC judgments and the literature. For example, setting the mean and mode equal to 3°C produced 95th percentiles of 5.6 and 8.6 °C, respectively, which are in the lower and upper end of the range in the literature. Finally, the median is closer to 3°C than is the mode for the truncated distributions selected by the IPCC (Hegerl, et al., 2006); the average median is 3.1 °C and the average mode is 2.3 °C, which is most consistent with a Roe and Baker distribution with the median set equal to 3 °C.

Roe 2008). In contrast, the other three distributions are mathematical functions that are arbitrarily chosen based on simplicity, convenience, and general shape. The Roe and Baker distribution results from three assumptions about climate response: (1) absent feedback effects, the equilibrium climate sensitivity is equal to 1.2 °C; (2) feedback factors are proportional to the change in surface temperature; and (3) uncertainties in feedback factors are normally distributed. There is widespread agreement on the first point and the second and third points are common assumptions.

Second, the calibrated Roe and Baker distribution better reflects the IPCC judgment that "values substantially higher than 4.5°C still cannot be excluded." Although the IPCC made no quantitative judgment, the 95th percentile of the calibrated Roe & Baker distribution (7.1 °C) is much closer to the mean and the median (7.2 °C) of the 95th percentiles of 21 previous studies summarized by Newbold and Daigneault (2009). It is also closer to the mean (7.5 °C) and median (7.9 °C) of the nine truncated distributions examined by the IPCC (Hegerl, et al., 2006) than are the 95th percentiles of the three other calibrated distributions (5.2-6.0 °C).

Finally, we note the IPCC judgment that the equilibrium climate sensitivity "is very likely larger than 1.5°C." Although the calibrated Roe & Baker distribution, for which the probability of equilibrium climate sensitivity being greater than 1.5°C is almost 99 percent, is not inconsistent with the IPCC definition of "very likely" as "greater than 90 percent probability," it reflects a greater degree of certainty about very low values of ECS than was expressed by the IPCC.

Figure 2: Estimates of the Probability Density Function for Equilibrium Climate Sensitivity (°C)



To show how the calibrated Roe and Baker distribution compares to different estimates of the probability distribution function of equilibrium climate sensitivity in the empirical literature, Figure 2 (below) overlays it on Figure 9.20 from the IPCC Fourth Assessment Report. These functions are scaled to integrate to unity between 0 °C and 10 °C. The horizontal bars show the respective 5 percent to 95 percent ranges; dots indicate the median estimate.[12]

E. Socio-Economic and Emissions Trajectories

Another key issue considered by the interagency group is how to select the set of socio-economic and emissions parameters for use in PAGE, DICE, and FUND. Socio-economic pathways are closely tied to climate damages because, all else equal, more and wealthier people tend to emit more greenhouse gases and also have a higher (absolute) willingness to pay to avoid climate disruptions. For this reason, we consider how to model several input parameters in tandem: GDP, population, CO_2 emissions, and non-CO_2 radiative forcing. A wide variety of scenarios have been developed and used for climate change policy simulations (e.g., SRES 2000, CCSP 2007, EMF 2009). In determining which scenarios are appropriate for inclusion, we aimed to select scenarios that span most of the plausible ranges of outcomes for these variables.

To accomplish this task in a transparent way, we decided to rely on the recent Stanford Energy Modeling Forum exercise, EMF-22. EMF-22 uses ten well-recognized models to evaluate substantial, coordinated global action to meet specific stabilization targets. A key advantage of relying on these data is that GDP, population, and emission trajectories are internally consistent for each model and scenario evaluated. The EMF-22 modeling effort also is preferable to the IPCC SRES due to their age (SRES were developed in 1997) and the fact that 3 of 4 of the SRES scenarios are now extreme outliers in one or more variables. Although the EMF-22 scenarios have not undergone the same level of scrutiny as the SRES scenarios, they are recent, peer-reviewed, published, and publicly available.

To estimate the SCC for use in evaluating domestic policies that will have a small effect on global cumulative emissions, we use socio-economic and emission trajectories that span a range of plausible scenarios. Five trajectories were selected from EMF-22 (see Table 2 below). Four of these represent potential business-as-usual (BAU) growth in population, wealth, and emissions and are associated with CO_2 (only) concentrations ranging from 612 to 889 ppm in 2100. One represents an emissions pathway that achieves stabilization at 550 ppm CO_2e (i.e., CO_2-only concentrations of 425 – 484 ppm or a radiative forcing of 3.7 W/m^2) in 2100, a lower-than-BAU trajectory.[13] Out of the 10 models included in the EMF-22 exercise, we selected the trajectories used by MiniCAM, MESSAGE, IMAGE, and the optimistic scenario from MERGE. For the BAU pathways, we used the GDP, population, and emission trajectories from each of these four models. For the 550 ppm CO_2e scenario, we averaged the GDP, population, and emission trajectories implied by these same four models.

---

[12] The estimates based on instrumental data are from Andronova and Schlesinger (2001), Forest et al. (2002; dashed line, anthropogenic forcings only), Forest et al. (2006; solid line, anthropogenic and natural forcings), Gregory et al. (2002a), Knutti et al. (2002), Frame et al. (2005), and Forster and Gregory (2006). Hegerl et al. (2006) are based on multiple palaeoclimatic reconstructions of north hemisphere mean temperatures over the last 700 years. Also shown are the 5-95 percent approximate ranges for two estimates from the last glacial maximum (dashed, Annan et al. 2005; solid, Schneider von Deimling et al. 2006), which are based on models with different structural properties.

[13] Such an emissions path would be consistent with widespread action by countries to mitigate GHG emissions, though it could also result from technological advances. It was chosen because it represents the most stringent case analyzed by the EMF-22 where all the models converge: a 550 ppm, not to exceed, full participation scenario.

Table 2: Socioeconomic and Emissions Projections from Select EMF-22 Reference Scenarios -

Reference Fossil and Industrial CO_2 Emissions ($GtCO_2$/yr) -

EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	26.6	31.9	36.9	40.0	45.3	60.1
MERGE Optimistic	24.6	31.5	37.6	45.1	66.5	117.9
MESSAGE	26.8	29.2	37.6	42.1	43.5	42.7
MiniCAM	26.5	31.8	38.0	45.1	57.8	80.5
550 ppm average	26.2	31.1	33.2	32.4	20.0	12.8

Reference GDP (using market exchange rates in trillion 2005$)[14]

EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	38.6	53.0	73.5	97.2	156.3	396.6
MERGE Optimistic	36.3	45.9	59.7	76.8	122.7	268.0
MESSAGE	38.1	52.3	69.4	91.4	153.7	334.9
MiniCAM	36.1	47.4	60.8	78.9	125.7	369.5
550 ppm average	37.1	49.6	65.6	85.5	137.4	337.9

Global Population (billions)

EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	6.1	6.9	7.6	8.2	9.0	9.1
MERGE Optimistic	6.0	6.8	7.5	8.2	9.0	9.7
MESSAGE	6.1	6.9	7.7	8.4	9.4	10.4
MiniCAM	6.0	6.8	7.5	8.1	8.8	8.7
550 ppm average	6.1	6.8	7.6	8.2	8.7	9.1

We explore how sensitive the SCC is to various assumptions about how the future will evolve without prejudging what is likely to occur. The interagency group considered formally assigning probability weights to different states of the world, but this proved challenging to do in an analytically rigorous way given the dearth of information on the likelihood of a full range of future socio-economic pathways.

There are a number of caveats. First, EMF BAU scenarios represent the modelers' judgment of the most likely pathway absent mitigation policies to reduce greenhouse gas emissions, rather than the wider range of possible outcomes. Nevertheless, these views of the most likely outcome span a wide range,

[14] While the EMF-22 models used market exchange rates (MER) to calculate global GDP, it is also possible to use purchasing power parity (PPP). PPP takes into account the different price levels across countries, so it more accurately describes relative standards of living across countries. MERs tend to make low-income countries appear poorer than they actually are. Because many models assume convergence in per capita income over time, use of MER-adjusted GDP gives rise to projections of higher economic growth in low income countries. There is an ongoing debate about how much this will affect estimated climate impacts. Critics of the use of MER argue that it leads to overstated economic growth and hence a significant upward bias in projections of greenhouse gas emissions, and unrealistically high future temperatures (e.g., Castles and Henderson 2003). Others argue that convergence of the emissions-intensity gap across countries at least partially offset the overstated income gap so that differences in exchange rates have less of an effect on emissions (Holtsmark and Alfsen, 2005; Tol, 2006). Nordhaus (2007b) argues that the ideal approach is to use superlative PPP accounts (i.e., using cross-sectional PPP measures for relative incomes and outputs and national accounts price and quantity indexes for time-series extrapolations). However, he notes that it important to keep this debate in perspective; it is by no means clear that exchange-rate-conversion issues are as important as uncertainties about population, technological change, or the many geophysical uncertainties.

from the more optimistic (e.g. abundant low-cost, low-carbon energy) to more pessimistic (e.g. constraints on the availability of nuclear and renewables).[15] Second, the socio-economic trajectories associated with a 550 ppm CO_2e concentration scenario are not derived from an assessment of what policy is optimal from a benefit-cost standpoint. Rather, it is indicative of one possible future outcome. The emission trajectories underlying some BAU scenarios (e.g. MESSAGE's 612 ppm) also are consistent with some modest policy action to address climate change.[16] We chose not to include socio-economic trajectories that achieve even lower GHG concentrations at this time, given the difficulty many models had in converging to meet these targets.

For comparison purposes, the Energy Information Agency in its 2009 Annual Energy Outlook projected that global carbon dioxide emissions will grow to 30.8, 35.6, and 40.4 gigatons in 2010, 2020, and 2030, respectively, while world GDP is projected to be $51.8, $71.0 and $93.9 trillion (in 2005 dollars using market exchange rates) in 2010, 2020, and 2030, respectively. These projections are consistent with one or more EMF-22 scenarios. Likewise, the United Nations' 2008 Population Prospect projects population will grow from 6.1 billion people in 2000 to 9.1 billion people in 2050, which is close to the population trajectories for the IMAGE, MiniCAM, and MERGE models.

In addition to fossil and industrial CO_2 emissions, each EMF scenario provides projections of methane, nitrous oxide, fluorinated greenhouse gases, and net land use CO_2 emissions out to 2100. These assumptions also are used in the three models while retaining the default radiative forcings due to other factors (e.g. aerosols and other gases). See the Appendix for greater detail.

F. Discount Rate

The choice of a discount rate, especially over long periods of time, raises highly contested and exceedingly difficult questions of science, economics, philosophy, and law. Although it is well understood that the discount rate has a large influence on the current value of future damages, there is no consensus about what rates to use in this context. Because carbon dioxide emissions are long-lived, subsequent damages occur over many years. In calculating the SCC, we first estimate the future damages to agriculture, human health, and other market and non-market sectors from an additional unit of carbon dioxide emitted in a particular year in terms of reduced consumption (or consumption equivalents) due to the impacts of elevated temperatures, as represented in each of the three IAMs. Then we discount the stream of future damages to its present value in the year when the additional unit of emissions was released using the selected discount rate, which is intended to reflect society's marginal rate of substitution between consumption in different time periods.

For rules with both intra- and intergenerational effects, agencies traditionally employ constant discount rates of both 3 percent and 7 percent in accordance with OMB Circular A-4. As Circular A-4 acknowledges, however, the choice of discount rate for intergenerational problems raises distinctive

[15] For instance, in the MESSAGE model's reference case total primary energy production from nuclear, biomass, and non-biomass renewables is projected to increase from about 15 percent of total primary energy in 2000 to 54 percent in 2100. In comparison, the MiniCAM reference case shows 10 percent in 2000 and 21 percent in 2100.
[16] For example, MiniCAM projects if all non-US OECD countries reduce CO_2 emissions to 83 percent below 2005 levels by 2050 (per the G-8 agreement) but all other countries continue along a BAU path CO_2 concentrations in 2100 would drop from 794 ppmv in its reference case to 762 ppmv.

problems and presents considerable challenges. After reviewing those challenges, Circular A-4 states, "If your rule will have important intergenerational benefits or costs you might consider a further sensitivity analysis using a lower but positive discount rate in addition to calculating net benefits using discount rates of 3 and 7 percent." For the specific purpose of developing the SCC, we adapt and revise that approach here.

Arrow et al. (1996) outlined two main approaches to determine the discount rate for climate change analysis, which they labeled "descriptive" and "prescriptive." The descriptive approach reflects a positive (non-normative) perspective based on observations of people's actual choices—e.g., savings versus consumption decisions over time, and allocations of savings among more and less risky investments. Advocates of this approach generally call for inferring the discount rate from market rates of return "because of a lack of justification for choosing a social welfare function that is any different than what decision makers [individuals] actually use" (Arrow et al. 1996).

One theoretical foundation for the cost-benefit analyses in which the social cost of carbon will be used—the Kaldor-Hicks potential-compensation test—also suggests that market rates should be used to discount future benefits and costs, because it is the market interest rate that would govern the returns potentially set aside today to compensate future individuals for climate damages that they bear (e.g., Just et al. 2004). As some have noted, the word "potentially" is an important qualification; there is no assurance that such returns will actually be set aside to provide compensation, and the very idea of compensation is difficult to define in the intergenerational context. On the other hand, societies provide compensation to future generations through investments in human capital and the resulting increase in knowledge, as well as infrastructure and other physical capital.

The prescriptive approach specifies a social welfare function that formalizes the normative judgments that the decision-maker wants explicitly to incorporate into the policy evaluation—e.g., how interpersonal comparisons of utility should be made, and how the welfare of future generations should be weighed against that of the present generation. Ramsey (1928), for example, has argued that it is "ethically indefensible" to apply a positive pure rate of time preference to discount values across generations, and many agree with this view.

Other concerns also motivate making adjustments to descriptive discount rates. In particular, it has been noted that the preferences of future generations with regard to consumption versus environmental amenities may not be the same as those today, making the current market rate on consumption an inappropriate metric by which to discount future climate-related damages. Others argue that the discount rate should be below market rates to correct for market distortions and uncertainties or inefficiencies in intergenerational transfers of wealth, which in the Kaldor-Hicks logic are presumed to compensate future generations for damage (a potentially controversial assumption, as noted above) (Arrow et al. 1996, Weitzman 1999).

Further, a legitimate concern about both descriptive and prescriptive approaches is that they tend to obscure important heterogeneity in the population. The utility function that underlies the prescriptive approach assumes a representative agent with perfect foresight and no credit constraints. This is an artificial rendering of the real world that misses many of the frictions that characterize individuals' lives and indeed the available descriptive evidence supports this. For instance, many individuals smooth consumption by borrowing with credit cards that have relatively high rates. Some are unable to access traditional credit markets and rely on payday lending operations or other high cost forms of smoothing consumption. Whether one puts greater weight on the prescriptive or descriptive approach, the high interest rates that credit-constrained individuals accept suggest that some account should be given to the discount rates revealed by their behavior.

We draw on both approaches but rely primarily on the descriptive approach to inform the choice of discount rate. With recognition of its limitations, we find this approach to be the most defensible and transparent given its consistency with the standard contemporary theoretical foundations of benefit-cost analysis and with the approach required by OMB's existing guidance. The logic of this framework also suggests that market rates should be used for discounting future consumption-equivalent damages. Regardless of the theoretical approach used to derive the appropriate discount rate(s), we note the inherent conceptual and practical difficulties of adequately capturing consumption trade-offs over many decades or even centuries. While relying primarily on the descriptive approach in selecting specific discount rates, the interagency group has been keenly aware of the deeply normative dimensions of both the debate over discounting in the intergenerational context and the consequences of selecting one discount rate over another.

Historically Observed Interest Rates

In a market with no distortions, the return to savings would equal the private return on investment, and the market rate of interest would be the appropriate choice for the social discount rate. In the real world risk, taxes, and other market imperfections drive a wedge between the risk-free rate of return on capital and the consumption rate of interest. Thus, the literature recognizes two conceptual discount concepts—the consumption rate of interest and the opportunity cost of capital.

According to OMB's Circular A-4, it is appropriate to use the rate of return on capital when a regulation is expected to displace or alter the use of capital in the private sector. In this case, OMB recommends Agencies use a discount rate of 7 percent. When regulation is expected to primarily affect private consumption—for instance, via higher prices for goods and services—a lower discount rate of 3 percent is appropriate to reflect how private individuals trade-off current and future consumption.

The interagency group examined the economics literature and concluded that the consumption rate of interest is the correct concept to use in evaluating the benefits and costs of a marginal change in carbon emissions (see Lind 1990, Arrow et al 1996, and Arrow 2000). The consumption rate of interest also is appropriate when the impacts of a regulation are measured in consumption (-equivalent) units, as is done in the three integrated assessment models used for estimating the SCC.

Individuals use a variety of savings instruments that vary with risk level, time horizon, and tax characteristics. The standard analytic framework used to develop intuition about the discount rate typically assumes a representative agent with perfect foresight and no credit constraints. The risk-free rate is appropriate for discounting certain future benefits or costs, but the benefits calculated by IAMs are uncertain. To use the risk-free rate to discount uncertain benefits, these benefits first must be transformed into "certainty equivalents," that is the maximum certain amount that we would exchange for the uncertain amount. However, the calculation of the certainty-equivalent requires first estimating the correlation between the benefits of the policy and baseline consumption.

If the IAM projections of future impacts represent expected values (not certainty-equivalent values), then the appropriate discount rate generally does not equal the risk-free rate. If the benefits of the policy tend to be high in those states of the world in which consumption is low, then the certainty-equivalent benefits will be higher than the expected benefits (and vice versa). Since many (though not necessarily all) of the important impacts of climate change will flow through market sectors such as agriculture and energy, and since willingness to pay for environmental protections typically increases with income, we might expect a positive (though not necessarily perfect) correlation between the net benefits from climate policies and market returns. This line of reasoning suggests that the proper discount rate would exceed the riskless rate. Alternatively, a negative correlation between the returns to climate policies and market returns would imply that a discount rate below the riskless rate is appropriate.

This discussion suggests that both the post-tax riskless and risky rates can be used to capture individuals' consumption-equivalent interest rate. As a measure of the post-tax riskless rate, we calculate the average real return from Treasury notes over the longest time period available (those from Newell and Pizer 2003) and adjust for Federal taxes (the average marginal rate from tax years 2003 through 2006 is around 27 percent).[17] This calculation produces a real interest rate of about 2.7 percent, which is roughly consistent with Circular A-4's recommendation to use 3 percent to represent the consumption rate of interest.[18] A measure of the post-tax risky rate for investments whose returns are positively correlated with overall equity market returns can be obtained by adjusting pre-tax rates of household returns to risky investments (approximately 7 percent) for taxes yields a real rate of roughly 5 percent.[19]

The Ramsey Equation

Ramsey discounting also provides a useful framework to inform the choice of a discount rate. Under this approach, the analyst applies either positive or normative judgments in selecting values for the key parameters of the Ramsey equation: η (coefficient of relative risk aversion or elasticity of the marginal utility of consumption) and ρ (pure rate of time preference).[20] These are then combined with g (growth

[17] The literature argues for a risk-free rate on government bonds as an appropriate measure of the consumption rate of interest. Arrow (2000) suggests that it is roughly 3-4 percent. OMB cites evidence of a 3.1 percent pre-tax rate for 10-year Treasury notes in the A-4 guidance. Newell and Pizer (2003) find real interest rates between 3.5 and 4 percent for 30-year Treasury securities.

[18] The positive approach reflects how individuals make allocation choices across time, but it is important to keep in mind that we wish to reflect preferences for society as a whole, which generally has a longer planning horizon.

[19] Cambell et al (2001) estimates that the annual real return from stocks for 1900-1995 was about 7 percent. The annual real rate of return for the S&P 500 from 1950 – 2008 was about 6.8 percent. In the absence of a better way to population-weight the tax rates, we use the middle of the 20 – 40 percent range to derive a post-tax interest rate (Kotlikoff and Rapson 2006).

[20] The parameter ρ measures the *pure rate of time preference*: people's behavior reveals a preference for an increase in utility today versus the future. Consequently, it is standard to place a lower weight on utility in the future. The parameter η captures *diminishing marginal utility*: consumption in the future is likely to be higher than consumption today, so diminishing marginal utility of consumption implies that the same monetary damage will

rate of per-capita consumption) to equal the interest rate at which future monetized damages are discounted: $\rho + \eta \cdot g$.[21] In the simplest version of the Ramsey model, with an optimizing representative agent with perfect foresight, what we are calling the "Ramsey discount rate," $\rho + \eta \cdot g$, will be equal to the rate of return to capital, i.e., the market interest rate.

A review of the literature provides some guidance on reasonable parameter values for the Ramsey discounting equation, based on both prescriptive and descriptive approaches.

- η. Most papers in the climate change literature adopt values for η in the range of 0.5 to 3 (Weitzman cites plausible values as those ranging from 1 to 4), although not all authors articulate whether their choice is based on prescriptive or descriptive reasoning.[22] Dasgupta (2008) argues that η should be greater than 1 and may be as high as 3, since η equal to 1 suggests savings rates that do not conform to observed behavior.

- ρ. With respect to the pure rate of time preference, most papers in the climate change literature adopt values for ρ in the range of 0 to 3 percent per year. The very low rates tend to follow from moral judgments involving intergenerational neutrality. Some have argued that to use any value other than $\rho = 0$ would unjustly discriminate against future generations (e.g., Arrow et al. 1996, Stern et al. 2006). However, even in an inter-generational setting, it may make sense to use a small positive pure rate of time preference because of the small probability of unforeseen cataclysmic events (Stern et al. 2006).

- g. A commonly accepted approximation is around 2 percent per year. For the socio-economic scenarios used for this exercise, the EMF models assume that g is about 1.5-2 percent to 2100.

Some economists and non-economists have argued for constant discount rates below 2 percent based on the prescriptive approach. When grounded in the Ramsey framework, proponents of this approach have argued that a ρ of zero avoids giving preferential treatment to one generation over another. The choice of η has also been posed as an ethical choice linked to the value of an additional dollar in poorer

---

cause a smaller reduction of utility for wealthier individuals, either in the future or in current generations. If $\eta = 0$, then a one dollar increase in income is equally valuable regardless of level of income; if $\eta = 1$, then a one percent increase in income is equally valuable no matter the level of income; and if $\eta > 1$, then a one percent increase in income is less valuable to wealthier individuals.

[21] In this case, g could be taken from the selected EMF socioeconomic scenarios or alternative assumptions about the rate of consumption growth.

[22] Empirical estimates of η span a wide range of values. A benchmark value of 2 is near the middle of the range of values estimated or used by Szpiro (1986), Hall and Jones (2007), Arrow (2007), Dasgupta (2006, 2008), Weitzman (2007, 2009), and Nordhaus (2008). However, Chetty (2006) developed a method of estimating η using data on labor supply behavior. He shows that existing evidence of the effects of wage changes on labor supply imposes a tight upper bound on the curvature of utility over wealth (CRRA < 2) with the mean implied value of 0.71 and concludes that the standard expected utility model cannot generate high levels of risk aversion without contradicting established facts about labor supply. Recent work has jointly estimated the components of the Ramsey equation. Evans and Sezer (2005) estimate $\eta = 1.49$ for 22 OECD countries. They also estimate $\rho = 1.08$ percent per year using data on mortality rates. Anthoff, et al. (2009b) estimate $\eta = 1.18$, and $\rho = 1.4$ percent. When they multiply the bivariate probability distributions from their work and Evans and Sezer (2005) together, they find $\eta = 1.47$, and $\rho = 1.07$.

countries compared to wealthier ones. Stern et al. (2006) applies this perspective through his choice of ρ = 0.1 percent per year, η = 1 and g = 1.3 percent per year, which yields an annual discount rate of 1.4 percent. In the context of permanent income savings behavior, however, Stern's assumptions suggest that individuals would save 93 percent of their income.[23]

Recently, Stern (2008) revisited the values used in Stern et al. (2006), stating that there is a case to be made for raising η due to the amount of weight lower values place on damages far in the future (over 90 percent of expected damages occur after 2200 with η = 1). Using Stern's assumption that ρ = 0.1 percent, combined with a η of 1.5 to 2 and his original growth rate, yields a discount rate greater 2 percent.

We conclude that arguments made under the prescriptive approach can be used to justify discount rates between roughly 1.4 and 3.1 percent. In light of concerns about the most appropriate value for η, we find it difficult to justify rates at the lower end of this range under the Ramsey framework.

Accounting for Uncertainty in the Discount Rate

While the consumption rate of interest is an important driver of the benefits estimate, it is uncertain over time. Ideally, we would formally model this uncertainty, just as we do for climate sensitivity. Weitzman (1998, 2001) showed theoretically and Newell and Pizer (2003) and Groom et al. (2006) confirm empirically that discount rate uncertainty can have a large effect on net present values. A main result from these studies is that if there is a persistent element to the uncertainty in the discount rate (e.g., the rate follows a random walk), then it will result in an effective (or certainty-equivalent) discount rate that declines over time. Consequently, lower discount rates tend to dominate over the very long term (see Weitzman 1998, 1999, 2001; Newell and Pizer 2003; Groom et al. 2006; Gollier 2008; Summers and Zeckhauser 2008; and Gollier and Weitzman 2009).

The proper way to model discount rate uncertainty remains an active area of research. Newell and Pizer (2003) employ a model of how long-term interest rates change over time to forecast future discount rates. Their model incorporates some of the basic features of how interest rates move over time, and its parameters are estimated based on historical observations of long-term rates. Subsequent work on this topic, most notably Groom et al. (2006), uses more general models of interest rate dynamics to allow for better forecasts. Specifically, the volatility of interest rates depends on whether rates are currently low or high and variation in the level of persistence over time.

While Newell and Pizer (2003) and Groom et al (2006) attempt formally to model uncertainty in the discount rate, others argue for a declining scale of discount rates applied over time (e.g., Weitzman 2001, and the UK's "Green Book" for regulatory analysis). This approach uses a higher discount rate

[23] Stern (2008) argues that building in a positive rate of exogenous technical change over time reduces the implied savings rate and that η at or above 2 are inconsistent with observed behavior with regard to equity. (At the same time, adding exogenous technical change—all else equal—would increase g as well.)

initially, but applies a graduated scale of lower discount rates further out in time.[24] A key question that has emerged with regard to both of these approaches is the trade-off between potential time inconsistency and giving greater weight to far future outcomes (see the EPA Science Advisory Board's recent comments on this topic as part of its review of their *Guidelines for Economic Analysis*).[25]

The Discount Rates Selected for Estimating SCC

In light of disagreement in the literature on the appropriate market interest rate to use in this context and uncertainty about how interest rates may change over time, we use three discount rates to span a plausible range of certainty-equivalent constant discount rates: 2.5, 3, and 5 percent per year. Based on the review in the previous sections, the interagency workgroup determined that these three rates reflect reasonable judgments under both descriptive and prescriptive approaches.

The central value, 3 percent, is consistent with estimates provided in the economics literature and OMB's Circular A-4 guidance for the consumption rate of interest. As previously mentioned, the consumption rate of interest is the correct discounting concept to use when future damages from elevated temperatures are estimated in consumption-equivalent units. Further, 3 percent roughly corresponds to the after-tax riskless interest rate. The upper value of 5 percent is included to represent the possibility that climate damages are positively correlated with market returns. Additionally, this discount rate may be justified by the high interest rates that many consumers use to smooth consumption across periods.

The low value, 2.5 percent, is included to incorporate the concern that interest rates are highly uncertain over time. It represents the average certainty-equivalent rate using the mean-reverting and random walk approaches from Newell and Pizer (2003) starting at a discount rate of 3 percent. Using this approach, the certainty equivalent is about 2.2 percent using the random walk model and 2.8 percent using the mean reverting approach.[26] Without giving preference to a particular model, the average of the two rates is 2.5 percent. Further, a rate below the riskless rate would be justified if climate investments are negatively correlated with the overall market rate of return. Use of this lower value also responds to certain judgments using the prescriptive or normative approach and to ethical objections that have been raised about rates of 3 percent or higher.

---

[24] For instance, the UK applies a discount rate of 3.5 percent to the first 30 years; 3 percent for years 31 - 75; 2.5 percent for years 76 - 125; 2 percent for years 126 - 200; 1.5 percent for years 201 - 300; and 1 percent after 300 years. As a sensitivity, it recommends a discount rate of 3 percent for the first 30 years, also decreasing over time.

[25] Uncertainty in future damages is distinct from uncertainty in the discount rate. Weitzman (2008) argues that Stern's choice of a low discount rate was "right for the wrong reasons." He demonstrates how the damages from a low probability, catastrophic event far in the future dominate the effect of the discount rate in a present value calculation and result in an infinite willingness-to-pay for mitigation today. Newbold and Daigneault, (2009) and Nordhaus (2009) find that Weitzman's result is sensitive to the functional forms chosen for climate sensitivity, utility, and consumption. Summers and Zeckhauser (2008) argue that uncertainty in future damages can also work in the other direction by increasing the benefits of waiting to learn the appropriate level of mitigation required.

[26] Calculations done by Pizer et al. using the original simulation program from Newell and Pizer (2003).

IV. Revised SCC Estimates

Our general approach to estimating SCC values is to run the three integrated assessment models (FUND, DICE, and PAGE) using the following inputs agreed upon by the interagency group:

- A Roe and Baker distribution for the climate sensitivity parameter bounded between 0 and 10 with a median of 3 °C and a cumulative probability between 2 and 4.5 °C of two-thirds.
- Five sets of GDP, population and carbon emissions trajectories based on EMF-22.
- Constant annual discount rates of 2.5, 3, and 5 percent.

Because the climate sensitivity parameter is modeled probabilistically, and because PAGE and FUND incorporate uncertainty in other model parameters, the final output from each model run is a distribution over the SCC in year *t*.

For each of the IAMS, the basic computational steps for calculating the SCC in a particular year *t* are:

1. Input the path of emissions, GDP, and population from the selected EMF-22 scenarios, and the extrapolations based on these scenarios for post-2100 years.

2. Calculate the temperature effects and (consumption-equivalent) damages in each year resulting from the baseline path of emissions.

   a. In PAGE, the consumption-equivalent damages in each period are calculated as a fraction of the EMF GDP forecast, depending on the temperature in that period relative to the pre-industrial average temperature in each region.
   b. In FUND, damages in each period depend on both the level and the rate of temperature change in that period.
   c. In DICE, temperature affects both consumption and investment, so we first adjust the EMF GDP paths as follows: Using the Cobb-Douglas production function with the DICE2007 parameters, we extract the path of exogenous technical change implied by the EMF GDP and population paths, then we recalculate the baseline GDP path taking into account climate damages resulting from the baseline emissions path.

3. Add an additional unit of carbon emissions in year *t*. (The exact unit varies by model.)

4. Recalculate the temperature effects and damages expected in all years beyond *t* resulting from this adjusted path of emissions, as in step 2.

5. Subtract the damages computed in step 2 from those in step 4 in each year. (DICE is run in 10 year time steps, FUND in annual time steps, while the time steps in PAGE vary.)

6. Discount the resulting path of marginal damages back to the year of emissions using the agreed upon fixed discount rates.

7. Calculate the SCC as the net present value of the discounted path of damages computed in step 6, divided by the unit of carbon emissions used to shock the models in step 3.

8. Multiply by 12/44 to convert from dollars per ton of carbon to dollars per ton of CO_2 (2007 dollars) in DICE and FUND. (All calculations are done in tons of CO_2 in PAGE).

The steps above were repeated in each model for multiple future years to cover the time horizons anticipated for upcoming rulemaking analysis. To maintain consistency across the three IAMs, climate damages are calculated as lost consumption in each future year.

It is important to note that each of the three models has a different default end year. The default time horizon is 2200 for PAGE, 2595 for DICE, and 3000 for the latest version of FUND. This is an issue for the multi-model approach because differences in SCC estimates may arise simply due to the model time horizon. Many consider 2200 too short a time horizon because it could miss a significant fraction of damages under certain assumptions about the growth of marginal damages and discounting, so each model is run here through 2300. This step required a small adjustment in the PAGE model only. This step also required assumptions about GDP, population, and greenhouse gas emission trajectories after 2100, the last year for which these data are available from the EMF-22 models. (A more detailed discussion of these assumptions is included in the Appendix.)

This exercise produces 45 separate distributions of the SCC for a given year, the product of 3 models, 3 discount rates, and 5 socioeconomic scenarios. This is clearly too many separate distributions for consideration in a regulatory impact analysis.

To produce a range of plausible estimates that still reflects the uncertainty in the estimation exercise, the distributions from each of the models and scenarios are equally weighed and combined to produce three separate probability distributions for SCC in a given year, one for each assumed discount rate. These distributions are then used to define a range of point estimates for the global SCC. In this way, no integrated assessment model or socioeconomic scenario is given greater weight than another. Because the literature shows that the SCC is quite sensitive to assumptions about the discount rate, and because no consensus exists on the appropriate rate to use in an intergenerational context, we present SCCs based on the average values across models and socioeconomic scenarios for each discount rate.

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC across models and socio-economic and emissions scenarios at the 2.5, 3, and 5 percent discount rates. The fourth value is included to represent the higher-than-expected economic impacts from climate change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95th percentile at a 3 percent discount rate. (The full set of distributions by model and scenario combination is included in the Appendix.) As noted above, the 3 percent discount rate is the central value, and so the central value that emerges is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range.

As previously discussed, low probability, high impact events are incorporated into the SCC values through explicit consideration of their effects in two of the three models as well as the use of a probability density function for equilibrium climate sensitivity. Treating climate sensitivity probabilistically results in more high temperature outcomes, which in turn lead to higher projections of damages. Although FUND does not include catastrophic damages (in contrast to the other two models), its probabilistic treatment of the equilibrium climate sensitivity parameter will directly affect the non-catastrophic damages that are a function of the rate of temperature change.

In Table 3, we begin by presenting SCC estimates for 2010 by model, scenario, and discount rate to illustrate the variability in the SCC across each of these input parameters. As expected, higher discount rates consistently result in lower SCC values, while lower discount rates result in higher SCC values for each socioeconomic trajectory. It is also evident that there are differences in the SCC estimated across the three main models. For these estimates, FUND produces the lowest estimates, while PAGE generally produces the highest estimates.

Table 3: Disaggregated Social Cost of CO_2 Values by Model, Socio-Economic Trajectory, and Discount Rate for 2010 (in 2007 dollars)

	Discount rate:	**5%**	**3%**	**2.5%**	**3%**
Model	*Scenario*	Avg	Avg	Avg	95th
DICE	IMAGE	10.8	35.8	54.2	70.8
	MERGE	7.5	22.0	31.6	42.1
	Message	9.8	29.8	43.5	58.6
	MiniCAM	8.6	28.8	44.4	57.9
	550 Average	8.2	24.9	37.4	50.8
PAGE	IMAGE	8.3	39.5	65.5	142.4
	MERGE	5.2	22.3	34.6	82.4
	Message	7.2	30.3	49.2	115.6
	MiniCAM	6.4	31.8	54.7	115.4
	550 Average	5.5	25.4	42.9	104.7
FUND	IMAGE	-1.3	8.2	19.3	39.7
	MERGE	-0.3	8.0	14.8	41.3
	Message	-1.9	3.6	8.8	32.1
	MiniCAM	-0.6	10.2	22.2	42.6
	550 Average	-2.7	-0.2	3.0	19.4

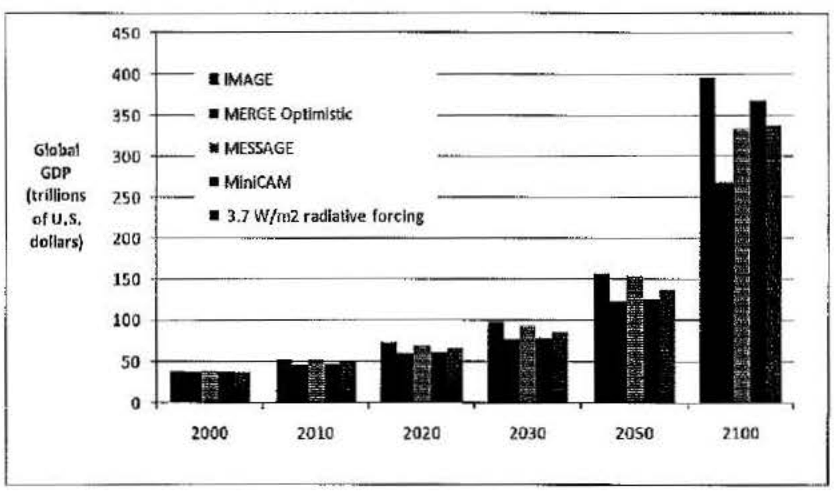
These results are not surprising when compared to the estimates in the literature for the latest versions of each model. For example, adjusting the values from the literature that were used to develop interim

SCC values to 2007 dollars for the year 2010 (assuming, as we did for the interim process, that SCC grows at 3 percent per year), FUND yields SCC estimates at or near zero for a 5 percent discount rate and around \$9 per ton for a 3 percent discount rate. There are far fewer estimates using the latest versions of DICE and PAGE in the literature: Using similar adjustments to generate 2010 estimates, we calculate a SCC from DICE (based on Nordhaus 2008) of around \$9 per ton for a 5 percent discount rate, and a SCC from PAGE (based on Hope 2006, 2008) close to \$8 per ton for a 4 percent discount rate. Note that these comparisons are only approximate since the literature generally relies on Ramsey discounting, while we have assumed constant discount rates.[27]

The SCC estimates from FUND are sensitive to differences in emissions paths but relatively insensitive to differences in GDP paths across scenarios, while the reverse is true for DICE and PAGE. This likely occurs because of several structural differences among the models. Specifically in DICE and PAGE, the fraction of economic output lost due to climate damages increases with the level of temperature alone, whereas in FUND the fractional loss also increases with the rate of temperature change. Furthermore, in FUND increases in income over time decrease vulnerability to climate change (a form of adaptation), whereas this does not occur in DICE and PAGE. These structural differences among the models make FUND more sensitive to the path of emissions and less sensitive to GDP compared to DICE and PAGE.

Figure 3 shows that IMAGE has the highest GDP in 2100 while MERGE Optimistic has the lowest. The ordering of global GDP levels in 2100 directly corresponds to the rank ordering of SCC for PAGE and DICE. For FUND, the correspondence is less clear, a result that is to be expected given its less direct relationship between its damage function and GDP.

Figure 3: Level of Global GDP across EMF Scenarios



[27] Nordhaus (2008) runs DICE2007 with ρ = 1.5 and η = 2. The default approach in PAGE2002 (version 1.4epm) treats ρ and η as random parameters, specified using a triangular distribution such that the min, mode, and max = 0.1, 1, and 2 for ρ, and 0.5, 1, and 2 for η, respectively. The FUND default value for η is 1, and Tol generates SCC estimates for values of ρ = 0, 1, and 3 in many recent papers (e.g. Anthoff et al. 2009). The path of per-capita consumption growth, g, varies over time but is treated deterministically in two of the three models. In DICE, g is endogenous. Under Ramsey discounting, as economic growth slows in the future, the large damages from climate change that occur far out in the future are discounted at a lower rate than impacts that occur in the nearer term.

Table 4 shows the four selected SCC values in five year increments from 2010 to 2050. Values for 2010, 2020, 2040, and 2050 are calculated by first combining all outputs (10,000 estimates per model run) from all scenarios and models for a given discount rate. Values for the years in between are calculated using a simple linear interpolation.

Table 4: Social Cost of CO_2, 2010 – 2050 (in 2007 dollars)

Discount Rate Year	5% Avg	3% Avg	2.5% Avg	3% 95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

The SCC increases over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change. Note that this approach allows us to estimate the growth rate of the SCC directly using DICE, PAGE, and FUND rather than assuming a constant annual growth rate as was done for the interim estimates (using 3 percent). This helps to ensure that the estimates are internally consistent with other modeling assumptions. Table 5 illustrates how the growth rate for these four SCC estimates varies over time. The full set of annual SCC estimates between 2010 and 2050 is reported in the Appendix.

Table 5: Changes in the Average Annual Growth Rates of SCC Estimates between 2010 and 2050

Average Annual Growth Rate (%)	**5%** Avg	**3%** Avg	**2.5%** Avg	**3.0%** 95th
2010-2020	3.6%	2.1%	1.7%	2.2%
2020-2030	3.7%	2.2%	1.8%	2.2%
2030-2040	2.7%	1.8%	1.6%	1.8%
2040-2050	2.1%	1.4%	1.1%	1.3%

While the SCC estimate grows over time, the future monetized value of emissions reductions in each year (the SCC in year *t* multiplied by the change in emissions in year *t*) must be discounted to the present to determine its total net present value for use in regulatory analysis. Damages from future emissions should be discounted at the same rate as that used to calculate the SCC estimates themselves to ensure internal consistency—i.e., future damages from climate change, whether they result from emissions today or emissions in a later year, should be discounted using the same rate. For example, climate damages in the year 2020 that are calculated using a SCC based on a 5 percent discount rate also should be discounted back to the analysis year using a 5 percent discount rate.[28]

V. Limitations of the Analysis

As noted, any estimate of the SCC must be taken as provisional and subject to further refinement (and possibly significant change) in accordance with evolving scientific, economic, and ethical understandings. During the course of our modeling, it became apparent that there are several areas in particular need of additional exploration and research. These caveats, and additional observations in the following section, are necessary to consider when interpreting and applying the SCC estimates.

Incomplete treatment of non-catastrophic damages. The impacts of climate change are expected to be widespread, diverse, and heterogeneous. In addition, the exact magnitude of these impacts is uncertain because of the inherent complexity of climate processes, the economic behavior of current and future populations, and our inability to accurately forecast technological change and adaptation. Current IAMs do not assign value to all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature (some of which are discussed above) because of lack of precise information on the nature of damages and because the science incorporated into these models understandably lags behind the most recent research. Our ability to quantify and monetize impacts will undoubtedly improve with time. But it is also likely that even in future applications, a number of potentially significant damage categories will remain non-monetized. (Ocean acidification is one example of a potentially large damage from CO_2 emissions not quantified by any of the three models. Species and wildlife loss is another example that is exceedingly difficult to monetize.)

Incomplete treatment of potential catastrophic damages. There has been considerable recent discussion of the risk of catastrophic impacts and how best to account for extreme scenarios, such as the collapse of the Atlantic Meridional Overturning Circulation or the West Antarctic Ice Sheet, or large releases of methane from melting permafrost and warming oceans. Weitzman (2009) suggests that catastrophic damages are extremely large—so large, in fact, that the damages from a low probability, catastrophic event far in the future dominate the effect of the discount rate in a present value calculation and result in an infinite willingness-to-pay for mitigation today. However, Nordhaus (2009) concluded that the conditions under which Weitzman's results hold "are limited and do not apply to a wide range of potential uncertain scenarios."

Using a simplified IAM, Newbold and Daigneault (2009) confirmed the potential for large catastrophe risk premiums but also showed that the aggregate benefit estimates can be highly sensitive to the shapes of both the climate sensitivity distribution and the damage function at high temperature changes. Pindyck (2009) also used a simplified IAM to examine high-impact low-probability risks, using a right-skewed gamma distribution for climate sensitivity as well as an uncertain damage coefficient, but in most cases found only a modest risk premium. Given this difference in opinion, further research in this area is needed before its practical significance can be fully understood and a reasonable approach developed to account for such risks in regulatory analysis. (The next section discusses the scientific evidence on catastrophic impacts in greater detail.)

---

[28] However, it is possible that other benefits or costs of proposed regulations unrelated to CO_2 emissions will be discounted at rates that differ from those used to develop the SCC estimates.

Uncertainty in extrapolation of damages to high temperatures: The damage functions in these IAMs are typically calibrated by estimating damages at moderate temperature increases (e.g., DICE was calibrated at 2.5 °C) and extrapolated to far higher temperatures by assuming that damages increase as some power of the temperature change. Hence, estimated damages are far more uncertain under more extreme climate change scenarios.

Incomplete treatment of adaptation and technological change: Each of the three integrated assessment models used here assumes a certain degree of low- or no-cost adaptation. For instance, Tol assumes a great deal of adaptation in FUND, including widespread reliance on air conditioning ; so much so, that the largest single benefit category in FUND is the reduced electricity costs from not having to run air conditioning as intensively (NRC 2009).

Climate change also will increase returns on investment to develop technologies that allow individuals to cope with adverse climate conditions, and IAMs to do not adequately account for this directed technological change.[29] For example, scientists may develop crops that are better able to withstand higher and more variable temperatures. Although DICE and FUND have both calibrated their agricultural sectors under the assumption that farmers will change land use practices in response to climate change (Mastrandrea, 2009), they do not take into account technological changes that lower the cost of this adaptation over time. On the other hand, the calibrations do not account for increases in climate variability, pests, or diseases, which could make adaptation more difficult than assumed by the IAMs for a given temperature change. Hence, models do not adequately account for potential adaptation or technical change that might alter the emissions pathway and resulting damages. In this respect, it is difficult to determine whether the incomplete treatment of adaptation and technological change in these IAMs under or overstate the likely damages.

Risk aversion: A key question unanswered during this interagency process is what to assume about relative risk aversion with regard to high-impact outcomes. These calculations do not take into account the possibility that individuals may have a higher willingness to pay to reduce the likelihood of low-probability, high-impact damages than they do to reduce the likelihood of higher-probability but lower-impact damages with the same expected cost. (The inclusion of the 95th percentile estimate in the final set of SCC values was largely motivated by this concern.) If individuals do show such a higher willingness to pay, a further question is whether that fact should be taken into account for regulatory policy. Even if individuals are not risk-averse for such scenarios, it is possible that regulatory policy should include a degree of risk-aversion.

Assuming a risk-neutral representative agent is consistent with OMB's Circular A-4, which advises that the estimates of benefits and costs used in regulatory analysis are usually based on the average or the expected value and that "emphasis on these expected values is appropriate as long as society is 'risk neutral' with respect to the regulatory alternatives. While this may not always be the case, [analysts] should in general assume 'risk neutrality' in [their] analysis."

Nordhaus (2008) points to the need to explore the relationship between risk and income in the context of climate change across models and to explore the role of uncertainty regarding various parameters in

[29] However these research dollars will be diverted from whatever their next best use would have been in the absence of climate change (so productivity/GDP would have been still higher).

the results. Using FUND, Anthoff et al (2009) explored the sensitivity of the SCC to Ramsey equation parameter assumptions based on observed behavior. They conclude that "the assumed rate of risk aversion is at least as important as the assumed rate of time preference in determining the social cost of carbon." Since Circular A-4 allows for a different assumption on risk preference in regulatory analysis if it is adequately justified, we plan to continue investigating this issue.

V. A Further Discussion of Catastrophic Impacts and Damage Functions

As noted above, the damage functions underlying the three IAMs used to estimate the SCC may not capture the economic effects of all possible adverse consequences of climate change and may therefore lead to underestimates of the SCC (Mastrandrea 2009). In particular, the models' functional forms may not adequately capture: (1) potentially discontinuous "tipping point" behavior in Earth systems, (2) inter-sectoral and inter-regional interactions, including global security impacts of high-end warming, and (3) limited near-term substitutability between damage to natural systems and increased consumption.

It is the hope of the interagency group that over time researchers and modelers will work to fill these gaps and that the SCC estimates used for regulatory analysis by the Federal government will continue to evolve with improvements in modeling. In the meantime, we discuss some of the available evidence.

Extrapolation of climate damages to high levels of warming

The damage functions in the models are calibrated at moderate levels of warming and should therefore be viewed cautiously when extrapolated to the high temperatures found in the upper end of the distribution. Recent science suggests that there are a number of potential climatic "tipping points" at which the Earth system may exhibit discontinuous behavior with potentially severe social and economic consequences (e.g., Lenton et al, 2008, Kriegler et al., 2009). These tipping points include the disruption of the Indian Summer Monsoon, dieback of the Amazon Rainforest and boreal forests, collapse of the Greenland Ice Sheet and the West Antarctic Ice Sheet, reorganization of the Atlantic Meridional Overturning Circulation, strengthening of El Niño-Southern Oscillation, and the release of methane from melting permafrost. Many of these tipping points are estimated to have thresholds between about 3 °C and 5 °C (Lenton et al., 2008). Probabilities of several of these tipping points were assessed through expert elicitation in 2005–2006 by Kriegler et al. (2009); results from this study are highlighted in Table 6. Ranges of probability are averaged across core experts on each topic.

As previously mentioned, FUND does not include potentially catastrophic effects. DICE assumes a small probability of catastrophic damages that increases with increased warming, but the damages from these risks are incorporated as expected values (i.e., ignoring potential risk aversion). PAGE models catastrophic impacts in a probabilistic framework (see Figure 1), so the high-end output from PAGE potentially offers the best insight into the SCC if the world were to experience catastrophic climate change. For instance, at the 95th percentile and a 3 percent discount rate, the SCC estimated by PAGE across the five socio-economic and emission trajectories of \$113 per ton of CO_2 is almost double the value estimated by DICE, \$58 per ton in 2010. We cannot evaluate how well the three models account for catastrophic or non-catastrophic impacts, but this estimate highlights the sensitivity of SCC values in the tails of the distribution to the assumptions made about catastrophic impacts.

Table 6: Probabilities of Various Tipping Points from Expert Elicitation -

Possible Tipping Points	Duration before effect is fully realized (in years)	Additional Warming by 2100		
		0.5-1.5 C	1.5-3.0 C	3-5 C
Reorganization of Atlantic Meridional Overturning Circulation	about 100	0-18%	6-39%	18-67%
Greenland Ice Sheet collapse	at least 300	8-39%	33-73%	67-96%
West Antarctic Ice Sheet collapse	at least 300	5-41%	10-63%	33-88%
Dieback of Amazon rainforest	about 50	2-46%	14-84%	41-94%
Strengthening of El Niño-Southern Oscillation	about 100	1-13%	6-32%	19-49%
Dieback of boreal forests	about 50	13-43%	20-81%	34-91%
Shift in Indian Summer Monsoon	about 1	Not formally assessed		
Release of methane from melting permafrost	Less than 100	Not formally assessed.		

PAGE treats the possibility of a catastrophic event probabilistically, while DICE treats it deterministically (that is, by adding the expected value of the damage from a catastrophe to the aggregate damage function). In part, this results in different probabilities being assigned to a catastrophic event across the two models. For instance, PAGE places a probability near zero on a catastrophe at 2.5 °C warming, while DICE assumes a 4 percent probability of a catastrophe at 2.5 °C. By comparison, Kriegler et al. (2009) estimate a probability of at least 16-36 percent of crossing at least one of their primary climatic tipping points in a scenario with temperatures about 2-4 °C warmer than pre-Industrial levels in 2100.

It is important to note that crossing a climatic tipping point will not necessarily lead to an economic catastrophe in the sense used in the IAMs. A tipping point is a critical threshold across which some aspect of the Earth system starts to shifts into a qualitatively different state (for instance, one with dramatically reduced ice sheet volumes and higher sea levels). In the IAMs, a catastrophe is a low-probability environmental change with high economic impact.

Failure to incorporate inter-sectoral and inter-regional interactions

The damage functions do not fully incorporate either inter-sectoral or inter-regional interactions. For instance, while damages to the agricultural sector are incorporated, the effects of changes in food supply on human health are not fully captured and depend on the modeler's choice of studies used to calibrate the IAM. Likewise, the effects of climate damages in one region of the world on another region are not included in some of the models (FUND includes the effects of migration from sea level rise). These inter-regional interactions, though difficult to quantify, are the basis for climate-induced national and economic security concerns (e.g., Campbell et al., 2007; U.S. Department of Defense 2010) and are particularly worrisome at higher levels of warming. High-end warming scenarios, for instance, project water scarcity affecting 4.3-6.9 billion people by 2050, food scarcity affecting about 120 million additional people by 2080, and the creation of millions of climate refugees (Easterling et al., 2007; Campbell et al., 2007).

Imperfect substitutability of environmental amenities

Data from the geological record of past climate changes suggests that 6 °C of warming may have severe consequences for natural systems. For instance, during the Paleocene-Eocene Thermal Maximum about 55.5 million years ago, when the Earth experienced a geologically rapid release of carbon associated with an approximately 5 °C increase in global mean temperatures, the effects included shifts of about 400-900 miles in the range of plants (Wing et al., 2005), and dwarfing of both land mammals (Gingerich, 2006) and soil fauna (Smith et al., 2009).

The three IAMs used here assume that it is possible to compensate for the economic consequences of damages to natural systems through increased consumption of non-climate goods, a common assumption in many economic models. In the context of climate change, however, it is possible that the damages to natural systems could become so great that no increase in consumption of non-climate goods would provide complete compensation (Levy et al., 2005). For instance, as water supplies become scarcer or ecosystems become more fragile and less bio-diverse, the services they provide may become increasingly more costly to replace. Uncalibrated attempts to incorporate the imperfect substitutability of such amenities into IAMs (Sterner and Persson, 2008) indicate that the optimal degree of emissions abatement can be considerably greater than is commonly recognized.

VI. Conclusion

The interagency group selected four SCC estimates for use in regulatory analyses. For 2010, these estimates are $5, $21, $35, and $65 (in 2007 dollars). The first three estimates are based on the average SCC across models and socio-economic and emissions scenarios at the 5, 3, and 2.5 percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95th percentile at a 3 percent discount rate. The central value is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. These SCC estimates also grow over time. For instance, the central value increases to $24 per ton of CO_2 in 2015 and $26 per ton of CO_2 in 2020.

We noted a number of limitations to this analysis, including the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion. The limited amount of research linking climate impacts to economic damages makes this modeling exercise even more difficult. It is the hope of the interagency group that over time researchers and modelers will work to fill these gaps and that the SCC estimates used for regulatory analysis by the Federal government will continue to evolve with improvements in modeling.

References

Andronova, N., and M. Schlesinger. 2001. "Objective estimation of the probability density function for climate sensitivity." *J. Geophys. Res.*, 106(D19), 22605–22611.

Annan, J., et al., 2005. "Efficiently constraining climate sensitivity with paleoclimate simulations." *Scientific Online Letters on the Atmosphere*, 1, 181–184.

Anthoff D, C. Hepburn, and R. Tol. 2009a. "Equity Weighting and the Marginal Damage Costs of Climate Change." *Ecological Economics* 68:836-849.

Anthoff, D., R. Tol, and G. Yohe. 2009b. "Risk aversion, time preference, and the social cost of carbon." *Environmental Research Letters* 4: 024002 (7pp).

Arrow, K. 2007. "Global climate change: a challenge to policy." *Economist's Voice* 4(3):Article 2.

Arrow, K. 2000. "A Comment on Cooper." *The World Bank Research Observer*. vol 15, no. 2.

Arrow, K., et al. 1996. *Benefit-Cost Analysis in Environmental, Health, and Safety Regulation: A Statement of Principles*. Washington, D.C., AEI Press. pp. 13-14.

Arrow, K.J., et al. 1996. "Intertemporal equity, discounting and economic efficiency," in Climate Change 1995: Economic and Social Dimensions of Climate Change, Contribution of Working Group III to the *Second Assessment Report of the Intergovernmental Panel on Climate Change*.

Campbell, J., P. Diamond, and J. Shoven. 2001. "Estimating the Real Rate of Return on Stocks Over the Long Term." Presented to the Social Security Advisory Board. August.

Campbell, K. et al. 2007. *The age of consequences: The foreign policy and national security implications of global climate change*. Center for Strategic & International Studies, 119 pp.

Castles, I. and D. Henderson. 2003. "The IPCC Emission Scenarios: An Economic-Statistical Critique." *Energy and Environment* 14(2-3): 159-185.

Chetty, R. 2006. "A New Method of Estimating Risk Aversion." *American Economic Review* 96(5): 1821–1834.

Dasgupta P. 2006. "Comments on the Stern Review's economics of climate change." University of Cambridge working paper.

Dasgupta P. 2008. "Discounting climate change." *Journal of Risk and Uncertainty* 37:141-169.

Easterling, W., et al. 2007. *Climate Change 2007: Impacts, Adaptation, and Vulnerability*. Intergovernmental Panel on Climate Change, 976 pp. http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg2_report_impacts_adaptation_and_vulnerability.htm, last accessed March 25, 2010.

Evans D., and H. Sezer. 2005. "Social discount rates for member countries of the European Union." *J. Econ. Stud.* 32 47–59.

Forest, C., et al. 2002. "Quantifying uncertainties in climate system properties with the use of recent observations." *Science* 295, 113.

Forest, D., P. Stone, and A. Sokolov. 2006. "Estimated PDFs of climate system properties including natural and anthropogenic forcings." *Geophys. Res. Lett.*, 33, L01705.

Forster, P., and J. Gregory. 2006. "The climate sensitivity and its components diagnosed from Earth radiation budget data." *J. Clim.*, 19, 39–52.

Frame, D., et al. 2005. "Constraining climate forecasts: The role of prior assumptions." *Geophys. Res. Lett.*, 32, L09702.

Gingerich, P. 2006. "Environment and evolution through the Paleocene-Eocene thermal maximum." *Trends Ecol. Evol.* 21: 246-253.

Gollier, C. 2008. "Discounting with fat-tailed economic growth." *Journal of Risk and Uncertainty* 37:171-186.

Gollier, C. and M. Weitzman (2009). "How Should the Distant Future be Discounted When Discount Rates are Uncertain?" Harvard University, mimeo, Nov 2009.

Gregory, J., et al. 2002a. "An observationally based estimate of the climate sensitivity." *J. Clim.*, 15(22), 3117–3121.

Groom, B., Koundouri, P., Panipoulou, E., Pantelidis, T. 2006. "An econometric approach to estimating long-run discount rates." *Journal of Applied Econometrics.*

Hall R, and C. Jones . 2007. "The value of life and the rise in health spending." Quarterly *Journal of Economics* 122(1):39-72.

Hansen, J.,M. Sato, P. Kharecha, G. Russell, D. W. Lea and M. Siddall. 2007. "Climate change and trace gases." *Phil. Trans. Roy. Soc. A* 365: 1925-1954.

Hegerl G, et al. 2007. "Understanding and attributing climate change." in Solomon S, et al. (eds) *Climate Change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press. http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html

Hegerl, G., T. Crowley, W. Hyde, and D. Frame. 2006. "Constraints on climate sensitivity from temperature reconstructions of the past seven centuries." *Nature* 440.

Holtsmark, B., and K. Alfsen. 2005. "PPP Correction of the IPCC Emission Scenarios – Does it Matter?" *Climatic Change* 68(1-2): 11-19.

Hope C. 2006. "The marginal impact of CO2 from PAGE2002: an integrated assessment model incorporating the IPCC's five reasons for concern." *The Integrated Assessment Journal* 6(1):19-56.

Hope C. 2008. "Optimal carbon emissions and the social cost of carbon under uncertainty." *The Integrated Assessment Journal* 8(1):107-122.

Intergovernmental Panel on Climate Change (2007). "Summary for Policymakers." In *Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Just, R., D. Hueth, and A. Schmitz. 2004. *The Welfare Economics of Public Policy*. Glos UK: Edward Elgar Publishing Limited.

Knutti, R., T. Stocker, F. Joos, and G. Plattner. 2002. "Constraints on radiative forcing and future climate change from observations and climate model ensembles." *Nature*, 416, 719–723.

Kriegler, E. et al. 2009. "Imprecise probability assessment of tipping points in the climate system." *Proc. Natl. Acad. Sci.* 106: 5041-5046.

Kotlikoff, L. and D. Rapson. 2006. "Does It Pay, at the Margin, to Work and Save? – Measuring Effective Marginal Taxes on Americans' Labor Supply and Saving." National Bureau of Economic Research, Working Paper, No. 12533.

Le Treut H., et al. 2007. "Historical Overview of Climate Change." in Solomon et al., *Climate Change 2007*.

Lenton, T., et al. 2008. "Tipping elements in the Earth's climate system." *Proc. Natl. Acad. Sci.* 105: 1786-1793.

Levy, M., et al. 2005. "Ecosystem conditions and human well-being." In: *Ecosystems and Human Well-being: Current State and Trends, Volume 1.* [R. Hassan, R. Scholes, and N. Ash, eds.] Washington: Island Press. pp. 123-164.

Lind, R. 1990. "Reassessing the Government's Discount Rate Policy in Light of New Theory and Data in a World Economy with a High Degree of Capital Mobility." *Journal of Environmental Economics and Management* 18, S-8-S-28.

Mastrandre, M. 2009. "Calculating the benefits of climate policy: Examining the assumptions of Integrated Assessment Models." Pew Center on Global Climate Change Working Paper, 60 pp.

Meehl, G, et al. 2007. "Global Climate Projections." in Solomon et al., *Climate Change 2007*.

National Research Council (2009). *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. National Academies Press.

Newbold S, Daigneault A. 2009. "Climate response uncertainty and the benefits of greenhouse gas emissions reductions." *Environmental and Resource Economics* 44:351-377.

Newell, R., and W. Pizer. 2003. Discounting the distant future: how much do uncertain rates increase valuations? *Journal of Environmental Economics and Management* 46: 52-71.

Nordhaus, W. 1994. "Expert Opinion on Climate Change." *American Scientist* 82: 45-51.

Nordhaus, W. 2007a. *Accompanying notes and documentation on development of DICE-2007 model: notes on DICE-2007.delta.v8 as of September 21, 2007.*

Nordhaus, W. 2007b. "Alternative measures of output in global economic-environmental models: Purchasing power parity or market exchange rates?" *Energy Economics* 29: 349-372.

Nordhaus W. 2008. *A Question of Balance: Weighing the Options on Global Warming Policies*. New Haven, CT: Yale University Press.

Nordhaus, W. 2009. "An Analysis of the Dismal Theorem. Cowles Foundation Discussion Paper. No. 1686. January.

Nordhaus W., and Boyer J. 2000. *Warming the World: Economic Models of Global Warming*. Cambridge, MA: MIT Press.

Pindyck, R. 2009. "Uncertain Outcomes and Climate Change Policy." NBER Working Paper, No. 15259. August.

Ramsey, F. 1928. "A Mathematical Theory of Saving." *The Economic Journal* 38(152): 543-559.

Roe, G. 2008. "Feedbacks, timescales, and seeing red." *Annual Review of Earth and Planetary Sciences* 37:5.1-5.23.

Roe, G., and M. Baker. 2007. "Why is climate sensitivity so unpredictable?" *Science* 318:629-632.

Schneider von Deimling, T., H. Held, A. Ganopolski, and S. Rahmstorf. 2006. "Climate sensitivity estimated from ensemble simulations of glacial climate." *Clim. Dyn.*, 27, 149–163.

Smith, J. et al. 2009. "Transient dwarfism of soil fauna during the Paleocene-Eocene Thermal Maximum." *Proc. Natl. Acad. Sci.* 106: 17665-17660.

Stern, N., et al. (2006), *Stern Review: The Economics of Climate Change*, HM Treasury, London. See http://www.hm-treasury.gov.uk/stern_review_report.htm, last accessed March 25, 2010.

Stern N. 2008. "The economics of climate change." *American Economic Review* 98(2):1-37.

Sterner, T., and U. Persson. 2008. An even Sterner review: Introducing relative prices into the discounting debate. *Rev. Env. Econ. Pol.* 2: 61-76.

Summers, L., and R. Zeckhauser. 2008. "Policymaking for Posterity." Journal of Risk and Uncertainty 37: 115-140.

Szpiro, G. 1986. "Measuring Risk Aversion: An Alternative Approach." *The Review of Economics and Statistics* 68(1): 156-9.

Tol, R. 2002a. "Estimates of the damage costs of climate change. Part I: benchmark estimates." *Environmental and Resource Economics* 21:47-73.

Tol, R. 2002b. "Estimates of the damage costs of climate change. Part II: dynamic estimates." *Environmental and Resource Economics* 21:135-160.

Tol, R. 2006. "Exchange Rates and Climate Change: An Application of FUND." *Climatic Change* 75(1-2): 59-80.

Tol, R. 2009. "An analysis of mitigation as a response to climate change." Copenhagen Consensus on Climate. Discussion Paper.

U.S. Department of Defense. 2010. Quadrennial Defense Review Report. February.

Warren, R., et al. 2006. "Spotlight Impact Functions in Integrated Assessment." Tyndall Center for Climate Change Research, Working Paper 91.

Weitzman, M. 2009. "On modeling and interpreting the economics of catastrophic climate change." *Review of Economics and Statistics* 91:1-19.

Weitzman, M. 2007. "A review of The Stern Review of the Economics of Climate Change." *Journal of Economic Literature* 45:703-724.

Weitzman, M. 1999. In Portney P.R. and Weyant J.P. (eds.), *Discounting and Intergenerational Equity*, Resources for the Future, Washington, D.C.

Weitzman, M. 1998. "Why the Far-Distant Future Should Be Discounted at Its Lowest Possible Rate." *Journal of Environmental Economics and Management* 36 (3): 201-208.

Wing, S. et al. 2005. "Transient floral change and rapid global warming at the Paleocene-Eocene boundary." *Science* 310: 993-996.

Appendix

Table A1: Annual SCC Values: 2010–2050 (in 2007 dollars)

Discount Rate Year	5% Avg	3% Avg	2.5% Avg	3% 95th
2010	4.7	21.4	35.1	64.9
2011	4.9	21.9	35.7	66.5
2012	5.1	22.4	36.4	68.1
2013	5.3	22.8	37.0	69.6
2014	5.5	23.3	37.7	71.2
2015	5.7	23.8	38.4	72.8
2016	5.9	24.3	39.0	74.4
2017	6.1	24.8	39.7	76.0
2018	6.3	25.3	40.4	77.5
2019	6.5	25.8	41.0	79.1
2020	6.8	26.3	41.7	80.7
2021	7.1	27.0	42.5	82.6
2022	7.4	27.6	43.4	84.6
2023	7.7	28.3	44.2	86.5
2024	7.9	28.9	45.0	88.4
2025	8.2	29.6	45.9	90.4
2026	8.5	30.2	46.7	92.3
2027	8.8	30.9	47.5	94.2
2028	9.1	31.5	48.4	96.2
2029	9.4	32.1	49.2	98.1
2030	9.7	32.8	50.0	100.0
2031	10.0	33.4	50.9	102.0
2032	10.3	34.1	51.7	103.9
2033	10.6	34.7	52.5	105.8
2034	10.9	35.4	53.4	107.8
2035	11.2	36.0	54.2	109.7
2036	11.5	36.7	55.0	111.6
2037	11.8	37.3	55.9	113.6
2038	12.1	37.9	56.7	115.5
2039	12.4	38.6	57.5	117.4
2040	12.7	39.2	58.4	119.3
2041	13.0	39.8	59.0	121.0
2042	13.3	40.4	59.7	122.7
2043	13.6	40.9	60.4	124.4
2044	13.9	41.5	61.0	126.1
2045	14.2	42.1	61.7	127.8
2046	14.5	42.6	62.4	129.4
2047	14.8	43.2	63.0	131.1
2048	15.1	43.8	63.7	132.8
2049	15.4	44.4	64.4	134.5
2050	15.7	44.9	65.0	136.2

This Appendix also provides additional technical information about the non-CO_2 emission projections used in the modeling and the method for extrapolating emissions forecasts through 2300, and shows the full distribution of 2010 SCC estimates by model and scenario combination.

1. Other (non-CO_2) gases

In addition to fossil and industrial CO_2 emissions, each EMF scenario provides projections of methane (CH_4), nitrous oxide (N_2O), fluorinated gases, and net land use CO_2 emissions to 2100. These assumptions are used in all three IAMs while retaining each model's default radiative forcings (RF) due to other factors (e.g., aerosols and other gases). Specifically, to obtain the RF associated with the non-CO_2 EMF emissions only, we calculated the RF associated with the EMF atmospheric CO_2 concentrations and subtracted them from the EMF total RF.[30] This approach respects the EMF scenarios as much as possible and at the same time takes account of those components not included in the EMF projections. Since each model treats non-CO_2 gases differently (e.g., DICE lumps all other gases into one composite exogenous input), this approach was applied slightly differently in each of the models.

FUND: Rather than relying on RF for these gases, the actual emissions from each scenario were used in FUND. The model default trajectories for CH_4, N_20, SF_6, and the CO_2 emissions from land were replaced with the EMF values.

PAGE: PAGE models CO_2, CH_4, sulfur hexafluoride (SF_6), and aerosols and contains an "excess forcing" vector that includes the RF for everything else. To include the EMF values, we removed the default CH_4 and SF_6 factors[31], decomposed the excess forcing vector, and constructed a new excess forcing vector that includes the EMF RF for CH_4, N_20, and fluorinated gases, as well as the model default values for aerosols and other factors. Net land use CO_2 emissions were added to the fossil and industrial CO_2 emissions pathway.

DICE: DICE presents the greatest challenge because all forcing due to factors other than industrial CO_2 emissions is embedded in an exogenous non-CO_2 RF vector. To decompose this exogenous forcing path into EMF non-CO_2 gases and other gases, we relied on the references in DICE2007 to the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report (AR4) and the discussion of aerosol forecasts in the IPCC's Third Assessment Report (TAR) and in AR4, as explained below. In DICE2007, Nordhaus assumes that exogenous forcing from all non-CO_2 sources is -0.06 W/m^2 in 2005, as reported in AR4, and increases linearly to 0.3 W/m^2 in 2105, based on GISS projections, and then stays constant after that time.

---

[30] Note EMF did not provide CO_2 concentrations for the IMAGE reference scenario. Thus, for this scenario, we fed the fossil, industrial and land CO_2 emissions into MAGICC (considered a "neutral arbiter" model, which is tuned to emulate the major global climate models) and the resulting CO_2 concentrations were used. Note also that MERGE assumes a neutral biosphere so net land CO_2 emissions are set to zero for all years for the MERGE Optimistic reference scenario, and for the MERGE component of the average 550 scenario (i.e., we add up the land use emissions from the other three models and divide by 4).

[31] Both the model default CH_4 emissions and the initial atmospheric CH_4 is set to zero to avoid double counting the effect of past CH_4 emissions.

According to AR4, the RF in 2005 from CH_4, N_2O, and halocarbons (approximately similar to the F-gases in the EMF-22 scenarios) was 0.48 + 0.16 + 0.34 = 0.98 W/m^2 and RF from total aerosols was -1.2 W/m^2. Thus, the -.06 W/m^2 non-CO_2 forcing in DICE can be decomposed into: 0.98 W/m^2 due to the EMF non-CO_2 gases, -1.2 W/m^2 due to aerosols, and the remainder, 0.16 W/m^2, due to other residual forcing.

For subsequent years, we calculated the DICE default RF from aerosols and other non-CO_2 gases based on the following two assumptions:

(1) RF from aerosols declines linearly from 2005 to 2100 at the rate projected by the TAR and then stays constant thereafter, and
(2) With respect to RF from non-CO_2 gases not included in the EMF-22 scenarios, the share of non-aerosol RF matches the share implicit in the AR4 summary statistics cited above and remains constant over time.

Assumption (1) means that the RF from aerosols in 2100 equals 66 percent of that in 2000, which is the fraction of the TAR projection of total RF from aerosols (including sulfates, black carbon, and organic carbon) in 2100 vs. 2000 under the A1B SRES emissions scenario. Since the SRES marker scenarios were not updated for the AR4, the TAR provides the most recent IPCC projection of aerosol forcing. We rely on the A1B projection from the TAR because it provides one of the lower aerosol forecasts among the SRES marker scenarios and is more consistent with the AR4 discussion of the post-SRES literature on aerosols:

Aerosols have a net cooling effect and the representation of aerosol and aerosol precursor emissions, including sulphur dioxide, black carbon and organic carbon, has improved in the post-SRES scenarios. Generally, these emissions are projected to be lower than reported in SRES. {WGIII 3.2, TS.3, SPM}.[32]

Assuming a simple linear decline in aerosols from 2000 to 2100 also is more consistent with the recent literature on these emissions. For example, Figure A1 shows that the sulfur dioxide emissions peak over the short-term of some SRES scenarios above the upper bound estimates of the more recent scenarios.[33] Recent scenarios project sulfur emissions to peak earlier and at lower levels compared to the SRES in part because of new information about present and planned sulfur legislation in some developing countries, such as India and China.[34] The lower bound projections of the recent literature have also shifted downward slightly compared to the SRES scenario (IPCC 2007).

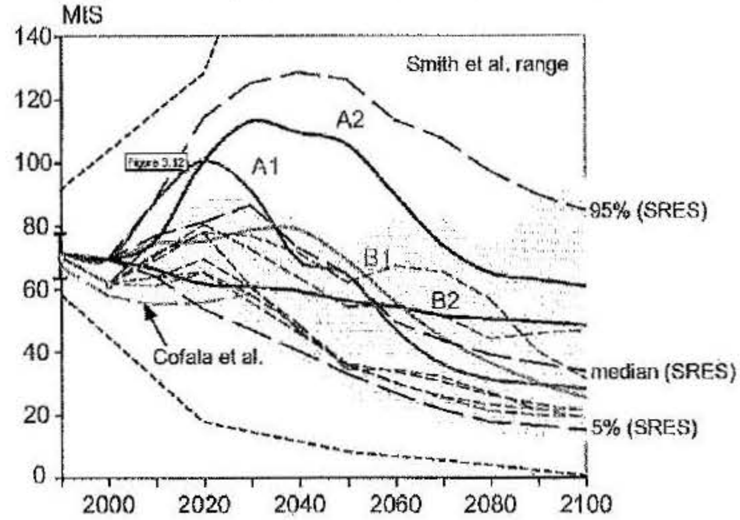
[32] AR4 Synthesis Report, p. 44, http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

[33] See Smith, S.J., R. Andres, E. Conception, and J. Lurz, 2004: Historical sulfur dioxide emissions, 1850-2000: methods and results. Joint Global Research Institute, College Park, 14 pp.

[34] See Carmichael, G., D. Streets, G. Calori, M. Amann, M. Jacobson, J. Hansen, and H. Ueda, 2002: Changing trends in sulphur emissions in Asia: implications for acid deposition, air pollution, and climate. Environmental Science and Technology, 36(22):4707- 4713; Streets, D., K. Jiang, X. Hu, J. Sinton, X.-Q. Zhang, D. Xu, M. Jacobson, and J. Hansen, 2001: Recent reductions in China's greenhouse gas emissions. Science, 294(5548): 1835-1837.

With these assumptions, the DICE aerosol forcing changes from -1.2 in 2005 to -0.792 in 2105 W/m^2; forcing due to other non-CO_2 gases not included in the EMF scenarios declines from 0.160 to 0.153 W/m^2.

Figure A1: Sulphur Dioxide Emission Scenarios -



Notes: Thick colored lines depict the four SRES marker scenarios and black dashed lines show the median, 5th and 95th percentile of the frequency distribution for the full ensemble of 40 SRES scenarios. The blue area (and the thin dashed lines in blue) illustrates individual scenarios and the range of Smith et al. (2004). Dotted lines indicate the minimum and maximum of SO_2 emissions scenarios developed pre-SRES.
Source: IPCC (2007), AR4 WGIII 3.2, http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch3-ens3-2-2-4.html.

Although other approaches to decomposing the DICE exogenous forcing vector are possible, initial sensitivity analysis suggests that the differences among reasonable alternative approaches are likely to be minor. For example, adjusting the TAR aerosol projection above to assume that aerosols will be maintained at 2000 levels through 2100 reduces average SCC values (for 2010) by approximately 3 percent (or less than $2); assuming all aerosols are phased out by 2100 increases average 2010 SCC values by 6-7 percent (or $0.50-$3)–depending on the discount rate. These differences increase slightly for SCC values in later years but are still well within 10 percent of each other as far out as 2050.

Finally, as in PAGE, the EMF net land use CO_2 emissions are added to the fossil and industrial CO_2 emissions pathway.

2. - Extrapolating Emissions Projections to 2300

To run each model through 2300 requires assumptions about GDP, population, greenhouse gas emissions, and radiative forcing trajectories after 2100, the last year for which these projections are available from the EMF-22 models. These inputs were extrapolated from 2100 to 2300 as follows:

1. Population growth rate declines linearly, reaching zero in the year 2200.
2. GDP/ per capita growth rate declines linearly, reaching zero in the year 2300.
3. The decline in the fossil and industrial carbon intensity (CO_2/GDP) growth rate over 2090-2100 is maintained from 2100 through 2300.
4. Net land use CO_2 emissions decline linearly, reaching zero in the year 2200.
5. Non-CO_2 radiative forcing remains constant after 2100.

Long run stabilization of GDP per capita was viewed as a more realistic simplifying assumption than a linear or exponential extrapolation of the pre-2100 economic growth rate of each EMF scenario. This is based on the idea that increasing scarcity of natural resources and the degradation of environmental sinks available for assimilating pollution from economic production activities may eventually overtake the rate of technological progress. Thus, the overall rate of economic growth may slow over the very long run. The interagency group also considered allowing an exponential decline in the growth rate of GDP per capita. However, since this would require an additional assumption about how close to zero the growth rate would get by 2300, the group opted for the simpler and more transparent linear extrapolation to zero by 2300.

The population growth rate is also assumed to decline linearly, reaching zero by 2200. This assumption is reasonably consistent with the United Nations long run population forecast, which estimates global population to be fairly stable after 2150 in the medium scenario (UN 2004).[35] The resulting range of EMF population trajectories (Figure A2) also encompass the UN medium scenario forecasts through 2300 – global population of 8.5 billion by 2200, and 9 billion by 2300.

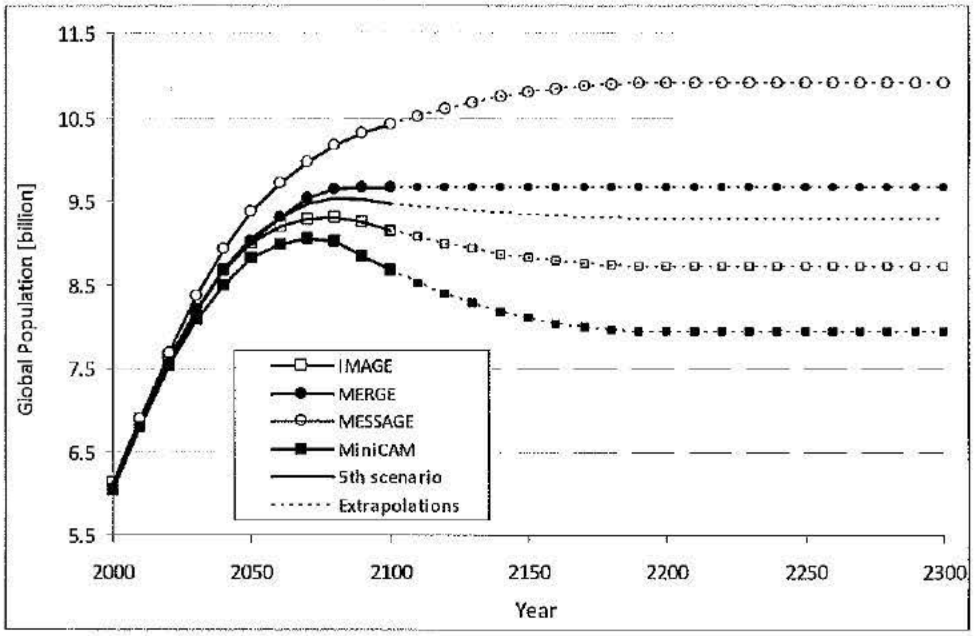
Maintaining the decline in the 2090-2100 carbon intensity growth rate (i.e., CO_2 per dollar of GDP) through 2300 assumes that technological improvements and innovations in the areas of energy efficiency and other carbon reducing technologies (possibly including currently unavailable methods) will continue to proceed at roughly the same pace that is projected to occur towards the end of the forecast period for each EMF scenario. This assumption implies that total cumulative emissions in 2300 will be between 5,000 and 12,000 GtC, which is within the range of the total potential global carbon stock estimated in the literature.

Net land use CO_2 emissions are expected to stabilize in the long run, so in the absence of any post 2100 projections, the group assumed a linear decline to zero by 2200. Given no a priori reasons for assuming a long run increase or decline in non-CO_2 radiative forcing, it is assumed to remain at the 2100 levels for each EMF scenario through 2300.

Figures A2-A7 show the paths of global population, GDP, fossil and industrial CO_2 emissions, net land CO_2 emissions, non-CO_2 radiative forcing, and CO_2 intensity (fossil and industrial CO_2 emissions/GDP) resulting from these assumptions.

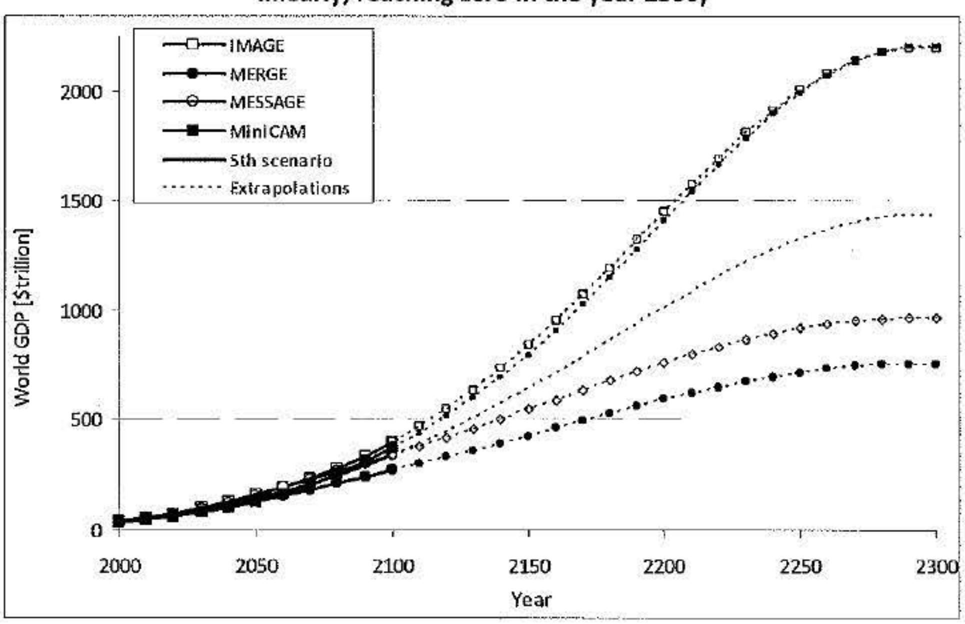
[35] United Nations. 2004. *World Population to 2300.*
http://www.un.org/esa/population/publications/longrange2/worldpop2300final.pdf

Figure A2. Global Population, 2000-2300 (Post-2100 extrapolations assume the population growth - rate changes linearly to reach a zero growth rate by 2200.) -



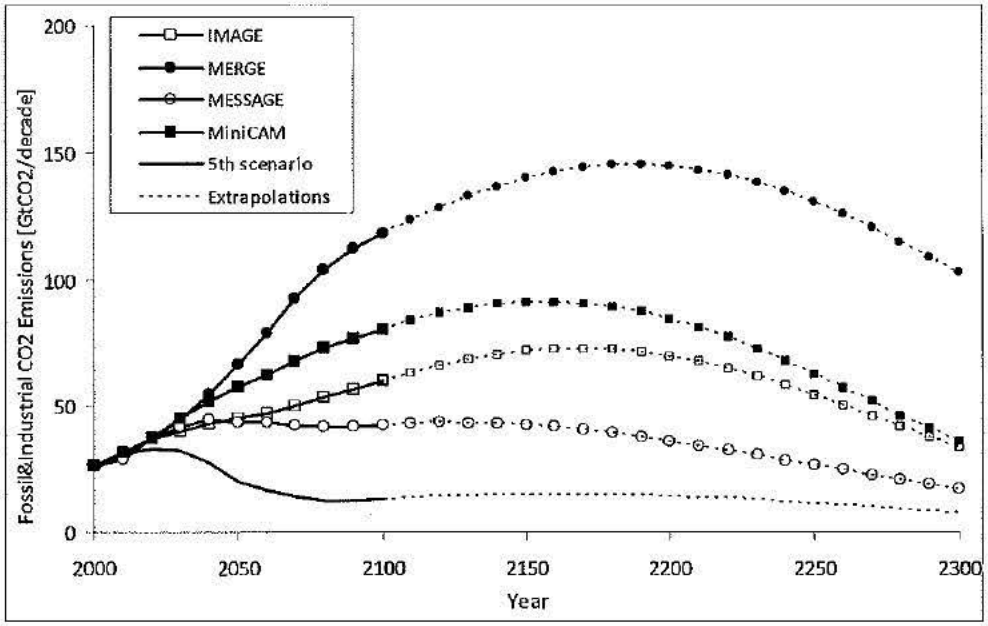
Note: In the fifth scenario, 2000-2100 population is equal to the average of the population under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

Figure A3. World GDP, 2000-2300 (Post-2100 extrapolations assume GDP per capita growth declines linearly, reaching zero in the year 2300)



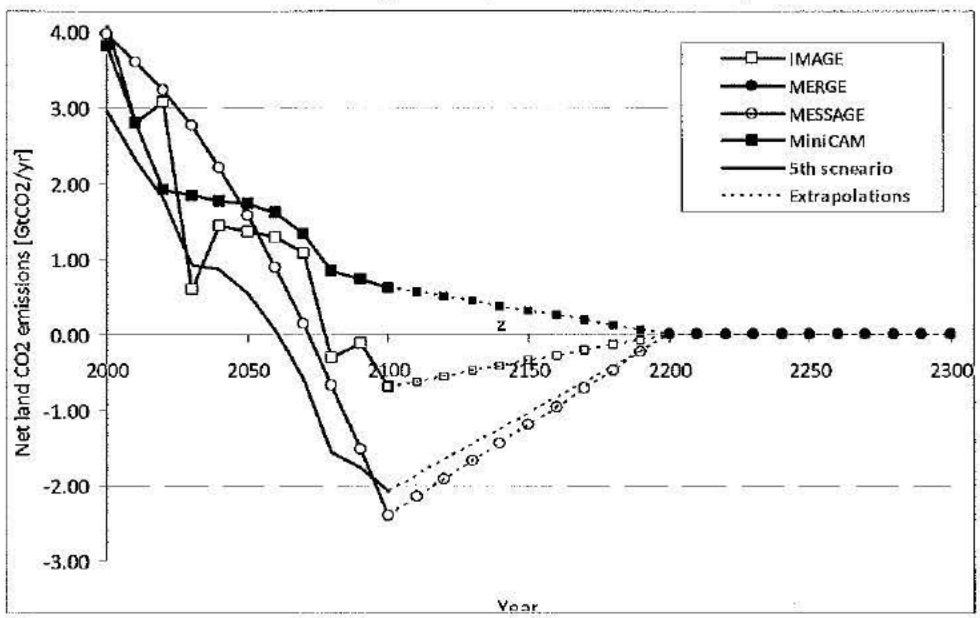
Note: In the fifth scenario, 2000-2100 GDP is equal to the average of the GDP under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

Figure A4. Global Fossil and Industrial CO_2 Emissions, 2000-2300 (Post-2100 extrapolations assume growth rate of CO_2 intensity (CO_2/GDP) over 2090-2100 is maintained through 2300.)



Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO2e, full-participation, not-to-exceed scenarios considered by each of the four models.

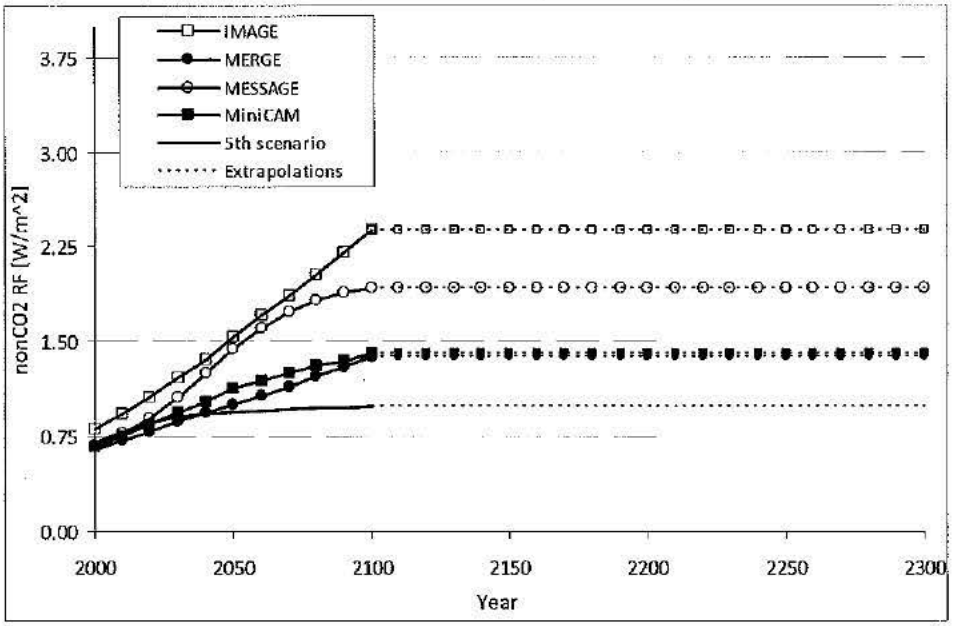
Figure A5. Global Net Land Use CO_2 Emissions, 2000-2300 (Post-2100 extrapolations assume emissions decline linearly, reaching zero in the year 2200)[36]



Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO2e, full-participation, not-to-exceed scenarios considered by each of the four models.

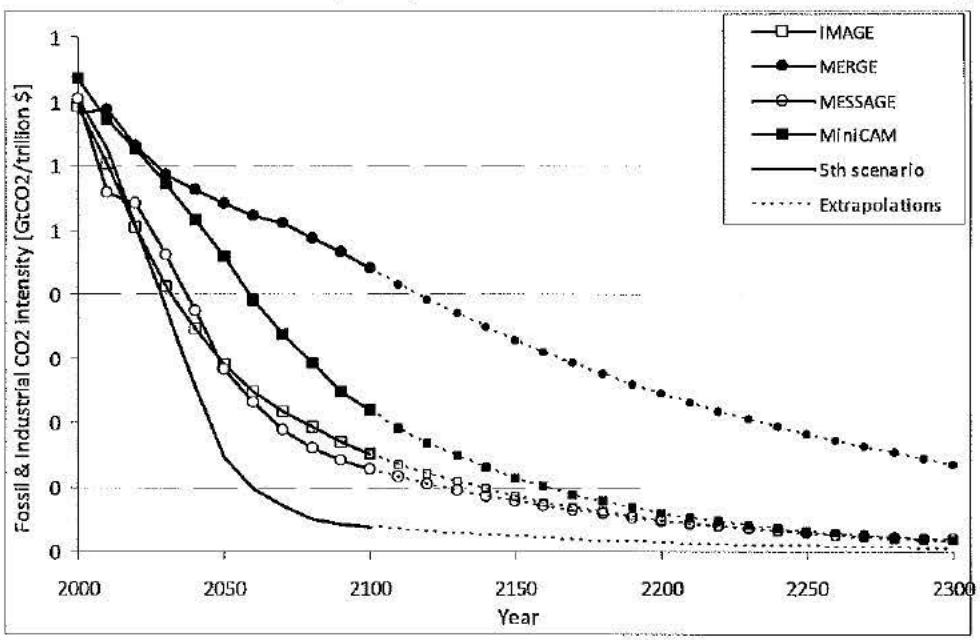
[36] MERGE assumes a neutral biosphere so net land CO_2 emissions are set to zero for all years for the MERGE Optimistic reference scenario, and for the MERGE component of the average 550 scenario (i.e., we add up the land use emissions from the other three models and divide by 4).

Figure A6. Global Non-CO_2 Radiative Forcing, 2000-2300 (Post-2100 extrapolations assume constant non-CO_2 radiative forcing after 2100.)



Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO2e, full-participation, not-to-exceed scenarios considered by each of the four models.

Figure A7. Global CO_2 Intensity (fossil & industrial CO_2 emissions/GDP), 2000-2300 (Post-2100 extrapolations assume decline in CO_2/GDP growth rate over 2090-2100 is maintained through 2300.)



Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

Table A2. 2010 Global SCC Estimates at 2.5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario						PAGE				
IMAGE	3.3	5.9	8.1	13.9	28.8	65.5	68.2	147.9	239.6	563.8
MERGE optimistic	1.9	3.2	4.3	7.2	14.6	34.6	36.2	79.8	124.8	288.3
Message	2.4	4.3	5.8	9.8	20.3	49.2	50.7	114.9	181.7	428.4
MiniCAM base	2.7	4.6	6.4	11.2	22.8	54.7	55.7	120.5	195.3	482.3
5th scenario	2.0	3.5	4.7	8.1	16.3	42.9	41.5	103.9	176.3	371.9
Scenario						DICE				
IMAGE	16.4	21.4	25	33.3	46.8	54.2	69.7	96.3	111.1	130.0
MERGE optimistic	9.7	12.6	14.9	19.7	27.9	31.6	40.7	54.5	63.5	73.3
Message	13.5	17.2	20.1	27	38.5	43.5	55.1	75.8	87.9	103.0
MiniCAM base	13.1	16.7	19.8	26.7	38.6	44.4	56.8	79.5	92.8	109.3
5th scenario	10.8	14	16.7	22.2	32	37.4	47.7	67.8	80.2	96.8
Scenario						FUND				
IMAGE	-33.1	-18.9	-13.3	-5.5	4.1	19.3	18.7	43.5	67.1	150.7
MERGE optimistic	-33.1	-14.8	-10	-3	5.9	14.8	20.4	43.9	65.4	132.9
Message	-32.5	-19.8	-14.6	-7.2	1.5	8.8	13.8	33.7	52.3	119.2
MiniCAM base	-31.0	-15.9	-10.7	-3.4	6	22.2	21	46.4	70.4	152.9
5th scenario	-32.2	-21.6	-16.7	-9.7	-2.3	3	6.7	20.5	34.2	96.8

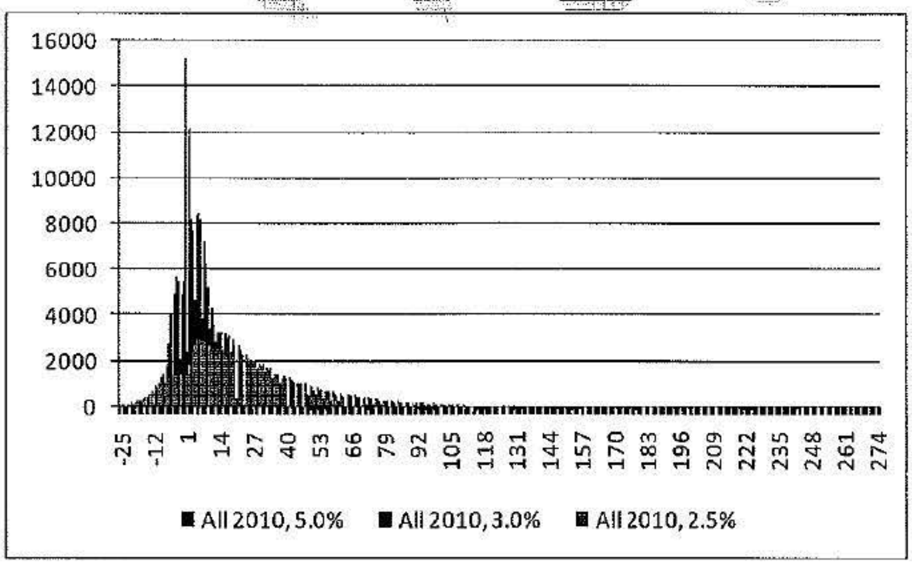
Table A3. 2010 Global SCC Estimates at 3 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario						PAGE				
IMAGE	2.0	3.5	4.8	8.1	16.5	39.5	41.6	90.3	142.4	327.4
MERGE optimistic	1.2	2.1	2.8	4.6	9.3	22.3	22.8	51.3	82.4	190.0
Message	1.6	2.7	3.6	6.2	12.5	30.3	31	71.4	115.6	263.0
MiniCAM base	1.7	2.8	3.8	6.5	13.2	31.8	32.4	72.6	115.4	287.0
5th scenario	1.3	2.3	3.1	5	9.6	25.4	23.6	62.1	104.7	222.5
Scenario						DICE				
IMAGE	11.0	14.5	17.2	22.8	31.6	35.8	45.4	61.9	70.8	82.1
MERGE optimistic	7.1	9.2	10.8	14.3	19.9	22	27.9	36.9	42.1	48.8
Message	9.7	12.5	14.7	19	26.6	29.8	37.8	51.1	58.6	67.4
MiniCAM base	8.8	11.5	13.6	18	25.2	28.8	36.9	50.4	57.9	67.8
5th scenario	7.9	10.1	11.8	15.6	21.6	24.9	31.8	43.7	50.8	60.6
Scenario						FUND				
IMAGE	-25.2	-15.3	-11.2	-5.6	0.9	8.2	10.4	25.4	39.7	90.3
MERGE optimistic	-24.0	-12.4	-8.7	-3.6	2.6	8	12.2	27	41.3	85.3
Message	-25.3	-16.2	-12.2	-6.8	-0.5	3.6	7.7	20.1	32.1	72.5
MiniCAM base	-23.1	-12.9	-9.3	-4	2.4	10.2	12.2	27.7	42.6	93.0
5th scenario	-24.1	-16.6	-13.2	-8.3	-3	-0.2	2.9	11.2	19.4	53.6

Table A4. 2010 Global SCC Estimates at 5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario						**PAGE**				
IMAGE	0.5	0.8	1.1	1.8	3.5	8.3	8.5	19.5	31.4	67.2
MERGE optimistic	0.3	0.5	0.7	1.2	2.3	5.2	5.4	12.3	19.5	42.4
Message	0.4	0.7	0.9	1.6	3	7.2	7.2	17	28.2	60.8
MiniCAM base	0.3	0.6	0.8	1.4	2.7	6.4	6.6	15.9	24.9	52.6
5th scenario	0.3	0.6	0.8	1.3	2.3	5.5	5	12.9	22	48.7
Scenario						**DICE**				
IMAGE	4.2	5.4	6.2	7.6	10	10.8	13.4	16.8	18.7	21.1
MERGE optimistic	2.9	3.7	4.2	5.3	7	7.5	9.3	11.7	12.9	14.4
Message	3.9	4.9	5.5	7	9.2	9.8	12.2	15.4	17.1	18.8
MiniCAM base	3.4	4.2	4.7	6	7.9	8.6	10.7	13.5	15.1	16.9
5th scenario	3.2	4	4.6	5.7	7.6	8.2	10.2	12.8	14.3	16.0
Scenario						**FUND**				
IMAGE	-11.7	-8.4	-6.9	-4.6	-2.2	-1.3	0.7	4.1	7.4	17.4
MERGE optimistic	-10.6	-7.1	-5.6	-3.6	-1.3	-0.3	1.6	5.4	9.1	19.0
Message	-12.2	-8.9	-7.3	-4.9	-2.5	-1.9	0.3	3.5	6.5	15.6
MiniCAM base	-10.4	-7.2	-5.8	-3.8	-1.5	-0.6	1.3	4.8	8.2	18.0
5th scenario	-10.9	-8.3	-7	-5	-2.9	-2.7	-0.8	1.4	3.2	9.2

Figure A8. Histogram of Global SCC Estimates in 2010 (2007$/ton CO_2), by discount rate



* The distribution of SCC values ranges from -$5,192 to $66,116 but the X-axis has been truncated at approximately the 1st and 99th percentiles to better show the data.

Table A5. Additional Summary Statistics of 2010 Global SCC Estimates -

Discount rate:	5%				3%				2.5%			
Scenario	Mean	Variance	Skewness	Kurtosis	Mean	Variance	Skewness	Kurtosis	Mean	Variance	Skewness	Kurtosis
DICE	9.0	13.1	0.8	0.2	28.3	209.8	1.1	0.9	42.2	534.9	1.2	1.1
PAGE	6.5	136.0	6.3	72.4	29.8	3,383.7	8.6	151.0	49.3	9,546.0	8.7	143.8
FUND	-1.3	70.1	28.2	1,479.0	6.0	16,382.5	128.0	18,976.5	13.6	150,732.6	149.0	23,558.3

Technical Support Document: -
Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis -
Under Executive Order 12866 -

Interagency Working Group on Social Cost of Greenhouse Gases, United States Government

With participation by

Council of Economic Advisers
Council on Environmental Quality
Department of Agriculture
Department of Commerce
Department of Energy
Department of the Interior
Department of Transportation
Department of the Treasury
Environmental Protection Agency
National Economic Council
Office of Management and Budget
Office of Science and Technology Policy

August 2016
See Appendix B for Details on Revisions since May 2013

Preface

The Interagency Working Group on the Social Cost of Greenhouse Gases (formerly the Interagency Working Group on the Social Cost of Carbon) has a longstanding commitment to ensure that the social cost of carbon estimates continue to reflect the best available science and methodologies. Given this commitment and public comments on issues of a deeply technical nature received by the Office of Management and Budget and federal agencies, the Interagency Working Group is seeking independent expert advice on technical opportunities to update the social cost of carbon estimates. The Interagency Working Group asked the National Academies of Sciences, Engineering, and Medicine in 2015 to review the latest research on modeling the economic aspects of climate change to inform future revisions to the social cost of carbon estimates presented in this technical support document. In January 2016, the Academies' Committee on the Social Cost of Carbon issued an interim report that recommended against a near-term update to the social cost of carbon estimates, but included recommendations for enhancing the presentation and discussion of uncertainty around the current estimates. This revision to the TSD responds to these recommendations in the presentation of the current estimates. It does not revisit the interagency group's 2010 methodological decisions or update the schedule of social cost of carbon estimates presented in the July 2015 revision. The Academies' final report (expected in early 2017) will provide longer term recommendations for a more comprehensive update.

Executive Summary

Executive Order 12866 requires agencies, to the extent permitted by law, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the social cost of carbon (SC-CO_2)[1] estimates presented here is to allow agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions. The SC-CO_2 is the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change.

The interagency process that developed the original U.S. government SC-CO_2 estimates is described in the 2010 Technical Support Document on the Social Cost of Carbon (TSD) (Interagency Working Group on Social Cost of Carbon 2010). Through that process the Interagency Working Group (IWG) selected SC-CO_2 values for use in regulatory analyses. For each emissions year, four values are recommended. Three of these values are based on the average SC-CO_2 from three integrated assessment models (IAMs), at discount rates of 2.5, 3, and 5 percent. In addition, as discussed in the 2010 TSD, there is extensive evidence in the scientific and economic literature on the potential for lower-probability, but higher-impact outcomes from climate change, which would be particularly harmful to society and thus relevant to the public and policymakers. The fourth value is thus included to represent the marginal damages associated with these lower-probability, higher-impact outcomes. Accordingly, this fourth value is selected from further out in the tail of the distribution of SC-CO_2 estimates; specifically, the fourth value corresponds to the 95th percentile of the frequency distribution of SC-CO_2 estimates based on a 3 percent discount rate. Because the present value of economic damages associated with CO_2 emissions change over time, a separate set of estimates is presented for each emissions year through 2050, which is sufficient to cover the time frame addressed in most current regulatory impact analyses.

In May of 2013, the IWG provided an update of the SC-CO_2 estimates based on new versions of each IAM (DICE, PAGE, and FUND). The 2013 update did not revisit other IWG modeling decisions (e.g., the discount rate, reference case socioeconomic and emission scenarios, or equilibrium climate sensitivity). Improvements in the way damages are modeled were confined to those that had been incorporated into the latest versions of the models by the developers themselves in the peer-reviewed literature. The IWG subsequently provided additional minor technical revisions in November of 2013 and July of 2015, as described in Appendix B.

The purpose of this 2016 revision to the TSD is to enhance the presentation and discussion of quantified uncertainty around the current SC-CO_2 estimates, as a response to recommendations in the interim report by the National Academies of Sciences, Engineering, and Medicine. Included herein are an expanded

[1] Throughout this Technical Support Document (TSD) we refer to the estimates as "SC-CO_2 estimates" rather than the more simplified "SCC" abbreviation used in previous versions of the TSD.

graphical presentation of the SC-CO_2 estimates highlighting a symmetric range of uncertainty around estimates for each discount rate, new sections that provide a unified discussion of the methodology used to incorporate sources of uncertainty, and a detailed explanation of the uncertain parameters in both the FUND and PAGE models.

The distributions of SC-CO_2 estimates reflect uncertainty in key model parameters chosen by the IWG such as the sensitivity of the climate to increases in carbon dioxide concentrations, as well as uncertainty in default parameters set by the original model developers. This TSD maintains the same approach to estimating the SC-CO_2 and selecting four values for each emissions year that was used in earlier versions of the TSD. Table ES-1 summarizes the SC-CO_2 estimates for the years 2010 through 2050. These estimates are identical to those reported in the previous version of the TSD, released in July 2015. As explained in previous TSDs, the central value is the average of SC-CO_2 estimates based on the 3 percent discount rate. For purposes of capturing uncertainty around the SC-CO_2 estimates in regulatory impact analysis, the IWG emphasizes the importance of considering all four SC-CO_2 values.

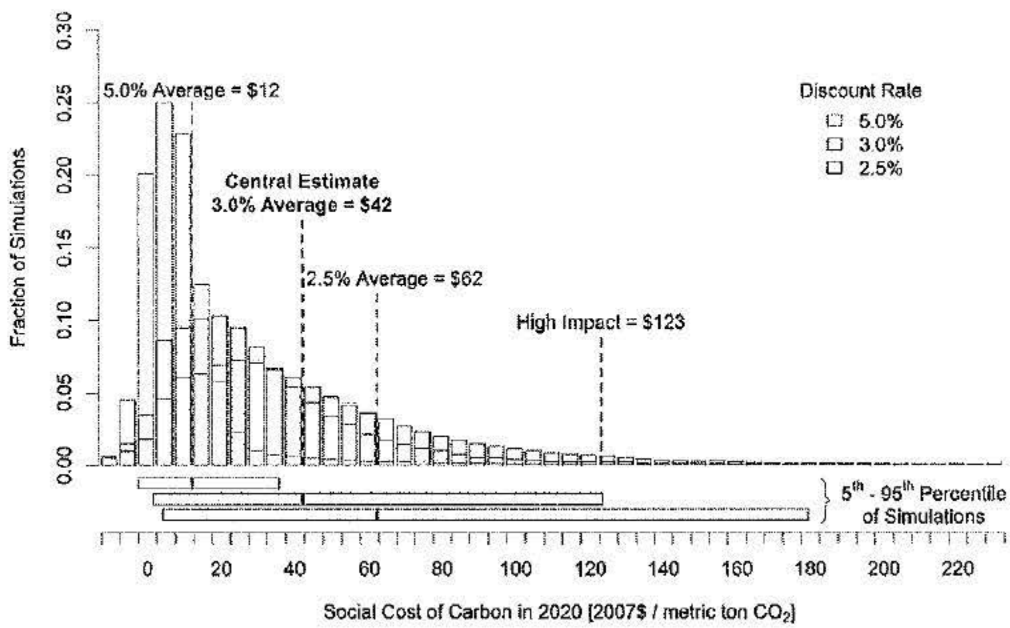
Table ES-1: Social Cost of CO_2, 2010 – 2050 (in 2007 dollars per metric ton of CO_2)

Year	5% Average	**3% Average**	2.5% Average	High Impact (95th Pct at 3%)
2010	10	**31**	50	86
2015	11	**36**	56	105
2020	12	**42**	62	123
2025	14	**46**	68	138
2030	16	**50**	73	152
2035	18	**55**	78	168
2040	21	**60**	84	183
2045	23	**64**	89	197
2050	26	**69**	95	212

While point estimates are important for providing analysts with a tractable approach for regulatory analysis, they do not fully quantify uncertainty associated with the SC-CO_2 estimates. Figure ES-1 presents the quantified sources of uncertainty in the form of frequency distributions for the SC-CO_2 estimates for emissions in 2020. To highlight the difference between the impact of the discount rate on the SC-CO_2 and other quantified sources of uncertainty, the bars below the frequency distributions provide a symmetric representation of quantified variability in the SC-CO_2 estimates for each discount rate. When an agency determines that it is appropriate to conduct additional quantitative uncertainty analysis, it should follow best practices for probabilistic analysis.[2] The full set of information that underlies the frequency distributions in Figure ES-1, which have previously been available upon request, are now available on Office of Management and Budget's (OMB) website for easy public access.

[2] See e.g. OMB Circular A-4, section on *Treatment of Uncertainty*. Available at: https://www.whitehouse.gov/omb/circulars_a004_a-4/#e.

Figure ES-1: Frequency Distribution of SC-CO_2 Estimates for 2020[3]



[3] Although the distributions in Figure ES-1 are based on the full set of model results (150,000 estimates for each discount rate), for display purposes the horizontal axis is truncated with 0.1 to 0.6 percent of the estimates lying below the lowest bin displayed and 0.2 to 3.7 percent of the estimates lying above the highest bin displayed, depending on the discount rate.

I. Purpose

The purpose of this document is to present the current schedule of social cost of carbon (SC-CO_2) estimates, along with an enhanced presentation and discussion of quantified sources of uncertainty around the estimates to respond to recommendations in the interim report of the National Academies of Sciences, Engineering, and Medicine (National Academies 2016).[4] Because the last substantive update to the SC-CO_2 estimates occurred in May 2013, this document maintains much of the earlier technical discussion from the May 2013 TSD. The SC-CO_2 estimates themselves remain unchanged since the July 2015 revision.

E.O. 13563 commits the Administration to regulatory decision making "based on the best available science."[5] Additionally, the IWG recommended in 2010 that the SC-CO_2 estimates be revisited on a regular basis or as model updates that reflect the growing body of scientific and economic knowledge become available.[6] By early 2013, new versions of the three integrated assessment models (IAMs) used by the U.S. government to estimate the SC-CO_2 (DICE, FUND, and PAGE) were available and had been published in the peer-reviewed literature. While acknowledging the continued limitations of the approach taken by the IWG in 2010 (documented in the original 2010 TSD), the May 2013 TSD provided an update of the SC-CO_2 estimates based on the latest peer-reviewed version of the models, replacing model versions that were developed up to ten years earlier in a rapidly evolving field. It did not revisit other assumptions with regard to the discount rate, reference case socioeconomic and emission scenarios, or equilibrium climate sensitivity. Improvements in the way damages are modeled were confined to those that had been incorporated into the latest versions of the models by the developers themselves in the peer-reviewed literature. The agencies participating in the IWG continue to investigate potential improvements to the way in which economic damages associated with changes in CO_2 emissions are quantified.

Section II summarizes the major features of the IAMs used in this TSD that were updated in 2013 relative to the versions of the models used in the 2010 TSD. Section III presents the SC-CO_2 estimates for 2010 – 2050 based on these versions of the models. Section IV discusses the treatment of uncertainty in the analysis. Section V provides a discussion of other model limitations and research gaps.

II. Summary of Model Updates

This section briefly reviews the features of the three IAMs used in this TSD (DICE 2010, FUND 3.8, and PAGE 2009) that were updated by the model developers relative to the versions of the models used by the IWG in 2010 (DICE 2007, FUND 3.5, and PAGE 2002). The focus here is on describing those model updates that are relevant to estimating the social cost of carbon, as summarized in Table 1. For example, both the DICE and PAGE models now include an explicit representation of sea level rise damages. Other

---

[4] In this document, we present all social cost estimates per metric ton of CO_2 emissions. Alternatively, one could report the social cost per metric ton of carbon emissions. The multiplier for translating between mass of CO_2 and the mass of carbon is 3.67 (the molecular weight of CO_2 divided by the molecular weight of carbon = 44/12 = 3.67).
[5] http://www.whitehouse.gov/sites/default/files/omb/inforeg/eo12866/eo13563_01182011.pdf
[6] See p. 1, 3, 4, 29, and 33 (Interagency Working Group on Social Cost of Carbon 2010).

revisions to PAGE include: updated adaptation assumptions, revisions to ensure damages are constrained by GDP, updated regional scaling of damages, and a revised treatment of potentially abrupt shifts in climate damages. The DICE model's simple carbon cycle has been updated to be more consistent with a more complex climate model. The FUND model includes updated damage functions for sea level rise impacts, the agricultural sector, and reduced space heating requirements, as well as changes to the transient response of temperature to the buildup of GHG concentrations and the inclusion of indirect effects of methane emissions. Changes made to parts of the models that are superseded by the IWG's modeling assumptions—regarding equilibrium climate sensitivity, discounting, and socioeconomic variables—are not discussed here but can be found in the references provided in each section below.

Table 1: Summary of Key Model Revisions Relevant to the IWG SC-CO_2 Estimates

IAM	Version used in 2010 IWG Analysis	Version Used since May 2013	Key changes relevant to IWG SC-CO_2
DICE	2007	2010	Updated calibration of the carbon cycle model and explicit representation of sea level rise (SLR) and associated damages.
FUND	3.5 (2009)	3.8 (2012)	Updated damage functions for space heating, SLR, agricultural impacts, changes to transient response of temperature to buildup of GHG concentrations, and inclusion of indirect climate effects of methane.
PAGE	2002	2009	Explicit representation of SLR damages, revisions to damage function to ensure damages do not exceed 100% of GDP, change in regional scaling of damages, revised treatment of potential abrupt damages, and updated adaptation assumptions.

A. DICE

DICE 2010 includes a number of changes over the previous 2007 version used in the 2010 TSD. The model changes that are relevant for the SC-CO_2 estimates developed by the IWG include: 1) updated parameter values for the carbon cycle model, 2) an explicit representation of sea level dynamics, and 3) a re-calibrated damage function that includes an explicit representation of economic damages from sea level rise. Changes were also made to other parts of the DICE model—including the equilibrium climate sensitivity parameter, the rate of change of total factor productivity, and the elasticity of the marginal utility of consumption—but these components of DICE are superseded by the IWG's assumptions and so will not be discussed here. More details on DICE2007 can be found in Nordhaus (2008) and on DICE2010 in Nordhaus (2010). The DICE2010 model and documentation is also available for download from the homepage of William Nordhaus.

Carbon Cycle Parameters

DICE uses a three-box model of carbon stocks and flows to represent the accumulation and transfer of carbon among the atmosphere, the shallow ocean and terrestrial biosphere, and the deep ocean. These parameters are "calibrated to match the carbon cycle in the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC)" (Nordhaus 2008, p. 44).[7] Carbon cycle transfer coefficient values in DICE2010 are based on re-calibration of the model to match the newer 2009 version of MAGICC (Nordhaus 2010, p. 2). For example, in DICE2010, in each decade 12 percent of the carbon in the atmosphere is transferred to the shallow ocean, 4.7 percent of the carbon in the shallow ocean is transferred to the atmosphere, 94.8 percent remains in the shallow ocean, and 0.5 percent is transferred to the deep ocean. For comparison, in DICE 2007, 18.9 percent of the carbon in the atmosphere is transferred to the shallow ocean each decade, 9.7 percent of the carbon in the shallow ocean is transferred to the atmosphere, 85.3 percent remains in the shallow ocean, and 5 percent is transferred to the deep ocean.

The implication of these changes for DICE2010 is in general a weakening of the ocean as a carbon sink and therefore a higher concentration of carbon in the atmosphere than in DICE2007 for a given path of emissions. All else equal, these changes will generally increase the level of warming and therefore the SC-CO_2 estimates in DICE2010 relative to those from DICE2007.

Sea Level Dynamics

A new feature of DICE2010 is an explicit representation of the dynamics of the global average sea level anomaly to be used in the updated damage function (discussed below). This section contains a brief description of the sea level rise (SLR) module; a more detailed description can be found on the model developer's website.[8] The average global sea level anomaly is modeled as the sum of four terms that represent contributions from: 1) thermal expansion of the oceans, 2) melting of glaciers and small ice caps, 3) melting of the Greenland ice sheet, and 4) melting of the Antarctic ice sheet.

The parameters of the four components of the SLR module are calibrated to match consensus results from the IPCC's Fourth Assessment Report (AR4).[9] The rise in sea level from thermal expansion in each time period (decade) is 2 percent of the difference between the sea level in the previous period and the long run equilibrium sea level, which is 0.5 meters per degree Celsius (°C) above the average global temperature in 1900. The rise in sea level from the melting of glaciers and small ice caps occurs at a rate of 0.008 meters per decade per °C above the average global temperature in 1900.

The contribution to sea level rise from melting of the Greenland ice sheet is more complex. The equilibrium contribution to SLR is 0 meters for temperature anomalies less than 1 °C and increases linearly from 0 meters to a maximum of 7.3 meters for temperature anomalies between 1 °C and 3.5 °C. The contribution to SLR in each period is proportional to the difference between the previous period's sea

[7] MAGICC is a simple climate model initially developed by the U.S. National Center for Atmospheric Research that has been used heavily by the Intergovernmental Panel on Climate Change (IPCC) to emulate projections from more sophisticated state of the art earth system simulation models (Randall et al. 2007).
[8] Documentation on the new sea level rise module of DICE is available on William Nordhaus' website at: http://nordhaus.econ.yale.edu/documents/SLR_021910.pdf.
[9] For a review of post-IPCC AR4 research on sea level rise, see Nicholls et al. (2011) and NAS (2011).

level anomaly and the equilibrium sea level anomaly, where the constant of proportionality increases with the temperature anomaly in the current period.

The contribution to SLR from the melting of the Antarctic ice sheet is -0.001 meters per decade when the temperature anomaly is below 3 °C and increases linearly between 3 °C and 6 °C to a maximum rate of 0.025 meters per decade at a temperature anomaly of 6 °C.

Re-calibrated Damage Function

Economic damages from climate change in the DICE model are represented by a fractional loss of gross economic output in each period. A portion of the remaining economic output in each period (net of climate change damages) is consumed and the remainder is invested in the physical capital stock to support future economic production, so each period's climate damages will reduce consumption in that period and in all future periods due to the lost investment. The fraction of output in each period that is lost due to climate change impacts is represented as a sigmoid, or "S"-shaped, function of the temperature anomaly in the period.[10] The loss function in DICE2010 has been expanded by including a quadratic sub-function of SLR. In DICE2010 the temperature anomaly coefficients have been recalibrated to avoid double-counting damages from sea level rise that were implicitly included in these parameters in DICE2007.

The aggregate damages in DICE2010 are illustrated by Nordhaus (2010, p. 3), who notes that "...damages in the uncontrolled (baseline) [i.e., reference] case ... in 2095 are $12 trillion, or 2.8 percent of global output, for a global temperature increase of 3.4 °C above 1900 levels." This compares to a loss of 3.2 percent of global output at 3.4 °C in DICE2007. However, in DICE2010, annual damages are lower in most of the early periods of the modeling horizon but higher in later periods than would be calculated using the DICE2007 damage function. Specifically, the percent difference between damages in the base run of DICE2010 and those that would be calculated using the DICE2007 damage function starts at +7 percent in 2005, decreases to a low of -14 percent in 2065, then continuously increases to +20 percent by 2300 (the end of the IWG analysis time horizon), and to +160 percent by the end of the model time horizon in 2595. The large increases in the far future years of the time horizon are due to the permanence associated with damages from sea level rise, along with the assumption that the sea level is projected to continue to rise long after the global average temperature begins to decrease. The changes to the loss function generally decrease the IWG SC-CO_2 estimates slightly given that relative increases in damages in later periods are discounted more heavily, all else equal.

B. FUND

FUND version 3.8 includes a number of changes over the previous version 3.5 (Narita et al. 2010) used in the 2010 TSD. Documentation supporting FUND and the model's source code for all versions of the model

[10] The model and documentation, including formulas, are available on the author's webpage at http://www.econ.yale.edu/~nordhaus/homepage/RICEmodels.htm.

is available from the model authors.[11] Notable changes, due to their impact on the SC-CO_2 estimates, are adjustments to the space heating, agriculture, and sea level rise damage functions in addition to changes to the temperature response function and the inclusion of indirect effects from methane emissions.[12] Each of these is discussed in turn.

Space Heating

In FUND, the damages associated with the change in energy needs for space heating are based on the estimated impact due to one degree of warming. These baseline damages are scaled based on the forecasted temperature anomaly's deviation from the one degree benchmark and adjusted for changes in vulnerability due to economic and energy efficiency growth. In FUND 3.5, the function that scales the base year damages adjusted for vulnerability allows for the possibility that in some simulations the benefits associated with reduced heating needs may be an unbounded convex function of the temperature anomaly. In FUND 3.8, the form of the scaling has been modified to ensure that the function is everywhere concave and that there will exist an upper bound on the benefits a region may receive from reduced space heating needs. The new formulation approaches a value of two in the limit of large temperature anomalies, or in other words, assuming no decrease in vulnerability, the reduced expenditures on space heating at any level of warming will not exceed two times the reductions experienced at one degree of warming. Since the reduced need for space heating represents a benefit of climate change in the model, or a negative damage, this change will increase the estimated SC-CO_2. This update accounts for a significant portion of the difference in the expected SC-CO_2 estimates reported by the two versions of the model when run probabilistically.

Sea Level Rise and Land Loss

The FUND model explicitly includes damages associated with the inundation of dry land due to sea level rise. The amount of land lost within a region depends on the proportion of the coastline being protected by adequate sea walls and the amount of sea level rise. In FUND 3.5 the function defining the potential land lost in a given year due to sea level rise is linear in the rate of sea level rise for that year. This assumption implicitly assumes that all regions are well represented by a homogeneous coastline in length and a constant uniform slope moving inland. In FUND 3.8 the function defining the potential land lost has been changed to be a convex function of sea level rise, thereby assuming that the slope of the shore line

---

[11] http://www.fund-model.org/. This report uses version 3.8 of the FUND model, which represents a modest update to the most recent version of the model to appear in the literature (version 3.7) (Anthoff and Tol, 2013a, 2013b). For the purpose of computing the SC-CO_2, the relevant changes (between 3.7 to 3.8) are associated with improving consistency with IPCC AR4 by adjusting the atmospheric lifetimes of CH_4 and N_2O and incorporating the indirect forcing effects of CH_4, along with making minor stability improvements in the sea wall construction algorithm.

[12] The other damage sectors (water resources, space cooling, land loss, migration, ecosystems, human health, and extreme weather) were not significantly updated.

increases moving inland. The effect of this change is to typically reduce the vulnerability of some regions to sea level rise based land loss, thereby lowering the expected SC-CO_2 estimate. [13]

[13] For stability purposes this report also uses an update to the model which assumes that regional coastal protection measures will be built to protect the most valuable land first, such that the marginal benefits of coastal protection is decreasing in the level of protection following Fankhauser (1995).

Agriculture

In FUND, the damages associated with the agricultural sector are measured as proportional to the sector's value. The fraction is bounded from above by one and is made up of three additive components that represent the effects from carbon fertilization, the rate of temperature change, and the level of the temperature anomaly. In both FUND 3.5 and FUND 3.8, the fraction of the sector's value lost due to the level of the temperature anomaly is modeled as a quadratic function with an intercept of zero. In FUND 3.5, the coefficients of this loss function are modeled as the ratio of two random normal variables. This specification had the potential for unintended extreme behavior as draws from the parameter in the denominator approached zero or went negative. In FUND 3.8, the coefficients are drawn directly from truncated normal distributions so that they remain in the range $[0,\infty)$ and $(-\infty,0]$, respectively, ensuring the correct sign and eliminating the potential for divide-by-zero errors. The means for the new distributions are set equal to the ratio of the means from the normal distributions used in the previous version. In general the impact of this change has been to decrease the range of the distribution while spreading out the distributions' mass over the remaining range relative to the previous version. The net effect of this change on the SC-CO_2 estimates is difficult to predict.

Transient Temperature Response

The temperature response model translates changes in global levels of radiative forcing into the current expected temperature anomaly. In FUND, a given year's increase in the temperature anomaly is based on a mean reverting function where the mean equals the equilibrium temperature anomaly that would eventually be reached if that year's level of radiative forcing were sustained. The rate of mean reversion defines the rate at which the transient temperature approaches the equilibrium. In FUND 3.5, the rate of temperature response is defined as a decreasing linear function of equilibrium climate sensitivity to capture the fact that the progressive heat uptake of the deep ocean causes the rate to slow at higher values of the equilibrium climate sensitivity. In FUND 3.8, the rate of temperature response has been updated to a quadratic function of the equilibrium climate sensitivity. This change reduces the sensitivity of the rate of temperature response to the level of the equilibrium climate sensitivity, a relationship first noted by Hansen et al. (1985) based on the heat uptake of the deep ocean. Therefore in FUND 3.8, the temperature response will typically be faster than in the previous version. The overall effect of this change is likely to increase estimates of the SC-CO_2 as higher temperatures are reached during the timeframe analyzed and as the same damages experienced in the previous version of the model are now experienced earlier and therefore discounted less.

Methane

The IPCC AR4 notes a series of indirect effects of methane emissions, and has developed methods for proxying such effects when computing the global warming potential of methane (Forster et al. 2007). FUND 3.8 now includes the same methods for incorporating the indirect effects of methane emissions. Specifically, the average atmospheric lifetime of methane has been set to 12 years to account for the feedback of methane emissions on its own lifetime. The radiative forcing associated with atmospheric methane has also been increased by 40% to account for its net impact on ozone production and stratospheric water vapor. This update to the model is relevant for the SC-CO_2 because most of the damage functions are non-linear functions of the temperature anomaly, which represents the fact that as the climate system becomes more stressed an additional unit of warming will have a greater impact on damages. Accounting for the indirect effects of CH_4 emissions on temperature will therefore move the model further up the damage curves in the baseline, making a marginal change in emissions of CO_2 more impactful. All else equal, the effect of this increased radiative forcing will be to increase the estimated SC-CO_2 values, due to greater projected temperature anomaly.

C. PAGE

PAGE09 (Hope 2013) includes a number of changes from PAGE2002, the version used in the 2010 TSD. The changes that most directly affect the SC-CO_2 estimates include: explicitly modeling the impacts from sea level rise, revisions to the damage function to ensure damages are constrained by GDP, a change in the regional scaling of damages, a revised treatment for the probability of a discontinuity within the damage function, and revised assumptions on adaptation. The model also includes revisions to the carbon cycle feedback and the calculation of regional temperatures.[14] More details on PAGE09 can be found in Hope (2011a, 2011b, 2011c). A description of PAGE2002 can be found in Hope (2006).

Sea Level Rise

While PAGE2002 aggregates all damages into two categories—economic and non-economic impacts—PAGE09 adds a third explicit category: damages from sea level rise. In the previous version of the model, damages from sea level rise were subsumed by the other damage categories. In PAGE09 sea level damages increase less than linearly with sea level under the assumption that land, people, and GDP are more concentrated in low-lying shoreline areas. Damages from the economic and non-economic sectors were adjusted to account for the introduction of this new category.

Revised Damage Function to Account for Saturation

In PAGE09, small initial economic and non-economic benefits (negative damages) are modeled for small temperature increases, but all regions eventually experience economic damages from climate change, where damages are the sum of additively separable polynomial functions of temperature and sea level rise. Damages transition from this polynomial function to a logistic path once they exceed a certain proportion of remaining Gross Domestic Product (GDP) to ensure that damages do not exceed 100 percent of GDP. This differs from PAGE2002, which allowed Eastern Europe to potentially experience large benefits from temperature increases, and which also did not bound the possible damages that could be experienced.

[14] Because several changes in the PAGE model are structural (e.g., the addition of sea level rise and treatment of discontinuity), it is not possible to assess the direct impact of each change on the SC-CO_2 in isolation as done for the other two models above.

Regional Scaling Factors

As in the previous version of PAGE, the PAGE09 model calculates the damages for the European Union (EU) and then, assumes that damages for other regions are proportional based on a given scaling factor. The scaling factors in PAGE09 are based on the length of each region's coastline relative to the EU (Hope 2011b). Because of the long coastline in the EU, other regions are, on average, less vulnerable than the EU for the same sea level and temperature increase, but all regions have a positive scaling factor. PAGE2002 based its scaling factors on four studies reported in the IPCC's third assessment report, and allowed for benefits from temperature increases in Eastern Europe, smaller impacts in developed countries, and higher damages in developing countries.

Probability of a Discontinuity

In PAGE2002, the damages associated with a "discontinuity" (nonlinear extreme event) were modeled as an expected value. Specifically, a stochastic probability of a discontinuity was multiplied by the damages associated with a discontinuity to obtain an expected value, and this was added to the economic and non-economic impacts. That is, additional damages from an extreme event, such as extreme melting of the Greenland ice sheet, were multiplied by the probability of the event occurring and added to the damage estimate. In PAGE09, the probability of discontinuity is treated as a discrete event for each year in the model. The damages for each model run are estimated either with or without a discontinuity occurring, rather than as an expected value. A large-scale discontinuity becomes possible when the temperature rises beyond some threshold value between 2 and 4°C. The probability that a discontinuity will occur beyond this threshold then increases by between 10 and 30 percent for every 1°C rise in temperature beyond the threshold. If a discontinuity occurs, the EU loses an additional 5 to 25 percent of its GDP (drawn from a triangular distribution with a mean of 15 percent) in addition to other damages, and other regions lose an amount determined by their regional scaling factor. The threshold value for a possible discontinuity is lower than in PAGE2002, while the rate at which the probability of a discontinuity increases with the temperature anomaly and the damages that result from a discontinuity are both higher than in PAGE2002. The model assumes that only one discontinuity can occur and that the impact is phased in over a period of time, but once it occurs, its effect is permanent.

Adaptation

As in PAGE2002, adaptation is available to help mitigate any climate change impacts that occur. In PAGE this adaptation is the same regardless of the temperature change or sea level rise and is therefore akin to what is more commonly considered a reduction in vulnerability. It is modeled by reducing the damages by some percentage. PAGE09 assumes a smaller decrease in vulnerability than the previous version of the model and assumes that it will take longer for this change in vulnerability to be realized. In the aggregated economic sector, at the time of full implementation, this adaptation will mitigate all damages up to a temperature increase of 1°C, and for temperature anomalies between 1°C and 2°C, it will reduce damages by 15-30 percent (depending on the region). However, it takes 20 years to fully implement this adaptation. In PAGE2002, adaptation was assumed to reduce economic sector damages up to 2°C by 50-90 percent after 20 years. Beyond 2°C, no adaptation is assumed to be available to mitigate the impacts of climate change. For the non-economic sector, in PAGE09 adaptation is available to reduce 15 percent of the damages due to a temperature increase between 0°C and 2°C and is assumed to take 40 years to fully implement, instead of 25 percent of the damages over 20 years assumed in PAGE2002. Similarly, adaptation is assumed to alleviate 25-50 percent of the damages from the first 0.20 to 0.25 meters of sea level rise but is assumed to be ineffective thereafter. Hope (2011c) estimates that the less optimistic assumptions regarding the ability to offset impacts of temperature and sea level rise via adaptation increase the SC-CO_2 by approximately 30 percent.

Other Noteworthy Changes

Two other changes in the model are worth noting. There is a change in the way the model accounts for decreased CO_2 absorption on land and in the ocean as temperature rises. PAGE09 introduces a linear feedback from global mean temperature to the percentage gain in the excess concentration of CO_2, capped at a maximum level. In PAGE2002, an additional amount was added to the CO_2 emissions each period to account for a decrease in ocean absorption and a loss of soil carbon. Also updated is the method by which the average global and annual temperature anomaly is downscaled to determine annual average regional temperature anomalies to be used in the regional damage functions. In PAGE2002, the scaling was determined solely based on regional difference in emissions of sulfate aerosols. In PAGE09, this regional temperature anomaly is further adjusted using an additive factor that is based on the average absolute latitude of a region relative to the area weighted average absolute latitude of the Earth's landmass, to capture relatively greater changes in temperature forecast to be experienced at higher latitudes.

III. SC-CO_2 Estimates

The three IAMs were run using the same methodology detailed in the 2010 TSD (Interagency Working Group on Social Cost of Carbon 2010). The approach, along with the inputs for the socioeconomic emissions scenarios, equilibrium climate sensitivity distribution, and discount rate remains the same. This includes the five reference scenarios based on the EMF-22 modeling exercise, the Roe and Baker equilibrium climate sensitivity distribution calibrated to the IPCC AR4, and three constant discount rates of 2.5, 3, and 5 percent.

As was previously the case, use of three models, three discount rates, and five scenarios produces 45 separate frequency distributions of SC-CO_2 estimates in a given year. The approach laid out in the 2010 TSD applied equal weight to each model and socioeconomic scenario in order to reduce the dimensionality down to three separate distributions, one for each of the three discount rates. The IWG selected four values from these distributions for use in regulatory analysis. Three values are based on the average SC-CO_2 across models and socioeconomic and emissions scenarios at the 2.5, 3, and 5 percent discount rates, respectively. The fourth value is included to provide information on the marginal damages associated with lower-probability, higher-impact outcomes that would be particularly harmful to society. As discussed in the 2010 TSD, there is extensive evidence in the scientific and economic literature of the potential for lower-probability, higher-impact outcomes from climate change, which would be particularly harmful to society and thus relevant to the public and policymakers. This points to the relevance of values above the mean in right skewed distributions. Accordingly, this fourth value is selected from further out in the tails of the frequency distribution of SC-CO_2 estimates, and, in particular, is set to the 95th percentile of the frequency distribution of SC-CO_2 estimates based on a 3 percent discount rate. (A detailed set of percentiles by model and scenario combination and additional summary statistics for the 2020 values is available in Appendix A.) As noted in the 2010 TSD, "the 3 percent discount rate is the central value, and so the central value that emerges is the average SC-CO_2 across models at the 3 percent discount rate" (Interagency Working Group on Social Cost of Carbon 2010, p. 25). However, for purposes of capturing the uncertainties involved in regulatory impact analysis, the IWG emphasizes the importance and value of including all four SC-CO_2 values.

Table 2 shows the four selected SC-CO_2 estimates in five year increments from 2010 to 2050. Values for 2010, 2020, 2030, 2040, and 2050 are calculated by first combining all outputs (10,000 estimates per model run) from all scenarios and models for a given discount rate. Values for the years in between are calculated using linear interpolation. The full set of revised annual SC-CO_2 estimates between 2010 and 2050 is reported in the Appendix and the full set of model results are available on the OMB website.[15]

Table 2: Social Cost of CO_2, 2010 – 2050 (in 2007 dollars per metric ton of CO_2)

Year	5% Average	**3% Average**	2.5% Average	High Impact (95th Pct at 3%)
2010	10	**31**	50	86
2015	11	**36**	56	105
2020	12	**42**	62	123
2025	14	**46**	68	138
2030	16	**50**	73	152
2035	18	**55**	78	168
2040	21	**60**	84	183
2045	23	**64**	89	197
2050	26	**69**	95	212

As was the case in the 2010 TSD, the SC-CO_2 increases over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change, and because GDP is growing over time and many damage categories are modeled as proportional to gross GDP. The approach taken by the IWG is to compute the cost of a marginal ton emitted in the future by running the models for a set of perturbation years out to 2050. Table 3 illustrates how the growth rate for these four SC-CO_2 estimates varies over time.

[15] https://www.whitehouse.gov/omb/oira/social-cost-of-carbon.

Table 3: Average Annual Growth Rates of SC-CO_2 Estimates between 2010 and 2050

Average Annual Growth Rate (%)	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010-2020	1.2%	3.2%	2.4%	4.4%
2020-2030	3.4%	2.1%	1.7%	2.3%
2030-2040	3.0%	1.9%	1.5%	2.0%
2040-2050	2.6%	1.6%	1.3%	1.6%

The future monetized value of emission reductions in each year (the SC-CO_2 in year *t* multiplied by the change in emissions in year *t*) must be discounted to the present to determine its total net present value for use in regulatory analysis. As previously discussed in the 2010 TSD, damages from future emissions should be discounted at the same rate as that used to calculate the SC-CO_2 estimates themselves to ensure internal consistency—i.e., future damages from climate change, whether they result from emissions today or emissions in a later year, should be discounted to the base year of the analysis using the same rate.

Current guidance contained in OMB Circular A-4 indicates that analysis of economically significant proposed and final regulations from the domestic perspective is required, while analysis from the international perspective is optional. However, the IWG (including OMB) determined that a modified approach is more appropriate in this case because the climate change problem is highly unusual in a number of respects. First, it involves a global externality: emissions of most greenhouse gases contribute to damages around the world even when they are emitted in the United States—and conversely, greenhouse gases emitted elsewhere contribute to damages in the United States. Consequently, to address the global nature of the problem, the SC-CO_2 must incorporate the full (global) damages caused by GHG emissions. Second, climate change presents a problem that the United States alone cannot solve. Other countries will also need to take action to reduce emissions if significant changes in the global climate are to be avoided. Emphasizing the need for a global solution to a global problem, the United States has been actively involved in seeking international agreements to reduce emissions. For example, the United States joined over 170 other nations and signed the Paris Agreement on April 22, 2016, signaling worldwide commitment to reduce GHG emissions. The United States has been active in encouraging other nations, including emerging major economies, to take significant steps to reduce emissions. Using a global estimate of damages in U.S. regulatory analyses sends a strong signal to other nations that they too should base their emissions reductions strategies on a global perspective, thus supporting a cooperative and mutually beneficial approach to achieving needed reduction. Thirteen prominent academics noted that these "are compelling reasons to focus on a global [SC-CO_2]" in a recent article on the SC-CO_2 (Pizer et al. 2014). In addition, adverse impacts on other countries can have spillover effects on the United States, particularly in the areas of national security, international trade, public health, and humanitarian concerns. When these considerations are taken as a whole, the IWG concluded that a global measure of the benefits from reducing U.S. emissions is appropriate. For additional discussion, see the 2010 TSD.

IV. Treatment of Uncertainty

Uncertainty about the value of the SC-CO_2 is in part inherent, as with any analysis that looks into the future, but it is also driven by current data gaps associated with the complex physical, economic, and behavioral processes that link GHG emissions to human health and well-being. Some sources of uncertainty pertain to aspects of the natural world, such as quantifying the physical effects of greenhouse gas emissions on Earth systems. Other sources of uncertainty are associated with current and future human behavior and well-being, such as population and economic growth, GHG emissions, the translation of Earth system changes to economic damages, and the role of adaptation. It is important to note that even in the presence of uncertainty, scientific and economic analysis can provide valuable information to the public and decision makers, though the uncertainty should be acknowledged and when possible taken into account in the analysis. This section summarizes the sources of uncertainty that the IWG was able to consider in a quantitative manner in estimating the SC-CO_2. Further discussion on sources of uncertainty that are active areas of research and have not yet been fully quantified in the SC-CO_2 estimates is provided in Section V and in the 2010 TSD.

In developing the SC-CO_2 estimates, the IWG considered various sources of uncertainty through a combination of a multi-model ensemble, probabilistic analysis, and scenario analysis. For example, the three IAMs used collectively span a wide range of Earth system and economic outcomes to help reflect the uncertainty in the literature and in the underlying dynamics being modeled. The use of an ensemble of three different models is also intended to, at least partially, address the fact that no single model includes all of the quantified economic damages. It also helps to reflect structural uncertainty across the models, which is uncertainty in the underlying relationships between GHG emissions, Earth systems, and economic damages that are included in the models. Bearing in mind the different limitations of each model (discussed in the 2010 TSD) and lacking an objective basis upon which to differentially weight the models, the three IAMs are given equal weight in the analysis.

The IWG used Monte Carlo techniques to run the IAMs a large number of times. In each simulation the uncertain parameters are represented by random draws from their defined probability distributions. In all three models the equilibrium climate sensitivity is treated probabilistically based on the probability distribution described in the 2010 TSD. The equilibrium climate sensitivity is a key parameter in this analysis because it helps define the strength of the climate response to increasing GHG concentrations in the atmosphere. In addition, the FUND and PAGE models define many of their parameters with probability distributions instead of point estimates. For these two models, the model developers' default probability distributions are maintained for all parameters other than those superseded by the IWG's harmonized inputs (i.e., equilibrium climate sensitivity, socioeconomic and emissions scenarios, and discount rates). More information on the uncertain parameters in PAGE and FUND is presented in Appendix C.

For the socioeconomic and emissions scenarios, uncertainty is included in the analysis by considering a range of scenarios, which are described in detail in the 2010 SC-CO_2 TSD. As noted in the 2010 TSD, while the IWG considered formally assigning probability weights to the different socioeconomic scenarios selected, it came to the conclusion that this could not be accomplished in an analytically rigorous way given the dearth of information on the likelihood of a full range of future socioeconomic pathways. Thus, the IWG determined that, because no basis for assigning differential weights was available, the most transparent way to present a range of uncertainty was simply to weight each of the five scenarios equally for the consolidated estimates. To provide additional information as to how the results vary with the scenarios, summarized results for each scenario are presented separately in Appendix A. The results of each model run are available on the OMB website.

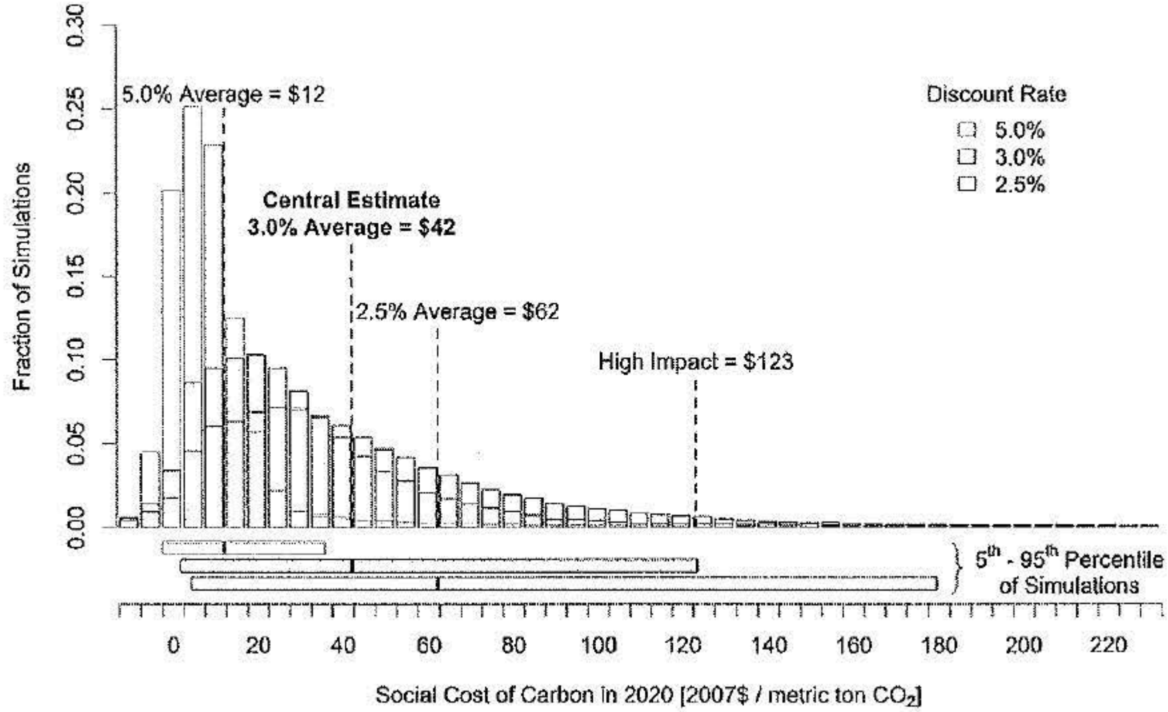
Finally, based on the review of the literature, the IWG chose discount rates that reflect reasonable judgements under both prescriptive and descriptive approaches to intergenerational discounting. As discussed in the 2010 TSD, in light of disagreement in the literature on the appropriate discount rate to use in this context and uncertainty about how rates may change over time, the IWG selected three certainty-equivalent constant discount rates to span a plausible range: 2.5, 3, and 5 percent per year. However, unlike the approach taken for consolidating results across models and socioeconomic and emissions scenarios, the SC-CO_2 estimates are not pooled across different discount rates because the range of discount rates reflects both uncertainty and, at least in part, different policy or value judgements.

The outcome of accounting for various sources of uncertainty using the approaches described above is a frequency distribution of the SC-CO_2 estimates for emissions occurring in a given year for each of the three discount rates. These frequency distributions reflect the uncertainty around the input parameters for which probability distributions were defined, as well as from the multi-model ensemble and socioeconomic and emissions scenarios where probabilities were implied by the equal weighting assumption. It is important to note that the set of SC-CO_2 estimates obtained from this analysis does not yield a probability distribution that fully characterizes uncertainty about the SC-CO_2 due to impact categories omitted from the models and sources of uncertainty that have not been fully characterized due to data limitations.

Figure 1 presents the frequency distribution of the SC-CO_2 estimates for emissions in 2020 for each of the three discount rates. Each of these distributions represents 150,000 estimates based on 10,000 simulations for each combination of the three models and five socioeconomic and emissions scenarios.[16] In general, the distributions are skewed to the right and have long right tails, which tend to be even longer for lower discount rates. To highlight the difference between the impact of the discount rate on the SC-CO_2 and other quantified sources of uncertainty, the bars below the frequency distributions provide a symmetric representation of quantified variability in the SC-CO_2 estimates conditioned on each discount rate. The full set of SC-CO_2 results through 2050 is available on OMB's website. This may be useful to analysts in situations that warrant additional quantitative uncertainty analysis (e.g., as recommended by OMB for rules that exceed $1 billion in annual benefits or costs). See OMB Circular A-4 for guidance and discussion of best practices in conducting uncertainty analysis in RIAs.

[16] Although the distributions in Figure 1 are based on the full set of model results (150,000 estimates for each discount rate), for display purposes the horizontal axis is truncated with 0.1 to 0.6 percent of the estimates lying below the lowest bin displayed and 0.2 to 3.7 percent of the estimates lying above the highest bin displayed, depending on the discount rate.

Figure 1: Frequency Distribution of $SC\text{-}CO_2$ Estimates for 2020 (in 2007$ per metric ton CO_2)



As previously described, the $SC\text{-}CO_2$ estimates produced by the IWG are based on a rigorous approach to accounting for quantifiable uncertainty using multiple analytical techniques. In addition, the scientific and economics literature has further explored known sources of uncertainty related to estimates of the $SC\text{-}CO_2$. For example, researchers have published papers that explore the sensitivity of IAMs and the resulting $SC\text{-}CO_2$ estimates to different assumptions embedded in the models (see, e.g., Hope (2013), Anthoff and Tol (2013a), and Nordhaus (2014)). However, there remain additional sources of uncertainty that have not been fully characterized and explored due to remaining data limitations. Additional research is needed in order to expand the quantification of various sources of uncertainty in estimates of the $SC\text{-}CO_2$ (e.g., developing explicit probability distributions for more inputs pertaining to climate impacts and their valuation). The IWG is actively following advances in the scientific and economic literature that could provide guidance on, or methodologies for, a more robust incorporation of uncertainty.

V. Other Model Limitations and Research Gaps

The 2010 $SC\text{-}CO_2$ TSD discusses a number of important limitations for which additional research is needed. In particular, the document highlights the need to improve the quantification of both non-catastrophic and catastrophic damages, the treatment of adaptation and technological change, and the way in which inter-regional and inter-sectoral linkages are modeled. While the more recent versions of the models discussed above offer some improvements in these areas, further research is still needed. Currently, IAMs do not include all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature due to a lack of precise information on the nature of damages and because the science incorporated into these models understandably lags behind the most recent research.[17] These individual limitations do not all work in the same direction in terms of their influence on the SC-CO_2 estimates; however, it is the IWG's judgment that, taken together, these limitations suggest that the SC-CO_2 estimates are likely conservative. In particular, the IPCC Fourth Assessment Report (Meehl et al. 2007), which was the most current IPCC assessment available at the time of the IWG's 2009-2010 review, concluded that SC-CO_2 estimates "very likely...underestimate the damage costs" due to omitted impacts. Since then, the peer-reviewed literature has continued to support this conclusion, as noted in the IPCC Fifth Assessment report (Oppenheimer et al. 2014).

Another area of active research relates to intergenerational discounting, including the application of discount rates to regulations in which some costs and benefits accrue intra-generationally while others accrue inter-generationally. Some experts have argued that a declining discount rate would be appropriate to analyze impacts that occur far into the future (Arrow et al. 2013). However, additional research and analysis is still needed to develop a methodology for implementing a declining discount rate and to understand the implications of applying these theoretical lessons in practice.

The 2010 TSD also discusses the need to more carefully assess the implications of risk aversion for SC-CO_2 estimation as well as the substitution possibilities between climate and non-climate goods at higher temperature increases, both of which have implications for the discount rate used. EPA, DOE, and other agencies continue to engage in research on modeling and valuation of climate impacts that can potentially improve SC-CO_2 estimation in the future. See the 2010 SC-CO_2 TSD for the full discussion.

[17] See, for example, Howard (2014) and EPRI (2014) for recent discussions.

References

Anthoff, D. and Tol, R.S.J. 2013a. The uncertainty about the social cost of carbon: a decomposition analysis using FUND. *Climatic Change* 117: 515–530.

Anthoff, D. and Tol, R.S.J. 2013b. Erratum to: The uncertainty about the social cost of carbon: A decomposition analysis using FUND. *Climatic Change*. Advance online publication. doi: 10.1007/s10584-013-0959-1.

Arrow, K., M. Cropper, C. Gollier, B. Groom, G. Heal, R. Newell, W. Nordhaus, R. Pindyck, W. Pizer, P. Portney, T. Sterner, R.S.J. Tol, and M. Weitzman. 2013. Determining Benefits and Costs for Future Generations. Science 341: 349-350.

Electric Power Research Institute. 2014. Understanding the Social Cost of carbon: A Technical Assessment. www.epri.com.

Fankhauser, S. 1995. Valuing climate change: The economics of the greenhouse. London, England: Earthscan.

Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland. 2007. Changes in Atmospheric Constituents and in Radiative Forcing. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Hansen, J., G. Russell, A. Lacis, I. Fung, D. Rind, and P. Stone. 1985. Climate Response Times: Dependence on climate sensitivity and ocean mixing. *Science* 229: 857–859.

Hope, Chris. 2006. "The Marginal Impact of CO_2 from PAGE2002: An Integrated Assessment Model Incorporating the IPCC's Five Reasons for Concern." *The Integrated Assessment Journal*. 6(1): 19–56.

Hope, Chris. 2011a. "The PAGE09 Integrated Assessment Model: A Technical Description" Cambridge Judge Business School Working Paper No. 4/2011 (April). Accessed November 23, 2011: http://www.jbs.cam.ac.uk/research/working_papers/2011/wp1104.pdf.

Hope, Chris. 2011b. "The Social Cost of CO_2 from the PAGE09 Model" Cambridge Judge Business School Working Paper No. 5/2011 (June). Accessed November 23, 2011: http://www.jbs.cam.ac.uk/research/working_papers/2011/wp1105.pdf.

Hope, Chris. 2011c. "New Insights from the PAGE09 Model: The Social Cost of CO_2" Cambridge Judge Business School Working Paper No. 8/2011 (July). Accessed November 23, 2011: http://www.jbs.cam.ac.uk/research/working_papers/2011/wp1108.pdf.

Hope, C. 2013. Critical issues for the calculation of the social cost of CO_2: why the estimates from PAGE09 are higher than those from PAGE2002. *Climatic Change* 117: 531–543.

Howard, Peter. 2014. Omitted Damages: What's Missing from the Social Cost of Carbon. http://costofcarbon.org/files/Omitted_Damages_Whats_Missing_From_the_Social_Cost_of_Carbon.pdf.

Interagency Working Group on Social Cost of Carbon. 2010. Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866. February. United States Government. http://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf.

Meehl, G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper, I.G. Watterson, A.J. Weaver and Z.-C. Zhao. 2007. Global Climate Projections. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Narita, D., R. S. J. Tol and D. Anthoff. 2010. Economic costs of extratropical storms under climate change: an application of FUND. *Journal of Environmental Planning and Management* 53(3): 371-384.

National Academy of Sciences (NAS). 2011. *Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia*. Washington, DC: National Academies Press, Inc.

National Academies of Sciences, Engineering, and Medicine (National Academies). 2016. Assessment of Approaches to Updating the Social Cost of Carbon: Phase 1 Report on a Near-Term Update. Washington, D.C.: National Academies Press. Available at: http://sites.nationalacademies.org/DBASSE/BECS/Social_Cost_of_Carbon_Near_Term_Update/index.htm.

Nicholls, R.J., N. Marinova, J.A. Lowe, S. Brown, P. Vellinga, D. de Gusmão, J. Hinkel and R.S.J. Tol. 2011. Sea-level rise and its possible impacts given a 'beyond 4°C world' in the twenty-first century. *Phil. Trans. R. Soc. A* 369(1934): 161-181.

Nordhaus, W. 2014. Estimates of the Social Cost of Carbon: Concepts and Results from the DICE-2013R Model and Alternative Approaches. *Journal of the Association of Environmental and Resource Economists* 1(1/2): 273-312.

Nordhaus, W. 2010. Economic aspects of global warming in a post-Copenhagen environment. *Proceedings of the National Academy of Sciences* 107(26): 11721-11726.

Nordhaus, W. 2008. A Question of Balance: Weighing the Options on Global Warming Policies. New Haven, CT: Yale University Press.

Oppenheimer, M., M. Campos, R.Warren, J. Birkmann, G. Luber, B. O'Neill, and K. Takahashi, 2014: Emergent risks and key vulnerabilities. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1039-1099.

Pizer, W., M. Adler, J. Aldy, D. Anthoff, M. Cropper, K. Gillingham, M. Greenstone, B. Murray, R. Newell, R. Richels, A. Rowell, S. Waldhoff, and J. Wiener. 2014. Using and Improving the Social Cost of Carbon. *Science* 346: 1181–82.

Randall, D.A., R.A. Wood, S. Bony, R. Colman, T. Fichefet, J. Fyfe, V. Kattsov, A. Pitman, J. Shukla, J. Srinivasan, R.J. Stouffer, A. Sumi and K.E. Taylor. 2007. Climate Models and Their Evaluation. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Appendix A

Table A1: Annual SC-CO_2 Values: 2010-2050 (2007$/metric ton CO_2)

Year	5% Average	**3% Average**	2.5% Average	High Impact (95th Pct at 3%)
2010	10	**31**	50	86
2011	11	**32**	51	90
2012	11	**33**	53	93
2013	11	**34**	54	97
2014	11	**35**	55	101
2015	11	**36**	56	105
2016	11	**38**	57	108
2017	11	**39**	59	112
2018	12	**40**	60	116
2019	12	**41**	61	120
2020	12	**42**	62	123
2021	12	**42**	63	126
2022	13	**43**	64	129
2023	13	**44**	65	132
2024	13	**45**	66	135
2025	14	**46**	68	138
2026	14	**47**	69	141
2027	15	**48**	70	143
2028	15	**49**	71	146
2029	15	**49**	72	149
2030	16	**50**	73	152
2031	16	**51**	74	155
2032	17	**52**	75	158
2033	17	**53**	76	161
2034	18	**54**	77	164
2035	18	**55**	78	168
2036	19	**56**	79	171
2037	19	**57**	81	174
2038	20	**58**	82	177
2039	20	**59**	83	180
2040	21	**60**	84	183
2041	21	**61**	85	186
2042	22	**61**	86	189
2043	22	**62**	87	192
2044	23	**63**	88	194
2045	23	**64**	89	197
2046	24	**65**	90	200
2047	24	**66**	92	203
2048	25	**67**	93	206
2049	25	**68**	94	209
2050	26	**69**	95	212

Table A2: 2020 Global SC-CO_2 Estimates at 2.5 Percent Discount Rate (2007$/metric ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario[18]					PAGE					
IMAGE	6	10	15	26	55	123	133	313	493	949
MERGE Optimistic	4	6	8	15	32	75	79	188	304	621
MESSAGE	4	7	10	19	41	104	103	266	463	879
MiniCAM Base	5	8	12	21	45	102	108	255	412	835
5th Scenario	2	4	6	11	24	81	66	192	371	915

Scenario					DICE					
IMAGE	25	31	37	47	64	72	92	123	139	161
MERGE Optimistic	14	18	20	26	36	40	50	65	74	85
MESSAGE	20	24	28	37	51	58	71	95	109	221
MiniCAM Base	20	25	29	38	53	61	76	102	117	135
5th Scenario	17	22	25	33	45	52	65	91	106	126

Scenario					FUND					
IMAGE	-14	-2	4	15	31	39	55	86	107	157
MERGE Optimistic	-6	1	6	14	27	35	46	70	87	141
MESSAGE	-16	-5	1	11	24	31	43	67	83	126
MiniCAM Base	-7	2	7	16	32	39	55	83	103	158
5th Scenario	-29	-13	-6	4	16	21	32	53	69	103

Table A3: 2020 Global SC-CO_2 Estimates at 3 Percent Discount Rate (2007$/metric ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario					PAGE					
IMAGE	4	7	9	17	36	87	91	228	369	696
MERGE Optimistic	2	4	6	10	22	54	55	136	222	461
MESSAGE	3	5	7	13	28	72	71	188	316	614
MiniCAM Base	3	5	7	13	29	70	72	177	288	597
5th Scenario	1	3	4	7	16	55	46	130	252	632

Scenario					DICE					
IMAGE	16	21	24	32	43	48	60	79	90	102
MERGE Optimistic	10	13	15	19	25	28	35	44	50	58
MESSAGE	14	18	20	26	35	40	49	64	73	83
MiniCAM Base	13	17	20	26	35	39	49	65	73	85
5th Scenario	12	15	17	22	30	34	43	58	67	79

Scenario					FUND					
IMAGE	-13	-4	0	8	18	23	33	51	65	99
MERGE Optimistic	-7	-1	2	8	17	21	29	45	57	95
MESSAGE	-14	-6	-2	5	14	18	26	41	52	82
MiniCAM Base	-7	-1	3	9	19	23	33	50	63	101
5th Scenario	-22	-11	-6	1	8	11	18	31	40	62

[18] See 2010 TSD for a description of these scenarios.

Table A4: 2020 Global SC-CO_2 Estimates at 5 Percent Discount Rate (2007$/metric ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario					PAGE					
IMAGE	1	2	2	4	10	27	26	68	118	234
MERGE Optimistic	1	1	2	3	6	17	17	43	72	146
MESSAGE	1	1	2	4	8	23	22	58	102	207
MiniCAM Base	1	1	2	3	8	20	20	52	90	182
5th Scenario	0	1	1	2	5	17	14	39	75	199
Scenario					DICE					
IMAGE	6	8	9	11	14	15	18	22	25	27
MERGE Optimistic	4	5	6	7	9	10	12	15	16	18
MESSAGE	6	7	8	10	12	13	16	20	22	25
MiniCAM Base	5	6	7	8	11	12	14	18	20	22
5th Scenario	5	6	6	8	10	11	14	17	19	21
Scenario					FUND					
IMAGE	-9	-5	-4	-1	2	3	6	10	14	24
MERGE Optimistic	-6	-4	-2	0	3	4	6	11	15	26
MESSAGE	-10	-6	-4	-1	1	2	5	9	12	21
MiniCAM Base	-7	-4	-2	0	3	4	6	11	14	25
5th Scenario	-11	-7	-5	-3	0	0	3	5	7	13

Table A5: Additional Summary Statistics of 2020 Global SC-CO_2 Estimates

Discount rate:	5.0%				3.0%				2.5%			
Statistic:	Mean	Variance	Skewness	Kurtosis	Mean	Variance	Skewness	Kurtosis	Mean	Variance	Skewness	Kurtosis
DICE	12	26	2	15	38	409	3	24	57	1097	3	30
PAGE	21	1481	5	32	68	13712	4	22	97	26878	4	23
FUND	3	41	5	179	19	1452	-42	8727	33	6154	-73	14931

Appendix B

The November 2013 revision of this TSD is based on two corrections to the runs based on the FUND model. First, the potential dry land loss in the algorithm that estimates regional coastal protections was misspecified in the model's computer code. This correction is covered in an erratum to Anthoff and Tol (2013a) published in the same journal (*Climatic Change*) in October 2013 (Anthoff and Tol (2013b)). Second, the equilibrium climate sensitivity distribution was inadvertently specified as a truncated Gamma distribution (the default in FUND) as opposed to the truncated Roe and Baker distribution as was intended. The truncated Gamma distribution used in the FUND runs had approximately the same mean and upper truncation point, but lower variance and faster decay of the upper tail, as compared to the intended specification based on the Roe and Baker distribution. The difference between the original estimates reported in the May 2013 version of this TSD and this revision are generally one dollar or less.

The July 2015 revision of this TSD is based on two corrections. First, the DICE model had been run up to 2300 rather than through 2300, as was intended, thereby leaving out the marginal damages in the last year of the time horizon. Second, due to an indexing error, the results from the PAGE model were in 2008 U.S. dollars rather than 2007 U.S. dollars, as was intended. In the current revision, all models have been run through 2300, and all estimates are in 2007 U.S. dollars. On average the revised SC-CO_2 estimates are one dollar less than the mean SC-CO_2 estimates reported in the November 2013 version of this TSD. The difference between the 95th percentile estimates with a 3% discount rate is slightly larger, as those estimates are heavily influenced by results from the PAGE model.

The July 2016 revision provides additional discussion of uncertainty in response to recommendations from the National Academy of Sciences, Engineering, and Medicine. It does not revisit the IWG's 2010 methodological decisions or update the schedule of SC-CO_2 estimates presented in the July 2015 revision. The IWG is currently seeking external expert advice from the National Academies on the technical merits and challenges of potential approaches to future updates of the SC-CO_2 estimates presented in this TSD. To date, the Academies' committee has issued an interim report that recommended against a near-term update to the SC-CO_2 estimates, but included recommendations for enhancing the presentation and discussion of uncertainty around the current estimates. This revision includes additional information that the IWG determined was appropriate to respond to these recommendations. Specifically, the executive summary presents more information about the range of quantified uncertainty in the SC-CO_2 estimates (including a graphical representation of symmetric high and low values from the frequency distribution of SC-CO_2 estimates conditional on each discount rate), and a new section has also been added that provides a unified discussion of the various sources of uncertainty and how they were handled in estimating the SC-CO_2. Efforts to make the sources of uncertainty clear have also been enhanced with the addition of a new appendix that describes in more detail the uncertain parameters in both the FUND and PAGE models (Appendix C). Furthermore, the full set of SC-CO_2 modeling results, which have previously been available upon request, are now provided on the OMB website for easy access. The Academies' final report (expected in early 2017) will provide longer term recommendations for a more comprehensive update. For more information on the status of the Academies' process, see: http://sites.nationalacademies.org/DBASSE/BECS/CurrentProjects/DBASSE_167526.

Appendix C

This appendix provides a general overview of the parameters that are treated probabilistically in each of the three integrated assessment models the IWG used to estimate the SC-CO_2. In the DICE model the only uncertain parameter considered was the equilibrium climate sensitivity as defined by the probability distribution harmonized across the three models. By default, all of the other parameters in the model are defined by point estimates and these definitions were maintained by the IWG. In the FUND and PAGE models many of the parameters, beyond the equilibrium climate sensitivity, are defined by probability distributions in the default versions of the models. The IWG maintained these default assumptions and allowed these parameters to vary in the Monte Carlo simulations conducted with the FUND and PAGE models.

Default Uncertainty Assumptions in FUND

In the version of the FUND model used by the IWG (version 3.8.1) over 90 of the over 150 parameters in the model are defined by probability distributions instead of point estimates, and for 30 of those parameters the values vary across the model's 16 regions. This includes parameters related to the physical and economic components of the model. The default assumptions in the model include parameters whose probability distributions are based on the normal, Gamma, and triangular distributions. In most cases the distributions are truncated from above or below. The choice of distributions and parameterizations are based on the model developers' assessment of the scientific and economic literature. Complete information on the exact probability distributions specified for each uncertain parameter is provided through the model's documentation, input data, and source code, available at: http://www.fund-model.org/home.

The physical components of the model map emissions to atmospheric concentrations, then map those concentrations to radiative forcing, which is then mapped to changes in global mean temperature. Changes in temperature are then used to estimate sea level rise. The parameters treated probabilistically in these relationships may be grouped into three main categories: atmospheric lifetimes, speed of temperature response, and sea level rise. First, atmospheric concentrations are determined by one box models, that capture a single representative sink, for each of the three non-CO_2 GHGs and a five box model for CO_2, that represents the multiple sinks in the carbon cycle that operate on different time frames. In each of these boxes, the lifetime of additions to the atmospheric concentration in the box are treated as uncertain. Second, parameters associated with speed at which the climate responds to changes in radiative forcing are treated as uncertain. In the FUND model radiative forcing, R_t, is mapped to changes in global mean temperature, T_t, through

$$T_t = T_{t-1} + \frac{1}{\theta_1 + \theta_2 ECS + \theta_3 ECS^2}\left(\frac{\psi ECS}{\ln(2)} R_t - T_{1-t}\right),$$

where the probability distribution for the equilibrium climate sensitivity, ECS, was harmonized across the models as discussed in the 2010 TSD. The parameters θ_i define the speed at which the temperature anomaly responds to changes in radiative forcing and are treated as uncertain in the model. Third, sea level rise is treated as a mean reverting function, where the mean is determined as proportional to the current global mean temperature anomaly. Both this proportionality parameter and the rate of mean reversion in this relationship are treated as uncertain in the model.

The economic components of the model map changes in the physical components to monetized damages. To place the uncertain parameters of the model associated with mapping physical endpoints to damages in context, it is useful to consider the general form of the damage functions in the model. Many of the damage functions in the model have forms that are roughly comparable to

$$D_{r,t} = \alpha_r Y_{r,t} \beta_{r,t} \left(\frac{y_{r,t}}{y_{r,b}} \right)^{\gamma} \left(\frac{N_{r,t}}{N_{r,b}} \right)^{\phi} T_t^{\delta}, \qquad (1)$$

where α_r is the damage at a 1 °C global mean temperature increase as a fraction of regional GDP, $Y_{r,t}$. The model considers numerous changes that may reduce a region's benchmark vulnerability to climate change. For example, γ represents the elasticity of damages with respect to changes in the region's GDP per capita, $y_{r,t}$, relative to a benchmark value, $y_{r,b}$; ϕ represents the elasticity of damages with respect to changes in the region's population, $N_{r,t}$, relative to a benchmark value, $N_{r,b}$; and the projection $\beta_{r,t}$ provides for an exogenous reduction in vulnerability (e.g., forecast energy efficiency improvements the affect space cooling costs). Once the benchmark damages have been scaled due to changes in vulnerability they are adjusted based on a non-linear scaling of the level of climate change forecast, using a power function with the exponent, δ.

Some damage categories have damage function specifications that differ from the example in (1). For example, agriculture and forestry damages take atmospheric concentrations of CO_2 and the rate of climate change into account in different forms, though the method by which they calculate the monetized impact in these cases is similar with respect to accounting for GDP growth and changes in vulnerability. In other cases the process by which damages are estimated is more complex. For example, in estimating damages from sea level rise the model considers explicit regional decision makers that choose levels of coastal protection in a given year based on a benefit-cost test. In estimating the damages from changes in cardiovascular mortality risk the model considers forecast changes in the proportion of the population over the age of 65 and deemed most vulnerable by the model developers. Other damage categories may also have functional forms that differ slightly from (1), but in general this form provides a useful framework for discussing the parameters for which the model developers have defined probability distributions as opposed to point estimates.

In many damage categories (e.g., sea level rise, water resources, biodiversity loss, agriculture and forestry, and space conditioning) the benchmark damages, α_r, are treated as uncertain parameters in the model and in most case they are assumed to vary by region. The elasticity of damages with respect to changes in regional GDP per capita, γ, and the elasticity with respect to changes in regional population, ϕ, are also treated as uncertain parameters in most damage functions in the model, though they are not assumed to vary across regions. In most cases the exponent, δ, on the power function that scales damages based on the forecast level of climate change are also treated as uncertain parameters, though they are not assumed to vary across regions in most cases.

Figure C1 presents results of an analysis from the developers of the FUND model that examines the uncertain parameters that have the greatest influence on estimates of the SC-CO_2 based on the default version of the model. While some of the modeling inputs are different for the SC-CO_2 estimates calculated by the IWG these parameters are likely to remain highly influential in the FUND modeling results.

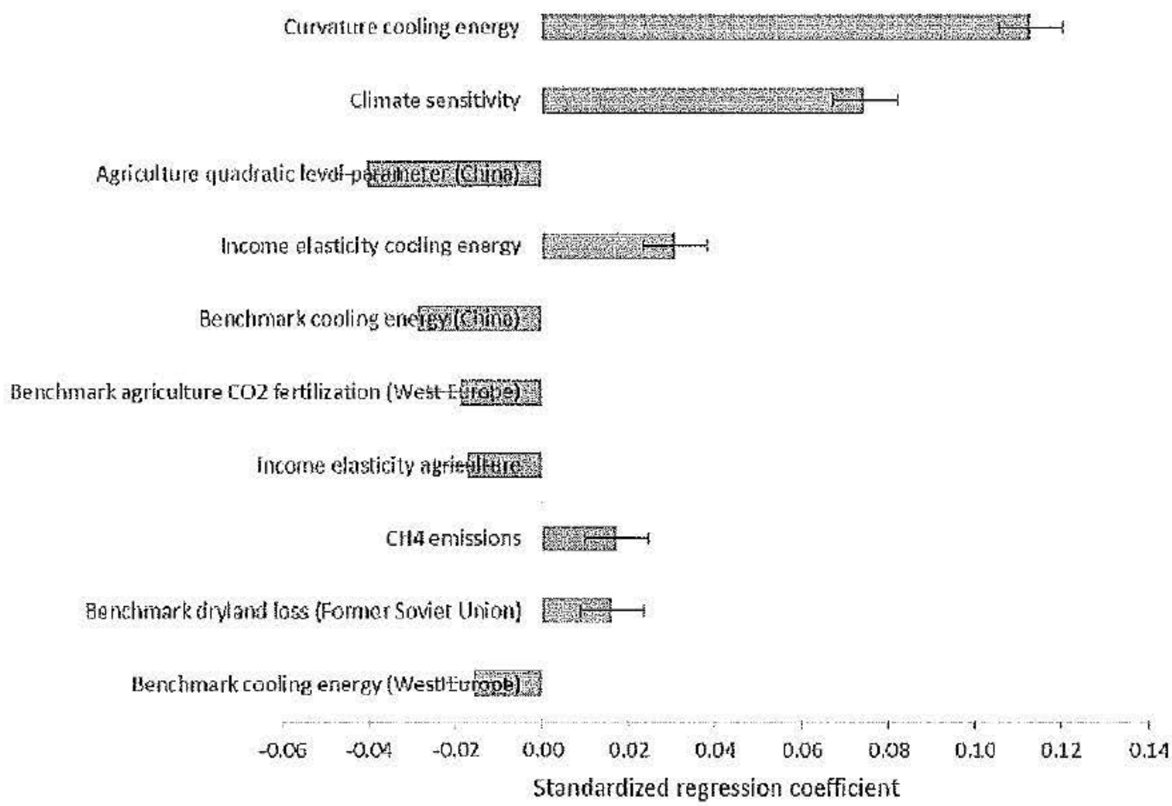


Figure C1: Influence of Key Uncertain Parameters in Default FUND Model (Anthoff and Tol 2013a)[19]

Default Uncertainty Assumptions in PAGE

In the version of the PAGE model used by the IWG (version PAGE09) there are over 40 parameters defined by probability distributions instead of point estimates.[20] The parameters can broadly be classified as related to climate science, damages, discontinuities, and adaptive and preventive costs. In the default version of the model, all of the parameters are modeled as triangular distributions except for the one variable related to the probability of a discontinuity occurring, with is represented by a uniform distribution. More detail on the model equations can be found in Hope (2006, 2011a) and the default minimum, mode, and maximum values for the parameters are provided in Appendix 2 of Hope (2011a). The calibration of these distributions is based on the developer's assessment of the IPCC's Fourth Assessment report and scientific articles referenced in Hope (2011a, 2011b, 2011c). The IWG added an uncertain parameter to the default model, specifically the equilibrium climate sensitivity parameter, which was harmonized across the models as discussed in the 2010 TSD.

In the climate component of the PAGE model, atmospheric CO_2 concentration is assumed to follow an initial rapid decay followed by an exponential decline to an equilibrium level. The parameters treated probabilistically in this decay are the proportion of the anthropogenic CO_2 emissions that enter the atmosphere, the half-life of the CO_2's atmospheric residence, and the fraction of cumulative emissions that ultimately remains in the atmosphere. A carbon cycle feedback is included to represent the impact of increasing temperatures on the role of the terrestrial biosphere and oceans in the carbon cycle. This feedback is modeled with probabilistic parameters representing the percentage increase in the CO_2 concentration anomaly and with an uncertain upper bound on this percentage.

The negative radiative forcing effect from sulfates is modeled with probabilistic parameters for the direct linear effect due to backscattering and the indirect logarithmic effect assumed for cloud interactions. The radiative forcing from CO_2, all other greenhouse gases, and sulfates are combined in a one box model to estimate the global mean temperature. Uncertainty in the global mean temperature response to change in radiative forcing is based on the uncertain equilibrium climate sensitivity parameter and uncertainty in the half-life of the global response to an increase in radiative forcing, which defines the inertia of the climate system in the model. Temperature anomalies in the model vary geographically, with larger increases over land and the poles. Probabilistic parameters are used for the ratios of the temperature anomaly over land relative to the ocean and the ratio of the temperature anomaly over the poles relative to the equator. The PAGE model also includes an explicit sea level component, modelled as a lagged function of the global mean temperature anomaly. The elements of this component that are treated

[19] Based on a coefficients of standardized regression of parameter draws on the SC-CO_2 using FUND 3.8.1 under Ramsey discounting with a pure rate of time preference of one percent and rate of relative risk aversion of 1.5. The 90 percent confidence intervals around the regression coefficients are presented as error bars.

[20] This appendix focuses on the parameters in the PAGE model related to estimating the climate impacts and principle calculation of the monetized damages. There are over 60 additional parameters in the model related to abatement and adaptation, which may be highly relevant for purposes other than estimating the SC-CO_2, but are not discussed here.

probabilistically include: sea level rise from preindustrial levels to levels in the year 2000, the asymptotic sea level rise expected with no temperature change, the predicted sea level rise experience with a temperature change, and the half-life of the sea level rise.

In the economic impacts module, damages are estimated for four categories: sea level rise, economic damages, non-economic damages, and damages from a discontinuity. Each damage category is calculated as a loss proportional to GDP. The model first calculates damages for a "focus region" (set to the European Union) assuming the region's base year GDP per capita. Damages for other regions are assumed to be proportional to the focus region's damage, represented by a regional weighting factor.

Economic damages, non-economic damages, and damages from sea level rise are modeled as polynomial functions of the temperature or sea level impact, which are defined as the regional temperature or sea level rise above a regional tolerable level. These functions are calibrated to damages at some reference level (e.g., damages at 3°C or damages for a ½ meter sea level rise). The specification allows for the possibility of "initial benefits" from small increases in regional temperature. The variables represented by a probability distributions in this specification are: the regional weighting factors; the initial benefits; the calibration point; the damages at the calibration point; and the exponent on the damage functions.

The damages from a discontinuity are treated differently from other damages in PAGE because the event either occurs or it does not in a given model simulation. In the PAGE model, the probability of a discontinuity is treated as a discrete event, where if it occurs, additional damages would be borne and therefore added to the other estimates of climate damages. Uncertain parameters related to this discontinuity include the threshold global mean temperature beyond which a discontinuity becomes possible and the increase in the probability of a discontinuity as the temperature anomaly continues to increase beyond this threshold. If the global mean temperature has exceeded the threshold for any time period in a model run, then the probability of a discontinuity occurring is assigned, otherwise the probability is set to zero. For each time period a uniform random variable is drawn and compared to this probability to determine if a discontinuity event has occurred in that simulation. The additional loss if a discontinuity does occur in a simulation is represented by an uncertain parameter and is multiplied by the uncertain regional weighting factor to obtain the regional effects.

Damages for each category in each region are adjusted to account for the region's forecast GDP in a given model year to reflect differences in vulnerability based on the relative level of economic development. Specifically, the damage estimates are multiplied by a factor equal to the ratio of a region's actual GDP per capita to the base year GDP per capita, where the ratio exponentiated with a value less than or equal to zero. The exponents vary across damage categories and in each case are treated as uncertain parameters.

Finally, in each region damages for each category are calculated sequentially (sea level rise, economic, non-economic, and discontinuity, in that order) and are assessed to ensure that they do not create total damages that exceed 100 percent of GDP for that region. Damages transition from a polynomial function to a logistic path once they exceed a certain proportion of remaining GDP, and the proportion where this transition begins is treated as uncertain. An additional parameter labeled the "statistical value of civilization," also treated as uncertain, caps total damages (including abatement and adaptation costs described below) at some maximum level.

Figure C2 presents results of an analysis from the developers of the PAGE model that examines the uncertain parameters that have the greatest influence on estimates of the SC-CO_2 based on the default version of the model. Although some of the modeling inputs are different for the SC-CO_2 estimates calculated by the IWG, these parameters are likely to remain highly influential in the PAGE modeling results.

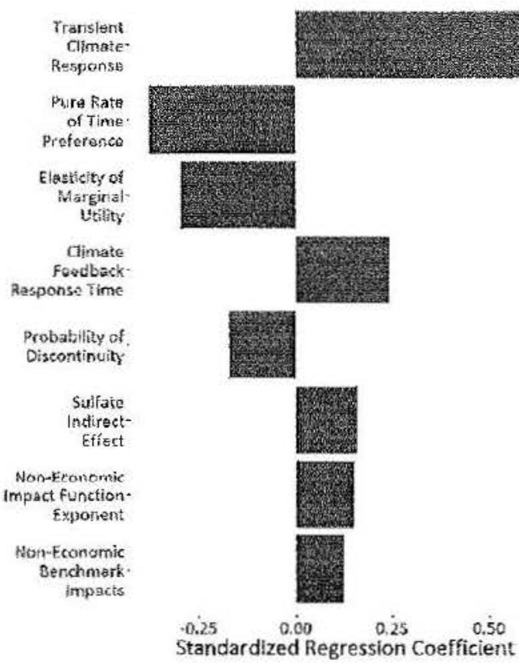


Figure C2: Influence of Key Uncertain Parameters in Default PAGE Model (Hope 2013)[21]

[21] Based on a standardized regression of the parameters. The values give the predicted increase in the SC-CO_2 in 2010 based on a one standard deviation increase in the coefficient, using the default parameters for PAGE09 under Ramsey discounting with an uncertain pure rate of time preference and rate of relative risk aversion.

30. What is the statutory charge to the Department with respect to efficiency standards? Which products are subject to statutory requirements and which are discretionary to the Department?

Response: The Energy Policy and Conservation Act of 1975 (EPCA), as amended, prescribes energy conservation standards for various consumer products and certain commercial and industrial equipment. (42 U.S.C. 6291, *et seq.*) For some consumer products and commercial and industrial equipment, Congress established initial energy conservation standards. For other consumer products and commercial and industrial equipment, Congress directed the Secretary of Energy to establish the initial energy conservation standard based on a determination by the Secretary that the new energy conservation standard would be designed to achieve the maximum improvement in energy efficiency that is technologically feasible and economically justified and that would result in significant conservation of energy. (42 U.S.C. 6295(o)(2)(A), 6295(o)(3)(B) and 6316(a)) Within six years of issuance of a final rule establishing or revising existing standards, the Secretary must make a determination whether an energy conservation standard should be amended and, if warranted, propose an amended standard. (42 U.S.C. 6295(m)(1) and 6316(a))

Congress delineated covered consumer products at 42 U.S.C. 6292(a) and covered commercial and industrial equipment at 42 U.S.C. 6311(1). In addition to these products and equipment, Congress authorized the Secretary of Energy to classify additional products and equipment as covered via 42 U.S.C. 6292(b) (for products) and 42 U.S.C. 6312(b) (for equipment).

Attached to this response is a list of all covered consumer products and commercial and industrial equipment (not all of which currently have standards) as well as a list of all covered consumer products and commercial and industrial equipment for which DOE has established energy conservation standards. The line items in bold are products or equipment for which DOE made a determination of coverage under EPCA.

As of 12/7/2016

	Currently Covered Products, Equipment	Products, Equipment with Final Standards	
1	2,601 - 3,300 lumen General Service Incandescent Lamps	Automatic commercial ice makers	
2	3-Way Incandescent Lamp	Battery Chargers	
3	Automatic commercial ice makers	Candelabra base incandescent lamp	
4	Battery Chargers	Ceiling Fan Light Kits	
5	Candelabra base incandescent lamp	Ceiling Fans	
6	Ceiling Fan Light Kits	Central Air Conditioners and Central Air Conditioning Heat Pumps	
7	Ceiling Fans	Clothes dryers	
8	Central Air Conditioners and Central Air Conditioning Heat Pumps	Commercial clothes washers	
9	Clothes dryers	Commercial Package Air Conditioners and Heat Pumps (a k a Commercial Unitary Air Conditioners and Heat Pumps) and Commercial Warm Air Furnaces	
10	Commercial clothes washers	Commercial Prerinse Spray Valves	
	Commercial Package Air Conditioners and Heat Pumps (a k a Commercial Unitary Air Conditioners and Heat Pumps) and Commercial Warm Air Furnaces	Commercial refrigerators, freezers, and refrigerator-freezers	
11	Commercial Prerinse Spray Valves	**Compressors**	
12	Commercial refrigerators, freezers, and refrigerator-freezers	Computer Room Air Conditioners	
13	**Compressors**	Dehumidifiers	
14	Computer Room Air Conditioners	Direct heating equipment	
15	Dehumidifiers	Dishwashers	
16	Direct heating equipment	Distribution Transformers	
17	Dishwashers	Electric Motors	
18	Distribution Transformers	External Power Supplies, Class A	
19	Electric Motors	External Power Supplies, non-Class A	
20	External Power Supplies, Class A	Faucets	
21	External Power Supplies, non-Class A	Fluorescent lamp ballasts	
22	Faucets	Furnaces	
23	Fluorescent lamp ballasts	General service fluorescent lamp	
24	Furnace Fans	General service incandescent lamp	
25	Furnaces	Illuminated Exit Signs	
26	General service fluorescent lamp	Incandescent reflector lamp (including ER/BR)	
27	General service incandescent lamp	Intermediate base incandescent lamp	
28	High-intensity discharge lamps	Kitchen ranges and ovens	
29	Illuminated Exit Signs	Large commercial package air conditioning and heating equipment	
30	Incandescent reflector lamp (including ER/BR)	Medium Base Compact Fluorescent Lamps	
31	Intermediate base incandescent lamp	Mercury Vapor Lamp Ballasts	
32	Kitchen ranges and ovens	Metal halide Lamp Fixtures	
33	Large commercial package air conditioning and heating equipment	**Miscellaneous Refrigeration Products**	
34	LED	Mobile Home Furnace	
35	Medium Base Compact Fluorescent Lamps	Packaged boilers (ASHRAE)	
36	Mercury Vapor Lamp Ballasts	Packaged terminal air conditioners and packaged terminal heat pumps (ASHRAE)	
37	Metal halide Lamp Fixtures	Pool heaters	
38	Microwave ovens	Pumps	
39	**Miscellaneous Refrigeration Products**	Refrigerated Beverage Vending Machines	
	Mobile Home Furnace	Refrigerators, Freezers and Refrigerator-Freezers	
40	OLED	Residential Boilers	
41	Packaged boilers (ASHRAE)	Residential Clothes washers	
42	Packaged terminal air conditioners and packaged terminal heat pumps (ASHRAE)	Residential Water heaters	
43	Pool heaters	Room Air Conditioners	
44	**Portable air conditioners**	Showerheads (except safety shower showerheads)	

45	Pumps	Single package vertical air conditioners and single package vertical heat pumps	
46	Refrigerated Beverage Vending Machines	Small commercial package air conditioning and heating equipment (ASHRAE)	
47	Refrigerators, Freezers and Refrigerator-Freezers	Small Electric Motors	
48	Residential Boilers	Small Furnaces	
49	Residential Clothes washers	Storage water heaters, instantaneous water heaters, and unfired hot water storage tanks (ASHRAE)	
50	Residential Water heaters	Torchieres	
51	Room Air Conditioners	Traffic Signal Modules and Pedestrian Modules	
52	Rough Service Lamp	Unit Heaters	
53	Shatter-Resistant Lamp	Urinals	
54	Showerheads (except safety shower showerheads)	Very large commercial package air conditioning and heating equipment (ASHRAE)	
55	Single package vertical air conditioners and single package vertical heat pumps	Walk-in coolers and walk-in freezers	
56	Small commercial package air conditioning and heating equipment (ASHRAE)	Water closets	
57	Small Electric Motors		
58	Small Furnaces		
59	Storage water heaters, instantaneous water heaters, and unfired hot water storage tanks (ASHRAE)		
60	Television sets		
61	Torchieres		
62	Traffic Signal Modules and Pedestrian Modules		
63	Unit Heaters		
64	Urinals		
65	Very large commercial package air conditioning and heating equipment (ASHRAE)		
66	Vibration Service Lamp		
	Walk-in coolers and walk-in freezers		
	Water closets		

* Products in bold are those for which DOE has made a coverage determination

31. Can you provide a list of all permitting authorities (and their authorizing statutes) currently held by DOE and their authorizing statutes?

Response: Presidential permits allowing electric facilities to cross international borders are issued under delegated authority provided in E.O. 10485, as amended by E.O. 12038. Electricity export authorizations are issued pursuant to section 202(e) of the Federal Power Act. Section 3 of the Natural Gas Act authorizes and in some instances requires the issuance of permits to import/export natural gas including liquefied natural gas.

Section 57(b) of the AEA makes it unlawful for any person to participate in production of special nuclear material outside the US unless authorized by the Secretary. In practical terms, what is prohibited is providing technical assistance to persons outside this country relating to commercial nuclear reactors or other nuclear operations. The Part 810 regulations spell out how such authorizations are obtained.

32. Are there statutory restrictions related to reinvigorating the Office of Civilian Radioactive Waste Management?

Response: No. There are no statutory restrictions, however, the appropriations necessary to carry out the program were affirmatively discontinued for FY2011 and years since then, leaving only the balances remaining in those accounts from prior years available to restart that office.

33. Are there any statutory restrictions to restarting the Yucca Mountain project?

Response: No. The same appropriations issues raised in #32 would have to be addressed here.

34. Does the Department have any thoughts on how to reduce the bureaucratic burden for exporting U.S. energy technology, including but not limited to commercial nuclear technology?

Response: DOE contributes to improving energy technology trade by developing the technical basis and tools to inform the development of interoperable and comparable standards for energy technologies. With regard to exporting commercial nuclear technology, where the Department does have statutory and regulatory responsibilities addressing the export of technology, the Department has reduced the amount of time for internal processing of requests submitted under 10 C.F.R. Part 810 to provide foreign atomic energy assistance, and is continuing to find efficiencies in that process through its process improvement plan and the use of technology. The Department also works with other U.S. government agencies who must be consulted on Part 810 requests to streamline the interagency process.

35. Can you provide a list of non-M&O procurements/awards that are currently pending and their status?

Response: Yes, attached is a list of non-M&O procurements/ awards that are currently pending and their status.

FY17 Business Clearance Data *

Program	Procurement Office	Submission/Action	Est Award Date
AR	ARPA-E	ARPA-E Support Services	(b) (5)
EE	Golden	FEMP ESPC Recompete	
EE	Golden	EERE Business Administration Support Services	
EE	Golden	EERE Communications Support Services	
EM	PPPO	Paducah Deactivation FFS JOFOC	
EM	EMCBC	Oak Ridge Technical Support Services	
EM	EMCBC	Los Alamos Legacy Cleanup Contract	
EM	EMCBC	Savannah River Site Liquid Waste Services	
EM	EMCBC	Oak Ridge Outfall 200	
EM	EMCBC	Portsmouth Paducah Project Office Technical Support Services Follow-on Contract (s)	
EM	EMCBC	Low-level Waste/Mixed Low-level Waste	
EM	EMCBC	Hanford Central Plateau Operations and Cleanup	
EM	EMCBC	Hanford Mission Essential Services	
EM	EMCBC	Hanford Waste Treatment Plant Operations	
EM	EMCBC	Hanford Occupational Medical Services	
EM	EMCBC	Hanford Small Business Primes	
EM	EMCBC	WIPP Transportation Services	
EM	EMCBC	Paducah Deactivation & Remediation (D&R)	
EM	EMCBC	Savannah River Site M&O	
EM	Carlsbad	TBD-WCS award for continued temporary waste storage for LANL waste and possible treatment of waste *	
FE	NETL	Site Support Services for NETL - Research and Development Implementation and Support (RADIS)	
FE	SPRO	Terminaling Services - Oil Distribution from BH Site *	
FE	SPRO	Architect-Engineering Services	
MA	HQ	Facilities Management for DOE HQ Facilities	
MA	HQ	Facilities Support Services for National Training Center-New Mexico	
MA	HQ	Cybersecurity, Operations & Systems Engineering (CBOSS)	

* All contract values except those with an * are greater than $50 million. Those with an * are greater than $5 million in accordance with Business Clearance requirements to provide highest valued actions for potential Headquarters review.

FY17 Business Clearance Data *

(b) (5)

MA	HQ	IT Support Services Policy & Governance
MA	HQ	Application, Infrastructure & Cyber Security Support
MA	HQ	Counterintelligence Support Services (Classified PWS)
MA	HQ	Program Support Services
NE	Idaho	Materials Science Support for Radioisotope Power Systems Programs *
NE	Idaho	Sustained Power System Design *
NE	Idaho	Deep Bore Hole Engineering *
NE	Idaho	Pilot Interim Storage of Spent Nuclear Fuel Generic Design and Topical Safety Analysis Report *
PMA	WAPA	Administrative Services *
PMA	WAPA	Technical Services *
PMA	WAPA	Large Scale Vegetation Removal for Right of Way *
PMA	WAPA	Vegetation Management Treatment Services *
PMA	WAPA	Operation Consolidated Software Application *
PMA	WAPA	Western Wide Security System Integration *
PMA	WAPA	Western Wide Steel Poles
PMA	WAPA	Shared Project Planning/Control/EVMS *
PMA	WAPA	Western Wide 15-245-kV Dead tank Power Circuit Breakers
SC	ISC-OR	Electric Utility Services for OR Reservation
SC	ISC-OR	Potable Water Services *

* All contract values except those with an * are greater than $50 million. Those with an * are greater than $5 million in accordance with Business Clearance requirements to provide highest valued actions for potential Headquarters review.

36. Does DOE have a plan to resume the Yucca Mountain license proceedings?

Response: No, the Department doesn’t not have a plan to resume the Yucca Mountain license proceedings.

37. Which Assistant Secretary positions are rooted in statute and which exist at the discretion and delegation of the Secretary?

Response: There are eight positions of Assistant Secretary of the Department of Energy of which seven are currently encumbered. Each of these positions is established by statute but the duties each are entirely dependent on delegations by the Secretary and designations of statutory functions listed in section 203 of the Department of Energy Organization Act (hereinafter also "the statute") (42 U.S.C. 7133, copy attached).

The seven Assistant Secretary positions currently encumbered are: (1) Fossil Energy, (2) Energy Efficiency & Renewable Energy, (3) Nuclear Energy, (4) Electricity Delivery and Energy Reliability, (5) International Affairs, (6) Congressional & Intergovernmental Affairs, and (7) Environmental Management. These specific seven Assistant Secretary positions are not identified in the statute; rather, section (a) of the statue provides the functions to be carried out by the Assistant Secretaries. As set forth in 42 U.S.C. § 7133(b), the President identifies the function or functions described in section (a) of this statute when an individual is nominated to the position of Assistant Secretary.

The Department consistently has understood the requirement to assign the statutorily-listed functions among the Assistant Secretaries as a means to assure a minimum level of prominence to be associated with those statutorily-identified functions, rather than preventing the Secretary from carrying them out himself, including through his immediate staff. Thus, there have been periods during which Public Affairs and policy functions were carried out by the immediate office of the Secretary. Similarly, where a statute enacted after the Department of Energy Organization Act and did not amend it but established a new organization within the Department headed by an individual appointed by the President with the advice and consent of the Senate placed parallel functions in that new organization, the Department has not viewed the previously enacted function in the Department of Energy Organization Act as still requiring assignment to an Assistant Secretary.

38. Can you provide a list of all Schedule C appointees, all non-career SES employees, and all Presidential appointees requiring Senate confirmation? Can you include their current position and how long they have served at the Department?

Response: The attached spreadsheet (effective December 21, 2016) provides a list of the Department's Presidentially Appointed/Senate Confirmed (PAS) positions, Non-Career SES positions, and Schedule C positions, current incumbents and their time in service at DOE.

DEPARTMENTAL ELEMENT	POSITION TITLE	NAME	TYPE OF APPOINTMENT	DATE STARTED IN DOE	TOTAL YEARS IN DOE
OFFICE OF THE SECRETARY OF ENERGY	SECRETARY OF ENERGY	MONIZ,ERNEST J	PRESIDENTIALLY APPOINTED SENATE CONFIRMED	5/21/2013	3 years, 6 months
OFFICE OF THE SECRETARY OF ENERGY	DEPUTY SECRETARY OF ENERGY	SHERWOOD-RANDALL,ELIZABETH	PRESIDENTIALLY APPOINTED SENATE CONFIRMED	10/5/2014	2 years, 2 months
ADVANCED RESEARCH PROJECTS AGENCY - ENERGY	DIRECTOR, ADVANCED RESEARCH PROJECTS AGENCY - ENERGY	WILLIAMS,ELLEN D	PRESIDENTIALLY APPOINTED SENATE CONFIRMED	9/22/2013	3 years, 2 months
OFFICE OF THE CHIEF FINANCIAL OFFICER	CHIEF FINANCIAL OFFICER	HEZIR,JOSEPH S	PRESIDENTIALLY APPOINTED SENATE CONFIRMED	4/8/2013	3 years, 7 months
OFFICE OF CONGRESSIONAL AND INTERGOVERNMENTAL AFFAIRS	ASSISTANT SECRETARY CONGRESSIONAL & INTERGOVERNMENTAL AFFAIR	VACANT	PRESIDENTIALLY APPOINTED SENATE CONFIRMED		
OFFICE OF ECONOMIC IMPACT AND DIVERSITY	DIRECTOR OF THE OFFICE OF MINORITY ECONOMIC IMPACT	HARRIS,LADORIS G	PRESIDENTIALLY APPOINTED SENATE CONFIRMED	4/22/2012	4 years, 7 months
OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY	ASSISTANT SECRETARY FOR ENERGY EFFICIENCY & RENEWABLE ENERGY	VACANT	PRESIDENTIALLY APPOINTED SENATE CONFIRMED		
U.S. ENERGY INFORMATION ADMINISTRATION	ADMINISTRATOR, ENERGY INFORMATION ADMINISTRATION	SIEMINSKI,ADAM E	PRESIDENTIALLY APPOINTED SENATE CONFIRMED	6/3/2012	4 years, 6 months
OFFICE OF INSPECTOR GENERAL	INSPECTOR GENERAL	VACANT	PRESIDENTIALLY APPOINTED SENATE CONFIRMED		
OFFICE OF ENVIRONMENTAL MANAGEMENT	ASSISTANT SECRETARY FOR ENVIRONMENTAL MANAGEMENT	REGALBUTO,MONICA C	PRESIDENTIALLY APPOINTED SENATE CONFIRMED	6/15/2014	2 years, 5 months
OFFICE OF FOSSIL ENERGY	ASSISTANT SECRETARY OF ENERGY (FOSSIL ENERGY)	SMITH,CHRISTOPHER A	PRESIDENTIALLY APPOINTED SENATE CONFIRMED	10/26/2009	7 years, 1 months
GENERAL COUNSEL	GENERAL COUNSEL	CROLEY,STEVEN P	PRESIDENTIALLY APPOINTED SENATE CONFIRMED	5/21/2014	2 years, 6 months
OFFICE OF NUCLEAR ENERGY	ASSISTANT SECRETARY OF ENERGY FOR NUCLEAR ENERGY	VACANT	PRESIDENTIALLY APPOINTED SENATE CONFIRMED		
NATIONAL NUCLEAR SECURITY ADMINISTRATION	PRINCIPAL DEPUTY ADMINISTRATOR FOR NATIONAL NUCLEAR SECURITY	CREEDON,MADELYN R	PRESIDENTIALLY APPOINTED SENATE CONFIRMED	8/10/2014	2 years, 3 months
NATIONAL NUCLEAR SECURITY ADMINISTRATION	DEPUTY ADMINISTRATOR FOR DEFENSE NUCLEAR NONPROLIFERATION	HARRINGTON,ANNE M	PRESIDENTIALLY APPOINTED SENATE CONFIRMED	10/24/2010	6 years, 1 months
NATIONAL NUCLEAR SECURITY ADMINISTRATION	UNDER SECRETARY FOR NUCLEAR SECURITY/ADMINISTRATOR FOR NUCLE	KLOTZ,FRANK G	PRESIDENTIALLY APPOINTED SENATE CONFIRMED	4/17/2014	2 years, 7 months
NATIONAL NUCLEAR SECURITY ADMINISTRATION	DEPUTY ADMINISTRATOR FOR DEFENSE PROGRAMS	VACANT	PRESIDENTIALLY APPOINTED SENATE CONFIRMED		
OFFICE OF ELECTRICITY DELIVERY AND ENERGY RELIABILITY	ASSISTANT SECRETARY (ELECTRICITY DELIVERY AND ENERGY RELIABI	HOFFMAN,PATRICIA A	PRESIDENTIALLY APPOINTED SENATE CONFIRMED	3/19/1995	21 years, 8 months
ASSISTANT SECRETARY FOR INTERNATIONAL AFFAIRS	ASSISTANT SECRETARY FOR POLICY & INTERNATIONAL AFFAIRS	ELKIND,JONATHAN H	PRESIDENTIALLY APPOINTED SENATE CONFIRMED	6/8/2009	7 years, 5 months
OFFICE OF THE UNDER SECRETARY (MANAGEMENT AND PERFORMANCE)	UNDER SECRETARY (MANAGEMENT AND PERFORMANCE)	VACANT	PRESIDENTIALLY APPOINTED SENATE CONFIRMED		
OFFICE OF THE UNDER SECRETARY OF SCIENCE (AND ENERGY)	UNDER SECRETARY FOR SCIENCE (AND ENERGY)	ORR JR,FRANKLIN M	PRESIDENTIALLY APPOINTED SENATE CONFIRMED	12/17/2014	1 years, 11 months
OFFICE OF SCIENCE	DIRECTOR, OFFICE OF SCIENCE	MURRAY,CHERRY A	PRESIDENTIALLY APPOINTED SENATE CONFIRMED	11/1/2015	1 years, 1 months
OFFICE OF CONGRESSIONAL AND INTERGOVERNMENTAL AFFAIRS	DEPUTY ASSISTANT SECRETARY FOR INTERGOVERNMENTAL & EXTERNAL	CARRILLO,FRANCISCO R	NON-CAREER SES	9/14/2015	1 years, 2 months
OFFICE OF CONGRESSIONAL AND INTERGOVERNMENTAL AFFAIRS	DEPUTY ASSISTANT SECRETARY FOR SENATE AFFAIRS	D' ERCOLE,JED D	NON-CAREER SES	2/27/2011	5 years, 9 months
OFFICE OF CONGRESSIONAL AND INTERGOVERNMENTAL AFFAIRS	PRINCIPAL DEPUTY ASSISTANT SECRETARY	KING,CHRISTOPHER J	NON-CAREER SES	3/24/2013	3 years, 8 months
OFFICE OF CONGRESSIONAL AND INTERGOVERNMENTAL AFFAIRS	DEPUTY ASSISTANT SECRATARY FOR HOUSE AFFAIRS	SHAPIRO,AARON I	NON-CAREER SES	11/9/2015	1 years, 0 months
OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY	ASSOCIATE ASSISTANT SECRETARY	BENNER,JANINE L	NON-CAREER SES	12/15/2013	2 years, 11 months
OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY	PRINCIPAL DEPUTY ASSISTANT SECRETARY	FRIEDMAN,DAVID J	NON-CAREER SES	7/19/2015	1 years, 4 months
OFFICE OF ENERGY POLICY & SYSTEMS ANALYSIS	DEP DIR CSE & SR ADV CLIMATE CHG TO THE SEC	GREENWALD,JUDITH M	NON-CAREER SES	7/31/2013	3 years, 4 months
OFFICE OF ENERGY POLICY & SYSTEMS ANALYSIS	DIRECTOR, FOR ENERGY POLICY AND SYSTEMS ANALYSIS	KENDERDINE,MELANIE A	NON-CAREER SES	5/23/2013	3 years, 6 months
OFFICE OF ENERGY POLICY & SYSTEMS ANALYSIS	SENIOR ADVISOR FOR DOMESTIC ENERGY POLICY	WAYLAND,KAREN G	NON-CAREER SES	8/11/2013	3 years, 3 months
OFFICE OF FOSSIL ENERGY	DAS FOR CLEAN COAL AND CARBON MANAGEMENT	MOHLER,DAVID W	NON-CAREER SES	3/22/2015	1 years, 8 months
OFFICE OF GENERAL COUNSEL	DEPUTY GENERAL COUNSEL FOR COMPLIANCE	PAYNE,KEDRIC L	NON-CAREER SES	8/18/2014	2 years, 3 months
OFFICE OF GENERAL COUNSEL	COUNSELOR	SAHGAL,RISHI R	NON-CAREER SES	7/22/2014	2 years, 4 months
OFFICE OF GENERAL COUNSEL	DEPUTY GENERAL COUNSEL FOR ENERGY POLICY	WALSH,SAMUEL T	NON-CAREER SES	1/21/2013	3 years, 10 months
OFFICE OF INTERNATIONAL AFFAIRS	PRINCIPAL DEPUTY ASSISTANT SECRETARY FOR IA	GANT,PAULA A	NON-CAREER SES	9/25/2013	3 years, 2 months
OFFICE OF INDIAN ENERGY POLICY AND PROGRAMS	DEPUTY DIRECTOR, OFFICE OF INDIAN ENERGY POLICY & PROGRAMS	CONRAD,DAVID F	NON-CAREER SES	10/13/2010	6 years, 1 months
OFFICE OF CHIEF INFORMATION OFFICER	CHIEF INFORMATION OFFICER	JOHNSON,MICHAEL M	NON-CAREER SES	3/8/2015	1 years, 8 months
LOAN PROGRAMS OFFICE	EXECUTIVE DIRECTOR, LOAN PROGRAM OFFICE	MCCALL,MARK A	NON-CAREER SES	7/22/2015	1 years, 4 months
OFFICE OF MANAGEMENT	DIRECTOR, OFFICE OF EXECUTIVE SECRETARIAT	DEMAGISTRIS,AMY B	NON-CAREER SES	3/18/2009	7 years, 8 months
OFFICE OF NUCLEAR ENERGY	PRINCIPAL DEPUTY ASSISTANT SECRETARY	KOTEK,JOHN F	NON-CAREER SES	1/25/2015	1 years, 10 months
NATIONAL NUCLEAR SECURITY ADMINISTRATION	ASSOCIATE ADMINISTRATOR FOR EXTERNAL AFFAIRS	BISHOP,CLARENCE T	NON-CAREER SES	11/25/2009	7 years, 0 months
OFFICE OF ELECTRICITY DELIVERY AND ENERGY RELIABILITY	DEP ASST SECRETARY, TRANSMISSION PERMITTING & TECHNICAL ASSI	CONKLIN,MEGHAN M	NON-CAREER SES	8/31/2015	1 years, 3 months
OFFICE OF ELECTRICITY DELIVERY AND ENERGY RELIABILITY	PRINCIPAL DEPUTY ASSISTANT SECRETARY	DALTON,ELIZABETH R	NON-CAREER SES	5/22/2011	5 years, 6 months
OFFICE OF THE SECRETARY OF ENERGY	DEPUTY CHIEF OF STAFF	DAVIS,CHRISTOPHER E	NON-CAREER SES	1/30/2011	5 years, 10 months
OFFICE OF THE SECRETARY OF ENERGY	DEPUTY CHIEF OF STAFF TO THE SECRETARY/EXECUTIVE SECRETARY	DE VOS,ERICA NMN	NON-CAREER SES	7/8/2013	3 years, 4 months
OFFICE OF THE SECRETARY OF ENERGY	CHIEF OF STAFF	KNOBLOCH,KEVIN T	NON-CAREER SES	6/24/2013	3 years, 5 months
OFFICE OF THE SECRETARY OF ENERGY	ASSOCIATE DEPUTY SECRETARY	MACWILLIAMS III,JOHN J	NON-CAREER SES	6/2/2013	3 years, 6 months
OFFICE OF THE SECRETARY OF ENERGY	SENIOR ADVISOR & DIR OF THE NAT'L LAB OPERATIONS BOARD	MARKOVITZ,ALISON J	NON-CAREER SES	10/9/2011	5 years, 1 months
OFFICE OF THE SECRETARY OF ENERGY	CHIEF OF STAFF TO THE DEPUTY SECRETARY	MCCLEES,TIMOTHY R	NON-CAREER SES	12/15/2013	2 years, 11 months
OFFICE OF THE SECRETARY OF ENERGY	SENIOR ADVISOR	SHAH,TARAK N	NON-CAREER SES	5/12/2014	2 years, 6 months
OFFICE OF PUBLIC AFFAIRS	DIRECTOR OF PUBLIC AFFAIRS	BURNHAM-SNYDER,EBEN W	NON-CAREER SES	5/11/2015	1 years, 6 months
OFFICE OF THE UNDER SECRETARY FOR MANAGEMENT AND PERFORAMNCE	DEPUTY UNDER SECRETARY FOR MANAGEMENT AND PERFORMANCE	KLAUS,DAVID M	NON-CAREER SES	7/8/2013	3 years, 4 months
OFFICE OF SMALL & DISADVANTAGED BUSINESS UTILIZATION	DIRECTOR, OFFICE OF SMALL AND DISADVANTAGED BUSINESS UTILIZA	HALE,JOHN H	NON-CAREER SES	7/23/2012	4 years, 4 months
OFFICE OF TECHNOLOGY TRANSITIONS	DIR, OFC OF TECH TRANSITS & TECN TRANSFER COORD	WONG,JETTA L	NON-CAREER SES	7/15/2012	4 years, 4 months
ADVANCED RESEARCH PROJECTS AGENCY - ENERGY	SPECIAL ADVISOR	FRITZE,EMILY N	SCHEDULE C	4/5/2015	1 years, 8 months
ADVANCED RESEARCH PROJECTS AGENCY - ENERGY	SENIOR ADVISOR	WILLIAMS-ALLEN,COREY S	SCHEDULE C	9/22/2013	3 years, 2 months
OFFICE OF CONGRESSIONAL AND INTERGOVERNMENTAL AFFAIRS	LEGISLATIVE AFFAIRS ADVISOR	ALGHUSSEIN,BESAMA K	SCHEDULE C	3/28/2016	0 years, 8 months
OFFICE OF CONGRESSIONAL AND INTERGOVERNMENTAL AFFAIRS	LEGISLATIVE AFFAIRS ADVISOR	ASLAMI,MOHAMMAD M	SCHEDULE C	7/27/2014	2 years, 4 months
OFFICE OF CONGRESSIONAL AND INTERGOVERNMENTAL AFFAIRS	SENIOR ADVISOR FOR INTERGOVERNMENTAL AND EXTERNAL AFFAIRS	CABRERA-BELL,KARINA C	SCHEDULE C	7/10/2016	0 years, 4 months
OFFICE OF CONGRESSIONAL AND INTERGOVERNMENTAL AFFAIRS	LEGISLATIVE ADVISOR	CHAPMAN,KYLE J	SCHEDULE C	8/1/2016	0 years, 4 months
OFFICE OF CONGRESSIONAL AND INTERGOVERNMENTAL AFFAIRS	SPECIAL ADVISOR	EASTON III,ALLEN R	SCHEDULE C	4/28/2014	2 years, 7 months
OFFICE OF CONGRESSIONAL AND INTERGOVERNMENTAL AFFAIRS	ADVISOR	FURUKAWA-MARTINEZ,GEORGET	SCHEDULE C	2/1/2016	0 years, 10 months
OFFICE OF CONGRESSIONAL AND INTERGOVERNMENTAL AFFAIRS	SPECIAL ASSISTANT	LANGE,EMMA K	SCHEDULE C	9/4/2016	0 years, 3 months
OFFICE OF CONGRESSIONAL AND INTERGOVERNMENTAL AFFAIRS	SPECIAL ADVISOR	LEWIS,JOURDAN M	SCHEDULE C	11/15/2015	1 years, 0 months

DEPARTMENTAL ELEMENT	POSITION TITLE	NAME	TYPE OF APPOINTMENT	DATE STARTED IN DOE	TOTAL YEARS IN DOE
OFFICE OF CONGRESSIONAL AND INTERGOVERNMENTAL AFFAIRS	SPECIAL ADVISOR	PENANSKY,MICHAEL K	SCHEDULE C	8/9/2015	1 years, 3 months
OFFICE OF CONGRESSIONAL AND INTERGOVERNMENTAL AFFAIRS	SPECIAL ADVISOR	PENDERGAST,SARAH M	SCHEDULE C	11/6/2016	0 years, 1 months
OFFICE OF CONGRESSIONAL AND INTERGOVERNMENTAL AFFAIRS	SPECIAL ASSISTANT	PHAM,MIRANDA N	SCHEDULE C	9/4/2016	0 years, 3 months
OFFICE OF CONGRESSIONAL AND INTERGOVERNMENTAL AFFAIRS	ADV FOR INTERGOVERNMENTAL & EXTERNAL AFFAIRS	SWENSON,WILLIAM J	SCHEDULE C	3/28/2016	0 years, 8 months
OFFICE OF CONGRESSIONAL AND INTERGOVERNMENTAL AFFAIRS	DIRECTOR OF EXTERNAL AFFAIRS	VANGENDEREN,HEIDI NMN	SCHEDULE C	5/8/2012	4 years, 6 months
OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY	SPECIAL ASSISTANT	BUNYAN,SIMON A	SCHEDULE C	11/15/2015	1 years, 0 months
OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY	SPECIAL ADVISOR	COHEN,EVAN N	SCHEDULE C	9/23/2014	2 years, 2 months
OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY	SENIOR ADVISOR	DEANE,DANIELLE NYSSA	SCHEDULE C	1/10/2016	0 years, 10 months
OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY	SPECIAL ADVISOR FOR STAKEHOLDER ENGAGEMENT	FOX,MICHAEL G	SCHEDULE C	10/11/2016	0 years, 1 months
OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY	CHIEF OF STAFF	NELSON,MATTHEW B	SCHEDULE C	3/12/2014	2 years, 8 months
OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY	DEPUTY, CHIEF OF STAFF	RAMOS,DERRICK D	SCHEDULE C	5/3/2010	6 years, 7 months
OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY	SENIOR ADVISOR	WALSH,JASON M	SCHEDULE C	4/8/2012	4 years, 7 months
OFFICE OF ENVIRONMENTAL MANAGEMENT	SPECIAL ASSISTANT	SZULMAN,ERIN R	SCHEDULE C	8/6/2012	4 years, 4 months
OFFICE OF ENERGY POLICY & SYSTEMS ANALYSIS	SPECIAL ADVISOR	DELL,REBECCA W	SCHEDULE C	3/20/2016	0 years, 8 months
OFFICE OF ENERGY POLICY & SYSTEMS ANALYSIS	SPECIAL ADVISOR	LEDESMA-RODRIGUEZ,RAISA S	SCHEDULE C	6/29/2014	2 years, 5 months
OFFICE OF ENERGY POLICY & SYSTEMS ANALYSIS	SENIOR ANALYST FOR ENERGY SECURITY	MOHAMMED,ALIA M	SCHEDULE C	5/15/2016	0 years, 6 months
OFFICE OF ENERGY POLICY & SYSTEMS ANALYSIS	SPECIAL ADVISOR	PORTER,ASA S	SCHEDULE C	11/9/2015	1 years, 0 months
OFFICE OF ENERGY POLICY & SYSTEMS ANALYSIS	DIRECTOR OF THE QUADRENNIAL ENERGY REVIEW SECRETARIAT	VENDETTA,LAURA C	SCHEDULE C	11/10/2014	2 years, 0 months
OFFICE OF FOSSIL ENERGY	SPECIAL ADVISOR	DAVIDSON,STEVEN B	SCHEDULE C	11/23/2015	1 years, 0 months
OFFICE OF FOSSIL ENERGY	SENIOR ADVISOR	RICHARDS,JOHN E	SCHEDULE C	9/19/2011	5 years, 2 months
OFFICE OF INTERNATIONAL AFFAIRS	SENIOR ADVISOR	KHAN,MAISAH A	SCHEDULE C	12/1/2013	3 years, 0 months
OFFICE OF INTERNATIONAL AFFAIRS	SPECIAL ASSISTANT	WENZEL,CASSANDRA A	SCHEDULE C	7/5/2016	0 years, 5 months
OFFICE OF CHIEF INFORMATION OFFICER	DEPUTY CHIEF OF STAFF	SILVERIO,JUANA D	SCHEDULE C	10/14/2015	1 years, 1 months
LOAN PROGRAMS OFFICE	SPECIAL ADVISOR	CONNOLLY,MATTHEW J	SCHEDULE C	11/15/2015	1 years, 0 months
LOAN PROGRAMS OFFICE	SENIOR ADVISOR TO THE EXECUTIVE DIRECTOR, LPO	THAKAR,NIDHI J	SCHEDULE C	12/3/2015	1 years, 0 months
OFFICE OF MANAGEMENT	SPECIAL ASSISTANT	BEHROOZIAN,KAYVON T	SCHEDULE C	7/27/2014	2 years, 4 months
OFFICE OF MANAGEMENT	SENIOR ADVISOR AND DIRECTOR OF SPECIAL PROJECTS	BRAMMER,ALISSA B	SCHEDULE C	7/25/2012	4 years, 4 months
OFFICE OF MANAGEMENT	SENIOR ADVISOR	CAMPBELL,NATASHA N	SCHEDULE C	7/27/2014	2 years, 4 months
OFFICE OF MANAGEMENT	SENIOR ADVANCE LEAD	CARSON,RONALD A	SCHEDULE C	7/31/2011	5 years, 4 months
OFFICE OF MANAGEMENT	DIRECTOR OF OPERATIONS	COLLINS,ADRIAN K	SCHEDULE C	10/12/2014	2 years, 1 months
OFFICE OF MANAGEMENT	SPECIAL ADVISOR	DODGE,MONICA M	SCHEDULE C	1/24/2016	0 years, 10 months
OFFICE OF MANAGEMENT	SPECIAL ADVISOR TO THE SECRETARY	FITZMAURICE,KEVIN J	SCHEDULE C	8/5/2013	3 years, 4 months
OFFICE OF MANAGEMENT	DIRECTOR OF SCHEDULING	HARRIS,FRANCINE R	SCHEDULE C	1/6/2014	2 years, 11 months
OFFICE OF MANAGEMENT	SPECIAL ASSISTANT	JOSEPH II,GREGORY K	SCHEDULE C	10/12/2016	0 years, 1 months
OFFICE OF MANAGEMENT	SENIOR ADVISOR FOR STRATEGIC PLANNING	MAAS,CARRIE A	SCHEDULE C	5/18/2014	2 years, 6 months
OFFICE OF MANAGEMENT	SPECIAL ADVISOR FOR STRATEGIC PLANNING	MOON,DANIELLE NMN	SCHEDULE C	12/7/2015	1 years, 0 months
OFFICE OF MANAGEMENT	DIRECTOR, OFFICE OF SCHEDULING & ADVANCE	QUINTERO,CHARLES L	SCHEDULE C	9/6/2015	1 years, 3 months
OFFICE OF MANAGEMENT	SCHEDULER AND SPECIAL ADVISOR TO THE DEPUTY SECRETARY	SUGAR-CARLSGAARD,JORDAN S	SCHEDULE C	11/9/2015	1 years, 0 months
OFFICE OF NUCLEAR ENERGY	ASSOCIATE DAS FOR POLICY AND SMR	BOWEN,MATTHEW T	SCHEDULE C	11/3/2009	7 years, 1 months
OFFICE OF NUCLEAR ENERGY	SENIOR COMMUNICATIONS ADVISOR	WICKER,WILLIAM A S	SCHEDULE C	6/30/2013	3 years, 5 months
NATIONAL NUCLEAR SECURITY ADMINISTRATION	CONGRESSIONAL AFFAIRS SPECIALIST	ALLEN,CLAYTON L	SCHEDULE C	7/18/2016	0 years, 4 months
NATIONAL NUCLEAR SECURITY ADMINISTRATION	PRESS SECRETARY	ISRAELI,FRANCIE MICHAL	SCHEDULE C	10/18/2015	1 years, 1 months
NATIONAL NUCLEAR SECURITY ADMINISTRATION	DIRECTOR OF THE PUBLIC AFFAIRS OFFICE	METZGER,THOMAS F	SCHEDULE C	2/8/2015	1 years, 9 months
NATIONAL NUCLEAR SECURITY ADMINISTRATION	DEPUTY DIRECTOR OF CONGRESSIONAL AFFAIRS	TORRES-JAEN,ORFA A	SCHEDULE C	10/27/2014	2 years, 1 months
OFFICE OF ELECTRICITY DELIVERY AND ENERGY RELIABILITY	SENIOR ADVISOR	DALLAFIOR,MICHELLE E	SCHEDULE C	10/7/2009	7 years, 2 months
OFFICE OF ELECTRICITY DELIVERY AND ENERGY RELIABILITY	SPECIAL ADVISOR, OFFICE OF THE ASST SECRETARY FOR OE	GLADDEN,DEVIN C	SCHEDULE C	1/10/2016	0 years, 10 months
OFFICE OF ELECTRICITY DELIVERY AND ENERGY RELIABILITY	SENIOR ADVISOR FOR EXTERNAL AFFAIRS	HART JR,PATRICK J	SCHEDULE C	11/2/2014	2 years, 1 months
OFFICE OF ELECTRICITY DELIVERY AND ENERGY RELIABILITY	SENIOR ADVISOR FOR EXTERNAL AFFAIRS	KENNEDY,ALISON M	SCHEDULE C	7/1/2012	4 years, 5 months
OFFICE OF THE SECRETARY OF ENERGY	WHITE HOUSE LIAISON AND SENIOR ADVISOR	ABRAHAM,SABEY MARINA	SCHEDULE C	12/13/2015	0 years, 11 months
OFFICE OF THE SECRETARY OF ENERGY	SPECIAL ADVISOR FOR FINANCE AND CLEAN ENERGY INVESTMENT	ALSTON,KENNETH A	SCHEDULE C	9/4/2012	4 years, 3 months
OFFICE OF THE SECRETARY OF ENERGY	SPECIAL ASSISTANT	BICKNELL,DANIEL P	SCHEDULE C	1/24/2016	0 years, 10 months
OFFICE OF THE SECRETARY OF ENERGY ADVISORY BOARD	SPECIAL ASSISTANT	BONARDI,MAXIMILLIAN C	SCHEDULE C	9/4/2016	0 years, 3 months
OFFICE OF THE SECRETARY OF ENERGY	SPECIAL ADVISOR	BUENO,MICHAEL A	SCHEDULE C	9/9/2015	1 years, 2 months
OFFICE OF THE SECRETARY OF ENERGY ADVISORY BOARD	DEPUTY DIRECTOR, SECRETARIAL BOARDS & COUNCIL	CALLEJAS,MARIA P	SCHEDULE C	8/14/2013	3 years, 3 months
OFFICE OF THE SECRETARY OF ENERGY ADVISORY BOARD	DIRECTOR & SENIOR ADVISOR, OFC OF SECRETARIAL BOARDS	GIBSON,KAREN L	SCHEDULE C	8/19/2013	3 years, 3 months
OFFICE OF THE SECRETARY OF ENERGY	SPECIAL ADVISOR FOR COMMUNICATIONS	GRANT,KATHRYN A	SCHEDULE C	10/5/2014	2 years, 2 months
OFFICE OF THE SECRETARY OF ENERGY	SPECIAL ASSISTANT	GRIGG,NICOLE C	SCHEDULE C	1/24/2016	0 years, 10 months
OFFICE OF THE SECRETARY OF ENERGY	SPECIAL ADVISOR	HOPOI,MILIKA L	SCHEDULE C	6/28/2015	1 years, 5 months
OFFICE OF THE SECRETARY OF ENERGY	SPECIAL ASSISTANT TO THE WHITE HOUSE LIAISON	ROBERTS,CARL E	SCHEDULE C	6/20/2016	0 years, 5 months
OFFICE OF THE SECRETARY OF ENERGY	ADVISOR TO THE SECRETARY OF OPERATIONS AND SUPPORT	ROBINSON,RYAN S	SCHEDULE C	3/18/2014	2 years, 8 months
OFFICE OF THE SECRETARY OF ENERGY	DEPUTY WHITE HOUSE LIAISON	RODRIGUEZ-OLVERA,LORENZO	SCHEDULE C	5/18/2014	2 years, 6 months
OFFICE OF THE SECRETARY OF ENERGY	SPECIAL ADVISOR FOR CLEAN ENERGY AND RISK MANAGEMENT	SARTORIUS,KATHARINE I	SCHEDULE C	11/17/2013	3 years, 0 months
OFFICE OF THE SECRETARY OF ENERGY	SPECIAL ASSISTANT TO THE CHIEF OF STAFF	SPOERER,KATIE K	SCHEDULE C	3/6/2016	0 years, 9 months
OFFICE OF THE SECRETARY OF ENERGY	SPECIAL ASSISTANT	TARANTO,JENNIFER M	SCHEDULE C	8/1/2016	0 years, 4 months
OFFICE OF THE SECRETARY OF ENERGY	SPECIAL ASSISTANT TO THE DEPUTY CHIEF OF STAFF	YANAI,HOLLY B	SCHEDULE C	8/21/2016	0 years, 3 months
OFFICE OF PUBLIC AFFAIRS	SPECIAL ADVISOR FOR DIGITAL COMMUNICATIONS	ADAMS,PATRICK R	SCHEDULE C	11/10/2014	2 years, 0 months
OFFICE OF PUBLIC AFFAIRS	PRESS SECRETARY	GUMBINER,ANDREW J	SCHEDULE C	12/29/2013	2 years, 11 months
OFFICE OF PUBLIC AFFAIRS	DEPUTY PRESS SECRETARY	HERWARD-BARTOL,BRIDGET A	SCHEDULE C	4/17/2016	0 years, 7 months

DEPARTMENTAL ELEMENT	POSITION TITLE	NAME	TYPE OF APPOINTMENT	DATE STARTED IN DOE	TOTAL YEARS IN DOE
OFFICE OF PUBLIC AFFAIRS	CHIEF SPEECHWRITER	LARUE,JOHN A	SCHEDULE C	9/8/2013	3 years, 2 months
OFFICE OF PUBLIC AFFAIRS	DIRECTOR OF DIGITAL STRATEGY	NEWHALL,MARISSA N	SCHEDULE C	8/5/2013	3 years, 4 months
OFFICE OF PUBLIC AFFAIRS	PRESS ASSISTANT	ORLOFF,HANNAH L	SCHEDULE C	8/15/2016	0 years, 3 months
OFFICE OF PUBLIC AFFAIRS	PRINCIPAL DEPUTY PRESS SECRETARY	SANDERS,JOSHUNDA V	SCHEDULE C	10/13/2015	1 years, 1 months
OFFICE OF PUBLIC AFFAIRS	PRESS SECRETARY	SELAK,DAWN M	SCHEDULE C	11/3/2013	3 years, 1 months
OFFICE OF PUBLIC AFFAIRS	ASSISTANT PRESS SECRETARY	WALSH,KATHRYN G	SCHEDULE C	11/15/2015	1 years, 0 months
OFFICE OF SCIENCE	SENIOR POLICY ADVISOR	HUERTA,MARCOS NMN	SCHEDULE C	7/25/2011	5 years, 4 months
OFFICE OF SCIENCE	SPECIAL ADVISOR	KINNEY,ROBERT A	SCHEDULE C	4/3/2016	0 years, 8 months
OFFICE OF TECHNOLOGY TRANSITIONS	SPECIAL ASSISTANT	ABREU,RANDY D	SCHEDULE C	8/15/2016	0 years, 3 months
OFFICE OF TECHNOLOGY TRANSITIONS	CHIEF OF STAFF	GRAHAM,CARLISSIA N	SCHEDULE C	3/20/2016	0 years, 8 months

39. Is the number of Assistant Secretaries set by statute? Does the statute establish the number as a minimum or a maximum, or is it silent on the question?

Response: The number of Assistant Secretaries is set by statute. Pursuant to section 203 of the Department of Energy Organization Act (42 U.S.C. § 7133), there is a maximum of eight Assistant Secretaries that may be appointed by the President with confirmation by the Senate.

41. Can you provide a list of the Loan Program Office's outstanding loans, including the parties responsible for paying the loan back, term of the loan, and objective of the loan?

Response: Yes, please see the attached list.

Loan Programs Office Portfolio List - December 22, 2016

Active Projects

Project Name (Borrower Name) *Denotes FIPP	Generation/ Capacity	Location (State)	Project Status as of 12/22/16	Loan Amount at Closing $MM
ATVM				$7,350
Ford (Ford Motor Company)	N/A	MI, IL, KY, OH, MO, NY	Operation	$5,900
Nissan (Nissan North America, Inc.)	N/A	TN	Operation	$1,450
Title XVII (§1705 - Recovery Act) Program				$13,189
Renewable Generation				$12,696
Photovoltaic Solar				*$4,741*
Agua Caliente (Agua Caliente Solar, LLC)	290 MW	AZ	Operation	$967
Alamosa (Cogentrix of Alamosa, LLC)	29 MW	CO	Operation	$91
AVSR (AV Solar Ranch 1, LLC)	242 MW	CA	Operation	$646
CVSR (High Plains Ranch II, LLC)	250 MW	CA	Operation	$1,200
Desert Sunlight (Desert Sunlight 250, LLC, Desert Sunlight 300, LLC)*	550 MW	CA	Operation	$1,500
Mesquite 1 (Mesquite Solar 1, LLC)	170 MW	AZ	Operation	$337
Concentrating Solar Power				*$5,839*
Crescent Dunes (Tonopah Solar Energy, LLC)	110 MW	NV	Operation	$737
Mojave (Mojave Solar, LLC)	250 MW	CA	Operation	$1,200
Genesis (Genesis Solar, LLC)*	250 MW	CA	Operation	$852
Ivanpah (Solar Partners I, LLC, Solar Partners II, LLC, Solar Partners VIII, LLC)	392 MW	CA	Operation	$1,600
Solana (Arizona Solar One, LLC)	250 MW	AZ	Operation	$1,450
Wind Generation				*$1,570*
Granite (Granite Reliable Power, LLC)*	99 MW	NH	Operation	$169
Record Hill (Record Hill Wind, LLC)	51 MW	ME	Operation	$102
Shepherds Flat (Caithness Shepherds Flat, LLC)*	845 MW	OR	Operation	$1,300
Geothermal Generation				*$546*
Nevada (NGP Blue Mountain I, LLC)*	39 MW	NV	Operation	$99
Ormat (OFC 2, LLC)*	89 MW	NV	Operation	$350
USG Oregon (USG Oregon, LLC)	22 MW	OR	Operation	$97
Solar Manufacturing				$150
1366 (1366 Technologies, Inc.)	1000 MW	MA	Development	$150
Transmission/Storage				$343
One Nevada Line (Great Basin Transmission South, LLC)	600 MW HVDC	NV	Operation	$343
Title XVII (§1703) Program				$8,300
Nuclear Generation				$8,300
Vogtle 3&4 (Georgia Power Company, Oglethorpe Power Corporation, MEAG Power SPVJ, SPVM, SPVP)	2,204 MW	GA	Construction	$3,400 $3,100 $1,800
Portfolio Total				$28,839

43. Can you provide a full accounting of DOE liabilities associated with any loan or loan guarantee programs?

Response: The Department's liabilities are limited to the loan guarantees. The table provided in response to Question 41 provides the specific amounts.

44. The Department recently announced the issuance of $4.5 billion in loan guarantees for electric vehicles (and perhaps associated infrastructure). Can you provide a status on this effort?

Response: The Department did not issue $4.5 billion in loan guarantees for electric vehicles or infrastructure. This announcement does not constitute the commitment of a loan guarantee(s) to any party, rather it is announcing the availability of loan funds to potential applicants. The Department published a supplement to its existing $4.5 billion Renewable Energy and Efficient Energy Projects solicitation on June 16, 2016. The supplement provides guidance to the public that, among other types of facilities, distributed energy facilities may include, in appropriate cases, electric vehicle (EV) charging facilities and associated hardware and software.

45. Is there an assessment of the funds it would take to replace aging infrastructure in the complex? Is there a priority list of which facilities to be decommissioned?

Response: (b) (5)

(b) (5)

(b) (5) Additional information regarding DOE's infrastructure can be found in the attached "State of General Purpose Infrastructure" Report.

With regard to the priority list for decommissioning, the facilities in the Office of Environmental Management's (EM) decommissioning program are prioritized on an annual basis as part of the budget planning process with each EM site office preparing an integrated priority list of all cleanup activities, including decommissioning.

While most facilities requiring decommissioning are part of EM's portfolio, many are owned by other DOE Program Offices (e.g., Science, Nuclear Energy and the National Nuclear Security Administration). To address all of these facilities, DOE established a working group that prepared the recently-issued report (attached) entitled "Plan for Deactivation and Decommissioning of Nonoperational Defense Nuclear Facilities" in response to a requirement in the 2016 National Defense Authorization Act. This report includes a list of facilities that require deactivation and decommissioning and their relative priority based on a risk assessment; estimated lifecycle and deactivation/decommissioning costs; options to accelerate cleanup and avoid costs; plans for transferring responsibilities for disposition of certain facilities; and planned FY 2017 deactivation and decommissioning activities.

U.S. DEPARTMENT OF ENERGY

Plan for Deactivation and Decommissioning of Nonoperational Defense Nuclear Facilities

Report to Congress
December 2016

United States Department of Energy
Washington, DC 20585

Message from the Secretary

This report provides the Department of Energy's plans for deactivating and decommissioning nonoperational defense nuclear facilities as required by 50 U.S.C. 2603 (Section 3133 of the National Defense Authorization Act for Fiscal Year 2016 (P.L. 114-92), which amends the Atomic Energy Defense Act).

This report is provided to the following Members of Congress:

- **The Honorable Thad Cochran**
  Chairman, Senate Committee on Appropriations

- **The Honorable Barbara A. Mikulski**
  Vice Chairwoman, Senate Committee on Appropriations

- **The Honorable John McCain**
  Chairman, Senate Committee on Armed Services

- **The Honorable Jack Reed**
  Ranking Member, Senate Committee on Armed Services

- **The Honorable Lamar Alexander**
  Chairman, Subcommittee on Energy and Water Development
  Senate Committee on Appropriations

- **The Honorable Dianne Feinstein**
  Ranking Member, Subcommittee on Energy and Water Development
  Senate Committee on Appropriations

- **The Honorable Jeff Sessions**
  Chairman, Subcommittee on Strategic Forces
  Senate Committee on Armed Services

- **The Honorable Joe Donnelly**
  Ranking Member, Subcommittee on Strategic Forces
  Senate Committee on Armed Services

- **The Honorable Harold Rogers**
  Chairman, House Committee on Appropriations

- **The Honorable Nita M. Lowey**
  Ranking Member, House Committee on Appropriations

- **The Honorable Mac Thornberry**
  Chairman, House Committee on Armed Services

- **The Honorable Adam Smith**
  Ranking Member, House Committee on Armed Services
- **The Honorable Mike Rogers**
  Chairman, Subcommittee on Strategic Forces
  House Committee on Armed Services
- **The Honorable Jim Cooper**
  Ranking Member, Subcommittee on Strategic Forces
  House Committee on Armed Services
- **The Honorable Mike Simpson**
  Chairman, Subcommittee on Energy and Water Development
  House Committee on Appropriations
- **The Honorable Marcy Kaptur**
  Ranking Member, Subcommittee on Energy and Water Development
  House Committee on Appropriations

If you have any questions or need additional information, please contact me or Mr. Christopher King, Acting Assistant Secretary for Congressional and Intergovernmental Affairs, at (202) 586-5450.

Sincerely,

Ernest J. Moniz

Executive Summary

The Department of Energy's (DOE) 2016 Plan for Deactivation and Decommissioning of Nonoperational Defense Nuclear Facilities in response to the National Defense Authorization Act for Fiscal Year 2016 (NDAA) includes:

- A list of facilities that require deactivation and decommissioning (D&D) and their relative priority based on a risk assessment;
- Estimated lifecycle and deactivation/decommissioning costs;
- Options to accelerate cleanup and avoid costs;
- Plans for transfer of responsibilities for disposition of certain facilities; and
- Planned Fiscal Year 2017 deactivation and decommissioning activities.

In January 2015, the Secretary of Energy established the Excess Contaminated Facilities Working Group (ECFWG) to develop an analysis and options for how DOE may prioritize and address the numerous contaminated excess facilities owned by the various DOE Program Offices. Also, in early 2015 the DOE Inspector General (IG) and the Government Accountability Office (GAO) issued reports that raised concerns regarding DOE's management of high-risk excess facilities, particularly those awaiting transition to DOE's Office of Environmental Management. These reports described what the IG characterized as increasing levels of risk due to delays in the cleanup and disposition of contaminated excess facilities. The reports recommended that DOE conduct an updated analysis and report providing information to Departmental leadership to support decisions regarding the path forward to address these facilities.

The ECFWG collected enterprise-wide data to obtain updated cost estimates to D&D excess facilities and developed a qualitative assessment of the risks they may pose. DOE used this data to define the scope of the challenge and to identify better approaches for prioritization of excess facilities. In summary, as of March 2016, DOE has 2,349 excess facilities. The March 2016 Rough Order of Magnitude (ROM) cost estimate to D&D these facilities is $32 billion. The cost estimates presented throughout the report are ROM estimates with a range of -50 percent to +100 percent and are in constant 2016 dollars. The ROM cost for D&D includes the costs for stabilization, cleanout, deactivation, and final demolition. This estimate does not include related costs connected with D&D, such as waste disposal cells or treatment facilities, and the costs may change as DOE conducts additional characterization of the facilities.

The analysis identified those excess facilities that pose a relatively higher degree of risk compared to the other excess facilities. That subset totals 203 facilities as of March 2016, with a ROM D&D cost estimate of $11.6 billion, excluding the additional costs such as waste disposal cells and subsequent remediation. Thus, of those facilities that are currently excess, approximately nine percent of the total number were identified as having relatively higher risk, representing over 36 percent of the total estimated D&D cost. The subset of relatively higher risk facilities cost more to D&D. In addition to the facilities that have been designated as excess as of March 2016, in the next 10 years an estimated 1,000 additional facilities may be designated as excess, adding to the number of facilities to D&D and the associated costs.

In addition to this data collection and risk assessment effort, the Department has focused on institutionalizing a corporate approach to addressing excess facilities. DOE's disposition priorities are to stabilize degraded relatively higher-risk facilities, characterize their hazards and conditions, remove hazardous materials, place them in the lowest risk condition possible, and ultimately eliminate the risk by demolishing the facility and disposing of the resulting waste.

An October 2015 report by the Congressionally-authorized Commission to Review the Effectiveness of the National Laboratories (CRENEL) provided recommendations to DOE regarding deferred maintenance and excess facilities. Specifically, CRENEL recommended that "DOE and the laboratories should continue efforts to improve laboratory facilities and infrastructure by halting the growth in deferred maintenance and speeding up the deactivation and decommissioning of excess facilities. DOE should work with Congress and OMB to agree upon the size and nature of the resources shortfall for facilities and infrastructure, and to develop a long-term plan to resolve it through a combination of increased funding, policy changes, and innovative financing." CRENEL, Volume 1 at p. 57. In its February 2016 response to the CRENEL report, DOE stated that it "agrees with this recommendation, and will continue to brief Congress and OMB on the updated data on the infrastructure and excess facilities challenges identified by the recent working groups." DOE Response to CRENEL at pp. 28-29.

DOE's response to CRENEL also states that the ECFWG "developed and executed an enterprise-wide data collection effort to obtain updated cost and risk assessments to deactivate, decontaminate, decommission, and demolish excess facilities. The updated data from the working group was used to define the scope of the challenge and to identify options for how DOE may better prioritize excess facilities. The group is developing policies to institutionalize a corporate approach, and updating and validating data gathered by the working group's efforts. The group also will be finalizing a report on its work. This report will be issued in 2016, also in response to a requirement of the 2016 National Defense Authorization Act." DOE Response at p. 27. This report follows through on that commitment.

This report also addresses the DOE commitment in response to the IG report. Specifically, DOE committed to the IG that it would issue a "report providing critical information on contaminated Department excess facilities that would be useful to policy makers for decisions regarding the path forward for addressing these facilities."

Plan for Deactivation and Decommissioning Nonoperational Defense Nuclear Facilities

Table of Contents

I. Legislative Language

This report responds to the National Defense Authorization Act for Fiscal Year 2016 Sections 3133, which amends the Atomic Energy Defense Act by adding new Section 4423.

SEC. 3133. PLAN FOR DEACTIVATION AND DECOMMISSIONING OF NONOPOERATIONAL DEFENSE NUCLEAR FACILITIES.

(a) IN GENERAL.—Subtitle B of title XLIV of the Atomic Energy Defense Act (50 U.S.C. 2602 et seq.) is amended by adding at the end the following new section:

SEC. 4423. PLAN FOR DEACTIVATION AND DECOMMISSIONING OF NONOPERATIONAL DEFENSE NUCLEAR FACILITIES.

(a) IN GENERAL.—The Secretary of Energy shall, during each even-numbered year beginning in 2016, develop and subsequently carry out a plan for the activities of the Department of Energy relating to the deactivation and decommissioning of nonoperational defense nuclear facilities.

(b) ELEMENTS.—The plan required by subsection (a) shall include the following:

(1) A list of nonoperational defense nuclear facilities, prioritized for deactivation and decommissioning based on the potential to reduce risks to human health, property, or the environment and to maximize cost savings.

(2) An assessment of the life cycle costs of each nonoperational defense nuclear facility during the period beginning on the date on which the plan is submitted under subsection (d) and ending on the earlier of—

(A) the date that is 25 years after the date on which the plan is submitted; or

(B) the estimated date for deactivation and decommissioning of the facility.

(3) An estimate of the cost and time needed to deactivate and decommission each nonoperational defense nuclear facility.

(4) A schedule for when the Office of Environmental Management will accept each nonoperational defense nuclear facility for deactivation and decommissioning.

(5) An estimate of costs that could be avoided by—

(A) accelerating the cleanup of nonoperational defense nuclear facilities; or

(B) other means, such as reusing such facilities for another purpose.

(c) PLAN FOR TRANSFER OF RESPONSIBILITY FOR CERTAIN FACILITIES.—The Secretary shall, during 2016, develop and subsequently carry out a plan under which the Administrator shall transfer, by March 31, 2019, to the Assistant Secretary for Environmental Management the responsibility for decontaminating and decommissioning facilities of the Administration that the Secretary determines—

(1) are nonoperational as of September 30, 2015; and

(2) meet the requirements of the Office of Environmental Management for such transfer.[1]

(d) SUBMISSION TO CONGRESS.—Not later than March 31 of each even-numbered year beginning in 2016, the Secretary shall submit to the appropriate congressional committees a report that includes—

(1) the plan required by subsection (a);

(2) a description of the deactivation and decommissioning actions expected to be taken during the following fiscal year pursuant to the plan;

(3) in the case of the report submitting during 2016, the plan required by subsection (c); and

(4) in the case of a report submitted during 2018 or any year thereafter, a description of the deactivation and decommissioning actions taken at each nonoperational defense nuclear facility during the preceding fiscal year.

****

[1] In addition to the reporting requirement in the FY 2016 National Defense Authorization Act, the FY 2016 Joint Explanatory Statement accompanying the Consolidated Appropriations Act, 2016, Public Law 114-113) in the Congressional Record contained the following text; "The Office of Environmental Management shall not accept ownership or responsibility for cleanup of any National Nuclear Security Administration facilities or sites without funding specifically designated for that purpose." The Department is directed to identify all requests for transfers of facilities or projects from other DOE offices in its budget request justification in future years." (161 Cong. Rec. H10106 [daily ed. Dec.17, 2015.]).

II. Background

The Department of Energy (DOE) leads the largest nuclear cleanup effort in the world. DOE's objective is to remediate the environmental legacy of more than seven decades of nuclear weapons research, development, and production, and government-sponsored nuclear energy research. The disposition of contaminated excess[2] facilities is an important part of this cleanup mission. Since the Office of Environmental Management (EM) was established in 1989, DOE's other Program Offices have transferred thousands of contaminated excess facilities for deactivation and decommissioning (D&D). EM has made substantial progress in D&D of these legacy contaminated excess facilities having completed almost 3,000 facilities over the past 25 years. As of March 2016, DOE has 2,349 excess facilities.

While EM's mission includes D&D of excess contaminated facilities, it also includes responsibility for the cleanup of millions of gallons of liquid radioactive waste, thousands of tons of spent (used) nuclear fuel and special nuclear material, disposition of large volumes of transuranic and mixed/low-level waste, and treatment of huge quantities of contaminated soil and water. Many of EM's cleanup responsibilities other than D&D result from regulatory and legal requirements. Because of competing regulatory and other compliance obligations and performance challenges in some areas, EM is unable to D&D all of the excess facilities already transferred from other programs at this time.

Until EM accepts an excess contaminated facility meeting transfer conditions into its portfolio, the DOE Program Office responsible for the excess facility must maintain that facility in a safe condition and readying it for transition to EM. In addition, the Program Office owning the excess facility is also responsible for D&D of all excess facilities in its portfolio that are not contaminated. Long periods between shutdown and demolition can combine to create increased risks associated with both contaminated and uncontaminated facilities. DOE's disposition priorities are to stabilize higher-risk facilities, characterize their hazards and conditions, remove hazardous materials, place them in the lowest risk condition possible, and ultimately eliminate the risk by demolishing the facility and disposing of the resulting waste. Regardless of which DOE program is responsible for the excess facility, the risk to safety, security, and programmatic objectives is not completely eliminated until the facility is demolished.

In early 2015, both the DOE Inspector General (IG)[3] and the Government Accountability Office

---

[2] For the purpose of this report, the term "excess" is synonymous with "nonoperational" and refers to a facility for which DOE no longer has a mission need.
[3] DOE Office of Inspector General, Audit Report, The Department of Energy's Management of High-Risk Excess Facilities, DOE/IG-0931, January 23, 2015.

(GAO)[4] issued reports raising concerns with DOE's management of high-risk excess facilities, particularly those awaiting transition to EM. These reports describe what the IG characterized as increasing levels of risk assumed by DOE due to delays in the cleanup and disposition of contaminated excess facilities. The IG also found that these delays were exacerbated by DOE prioritization practices. As noted in these reports, DOE's progress in disposing of excess facilities, while substantial, has not included all of the relatively higher risk excess facilities. According to the reports, additional attention, improved strategic direction, and better prioritization would help maximize the use of available resources to address these issues. These reports recommended that DOE conduct an updated analysis and provide a report with critical information on contaminated excess facilities to DOE leadership to support decisions regarding the path forward for addressing these facilities.

In January 2015, the Secretary of Energy established the Excess Contaminated Facilities Working Group (ECFWG) to explore the issues and develop options for disposition of DOE's excess facilities. The ECFWG, with membership from across the DOE complex, collected enterprise-wide data and developed common metrics and definitions to provide a framework for evaluating options. The information gathered on each excess facility included rough order of magnitude (ROM) costs for D&D; cost ranges for maintenance, surveillance, repairs, and operations (MSRO); and an assessment of potential risk to public health and the environment, worker safety, and mission. The potential risk was assessed using a qualitative approach as described in III.B., Prioritization.

The updated data helped to further define the scope of the challenge and to suggest risk-informed approaches for addressing DOE's contaminated excess facilities. DOE is using this information to determine the best strategy to reduce risk from excess facilities.

In addition, DOE has made significant changes to improve management of facilities and infrastructure. For instance, NNSA established the Office of Safety, Infrastructure and Operations in January 2015 to ensure infrastructure needs are adequately represented and necessary investments are made. NNSA also deployed new data-driven, risk-informed decision-making tools such as the Master Asset Plan (MAP), Mission Dependency Index (MDI), BUILDER, and the G2 Program Management System to make most efficient use of resources. Finally, NNSA increased resources allocated to improving the condition of critical infrastructure and disposing of unneeded facilities.

More recently, the congressionally-authorized Commission to Review the Effectiveness of the National Laboratories (CRENEL) provided recommendations in its October 2015 report regarding DOE's deferred maintenance and excess facilities backlog including that DOE should "speed[] up the deactivation and decommissioning of excess facilities." In its February 2016

---

[4] United States Government Accountability Office, Report to the Chairman, Subcommittee of Energy and Water Development, Committee of Appropriations, U.S. Senate, DOE Real Property: Better Data and a More Productive Approach Needed to Facilitate Property Disposal, GAO-15-305, February 2015; and United States Government Accountability Office, Report to the Committee on Armed Services, U.S. Senate, DOE Facilities: Better Prioritization and Life Cycle Costs Analysis Would Improve Disposition Planning, GAO-15-272, March 2015.

response to the CRENEL report, DOE agreed with these recommendations and committed to "continue briefing Congress and OMB on the updated data on the infrastructure and excess facilities challenges identified by the recent working groups."

This report articulates the scope of the excess facilities challenge identified through these efforts, including identifying in Appendix B those facilities considered to present relatively higher risks based on the qualitative assessment, and discussing options to accelerate cleanup.

III. The Department of Energy's Nonoperational Defense Nuclear Facilities

III.A. Scope of the Challenge

Using common metrics and definitions, DOE obtained updated information relating to excess facilities, maintenance, and D&D of those facilities. The effort covered those facilities owned by the following DOE programs: EM, the Office of Science (SC), the Office of Nuclear Energy (NE), and the National Nuclear Security Administration (NNSA). The scope of the data collected was not limited to defense nuclear facilities but rather included all excess facilities to provide a complete picture of scope of the facilities to D&D. This effort obtained updated ROM cost to stabilize and D&D all of DOE's excess facilities and information on various levels of risk for each facility (public health and the environment, worker safety, and mission). The data in this report provides information on excess facilities as of March 2016. Excess facility inventory is not static; facility data are updated annually with ongoing stabilization and D&D projects underway each fiscal year. In the next 10 years, up to 1,000 additional facilities may be designated as excess, adding to the backlog of facilities awaiting D&D.

The data collection identified 2,349 excess facilities with a ROM cost to D&D of $32 billion. The cost estimates presented throughout this report are ROM estimates with a range of -50 percent to +100 percent and are in constant 2016 dollars. Figures 1 and 2 include the number of excess facilities and ROM D&D cost by current owner.[5]

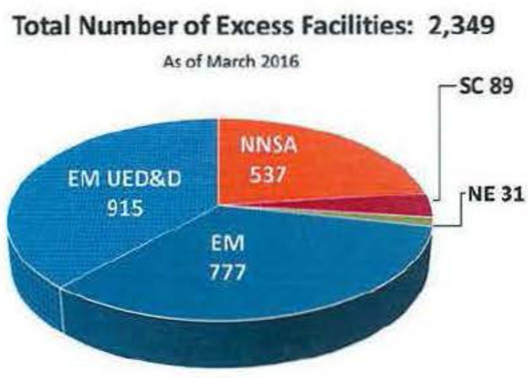


Figure 1

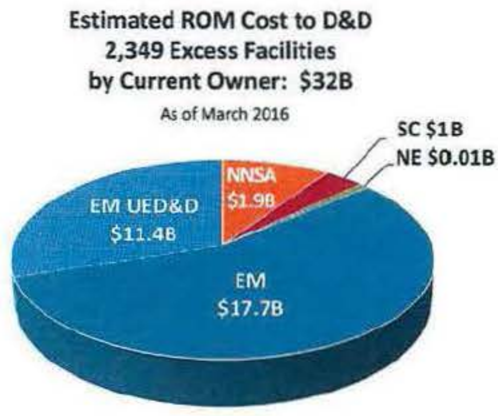


Figure 2

This report provides information on excess facilities as of March 2016.

[5] The Energy Policy Act of 1992 authorized annual contributions to the Uranium Enrichment Decontamination and Decommissioning (UED&D) Fund, which came from both a special assessment on domestic nuclear utilities and annual Congressional appropriations, to support the EM responsibilities at the nation's three Gaseous Diffusion Plants (GDPs) at Portsmouth, Ohio; Paducah, Kentucky; and Oak Ridge, Tennessee.

The ROM cost for D&D includes the costs for stabilization, cleanout, deactivation, and final demolition, as discussed below in Section III.C. Estimates will be further refined as part of project planning and revised as warranted by new information or the discovery of unexpected conditions.

III.B. Prioritization

The evaluation of excess facilities included an assessment of their potential risk. This risk posed by the contaminated excess facilities was determined using a qualitative approach that considered impacts to public health and the environment, worker safety, and the mission. DOE Program Offices, with input from the sites, used the Assessment Guide in Appendix A to determine the potential impacts from each excess facility

The ECFWG used this information to identify a subset of the total of excess facilities that pose relatively higher risk. These higher risk facilities fell into one of the two tiers described below. All other facilities were determined to be of lower relative risk.

> **Tier I.** Major or Significant risk to public health and the Environment; worker safety; **and** mission.
> **Tier II.** Major or Significant risk to public health and the Environment **and/or** worker safety (independent of mission impact).

These tiers were determined based on initial qualitative assessments; however, DOE is working on continuously improving the quality of its data and assessments, which may change the understanding of a given facility's relative risk.

The following sections summarize the scope of DOE excess facilities and the associated ROM cost to D&D those facilities, including a discussion of the subset of relatively higher-risk facilities. The subset of facilities currently owned by EM is identified first, followed by those excess facilities currently owned by other Program Offices.

III.C. EM Excess Facilities

This section focuses on the subset of excess facilities that have been transferred to EM and have not yet completed D&D. The EM D&D program is funded through annual Congressional appropriations, including the UED&D program for the former Gaseous Diffusion Plants (GDPs) at East Tennessee Technology Park (ETTP) in Oak Ridge, Tennessee; Portsmouth, Ohio; and Paducah, Kentucky. EM has historically spent between $500 and $900 million per year to D&D excess facilities located across the country. As of March 2016, EM had 1,692 excess facilities (previously accepted from other Program Offices) with a D&D ROM cost of $29 billion, not including additional associated costs detailed below. The EM responsibility for the currently estimated excess facility D&D scope represents approximately 91 percent of the total DOE D&D ROM cost. An estimated $11.4 billion of the $29 billion is associated with D&D of the former

GDP facilities through the UED&D program.[6] The facilities included in these cost estimates are located throughout the DOE complex. Figure 3 illustrates the sites where these facilities are located.

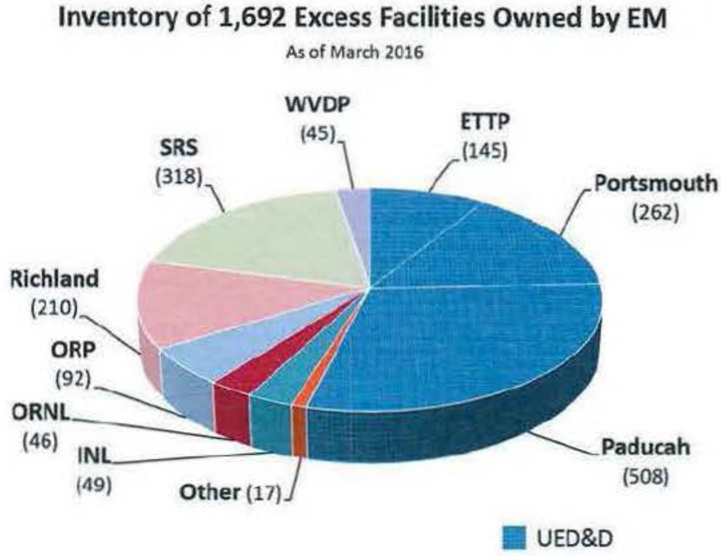


Figure 3

EM evaluates its projects based on risk, compliance and regulatory agreements, cost/benefit, and the optimized order of implementation for each project. This effort results in a prioritization of site-wide activities covering the following five major EM mission cleanup areas:

1. Radioactive tank waste stabilization, treatment and disposal;
2. Spent (used) nuclear fuel storage, receipt, and disposition;
3. Special nuclear materials consolidation, stabilization, and disposition;
4. Transuranic and mixed/low-level waste disposition;
5. Soil and groundwater remediation; and
6. Excess facilities deactivation and decommissioning.

EM balances the prioritized site lists with regulatory and other compliance requirements and related programmatic priorities, with practices to be as efficient as possible.

With respect to excess facilities, 158 of the 1,692 EM excess facilities have been identified as higher-risk facilities using the prioritization approach described above. The total ROM cost to complete D&D of these facilities is $9.3 billion as of March 2016, as shown in Figure 4 below.

[6] This estimate was based on the approved D&D costs at the end of FY 2015 and includes such activities as stabilization, cleanout, deactivation, and final demolition. These D&D estimates are then updated and adjusted to account for pending change requests and environmental liability adjustments at the 50% budget confidence level for D&D operating activities costs, and 80% budget confidence level for D&D capital projects for Project Baseline Summary (PBS-40), adjusted to account exclusively for D&D Activities.

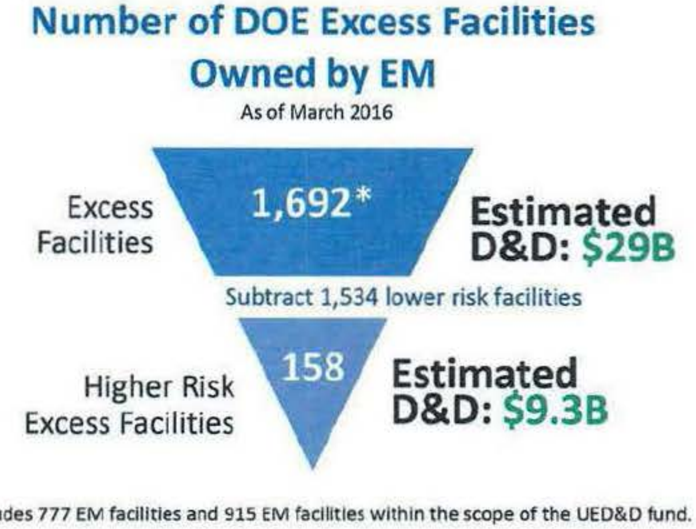


Figure 4

The ROM D&D cost of $29 billion discussed above does not include funding for additional projects that must be completed prior to initiating D&D. These precursor or prerequisite activities can involve the construction of new, or the expansion of, existing on-site CERCLA disposal cells to handle the increased volume of D&D waste. Another example is the requirement to build the Outfall 200 Mercury Treatment Facility at Oak Ridge before D&D of facilities contaminated with mercury can start at the Y-12 National Security Complex (Y-12). Projects that are not a prerequisite to D&D may also effect costs. For instance, the ROM costs for the D&D of a number of facilities at Y-12 assume reconfiguration of the protected area, which would avoid costs associated with D&D inside of a secured area. Examples of precursor or prerequisite activities for D&D include: design/construction of a new on-site CERCLA disposal cell at Portsmouth, design/construction of a new on-site CERCLA disposal cell at Paducah, construction and operation of the Outfall 200 Mercury Treatment Facilities at Y-12, and the Fast Flux Test Facility (FFTF) at Hanford. Each of these activities would cost in the hundreds of millions of dollars, and would represent additional expenditures before D&D can begin.

In addition to the above precursor activities, there are post-D&D expenditures also not incorporated in the $29 billion estimate. Many sites will need substantial additional work (e.g., soil and groundwater remediation, long-term monitoring) following D&D before an area is cleaned up, closed, or returned for public reuse.

III.D. Excess Facilities Owned by Programs Other than EM

This section focuses on the total of 657 excess facilities that as of March 2016 were owned and maintained by DOE Program Offices other than EM. The total ROM cost to complete D&D of these facilities is $2.94 billion, as shown in Figure 5 below. The precursor and prerequisite activities, as discussed above are not included in these estimates.

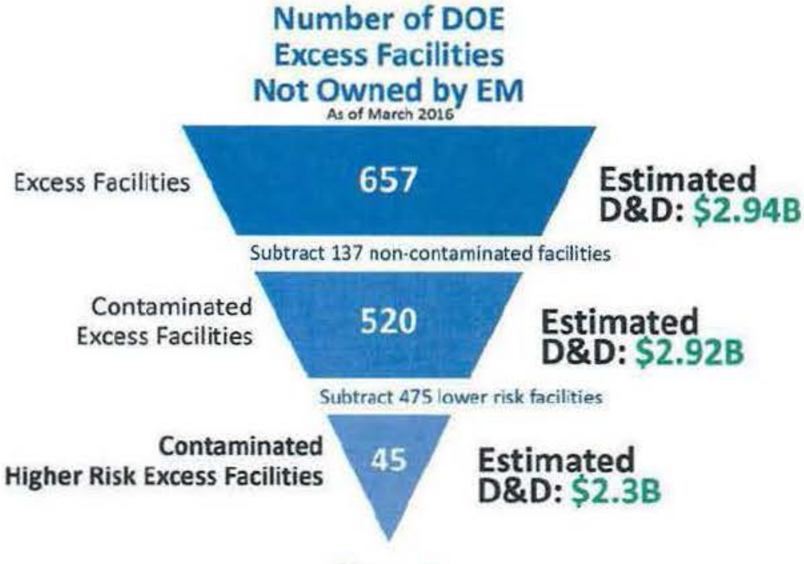


Figure 5

The facilities in Figure 5 above were grouped as follows:

1. **Excess Facilities**. The 657 excess facilities owned by programs other than EM have an estimated ROM D&D cost of $2.94 billion.
2. **Contaminated Excess Facilities**. This is a subset of category #1 and reflects the subtraction of 137 non-contaminated facilities that are not owned by EM and will remain the responsibility of the current program office to D&D. The 520 contaminated facilities have an estimated ROM D&D cost of $2.92 billion.
3. **Contaminated Higher-Risk Excess Facilities**. This is a subset of category #2, which reflects those facilities identified as relatively higher risk based on the prioritization factors described above. The 45 higher-risk facilities owned by programs other than EM have a ROM D&D cost of $2.3 billion as of March 2016.

As shown in Figure 5, almost 80 percent of the total estimated cost to D&D the facilities currently owned by other programs resides in the 45 higher-risk facilities (seven percent of the facilities), underscoring the higher costs to address the risks and contamination from these facilities.

III.E. DOE Contaminated Higher-Risk Excess Facilities

Appendix B contains a list of the facilities across the DOE/NNSA complex that have been identified as relatively higher risk (both EM facilities and those owned by other programs), along with the estimated D&D and MSRO (carrying) costs. These are listed as either "Tier I or Tier II, as explained above in Section III.B. Lower risk facilities are not included in this Appendix. Table 1 below provides a summary of both the total inventory of excess facilities and the facilities identified as relatively higher risk.

Table 1: Summary of Inventory of Excess Facilities as of March 2016

Program	Total Excess Facilities		Higher Risk Facilities	
	# Facilities	ROM Cost	# Facilities	ROM Cost
EM	1,692	$29 B	158	$9.3 B
NNSA, SC, NE	657	$3 B	45	$2.3 B
TOTALS	**2,349**	**$32 B**	**203**	**$11.6 B**

Of the 45 relatively higher risk facilities owned by programs other than EM, 33 may be process contaminated[7] and therefore eligible for transfer to EM. These facilities have a ROM D&D cost of $2.0 billion, not including additional associated costs. The remaining relatively higher risk facilities owned by programs other than EM are industrially contaminated and therefore the program owner is responsible for D&D. Figure 6 below shows the breakout of the higher-risk excess facilities by program owner and ROM cost to D&D.

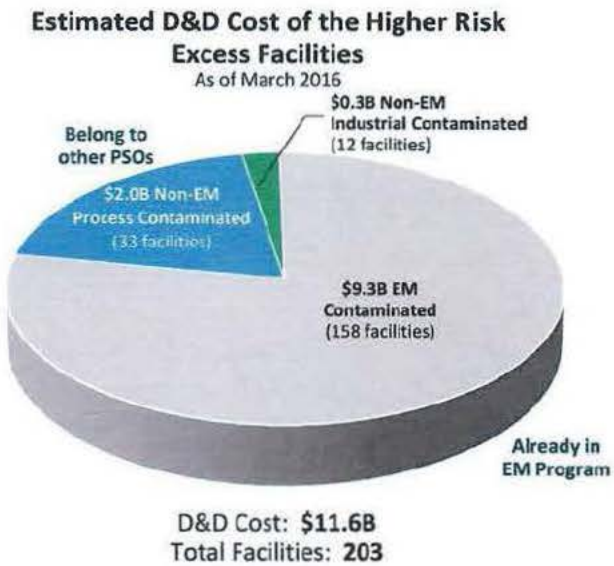


Figure 6

[7] Process contaminated facilities are those that are contaminated with hazardous chemical and/or radioactive substances. This definition excludes facilities that contain no residual hazardous substances other than those present in building materials and components, such as asbestos, lead-based paint, or equipment containing PCBs (DOE Order 430.1B).

IV. Options to Accelerate Cleanup and Avoid Costs

Addressing the contaminated higher-risk excess facility scope in the near term will require substantial resources. For example, the President's FY2017 budget request included a request for $37M to begin addressing the higher-risk facilities of Alpha 5 and Beta 4 at Y-12. The subsequent D&D of these facilities is estimated to cost hundreds of missions of dollars. DOE considered several approaches to accelerating the disposition of higher-risk facilities. These options consider different resource requirements, timeframes, and benefits. These options are scalable in the number of facilities addressed and the duration of execution.

In general, accelerating the D&D of excess facilities would reduce the risk posed by these facilities, and avoid annual maintenance and other costs associated with delaying D&D. As the data in Appendix B shows, MSRO costs can run into the millions of dollars per year to keep the facilities safe and stable. These costs are avoided when a facility is demolished. In addition to incurring ongoing MSRO costs delaying D&D may:

- Expose individuals and the environment to increasing levels of risk;
- Lead to escalating disposition costs. As an example, the IG report indicated that roof degradation of the Alpha 5 building at Y-12 has resulted in a spread of contamination; and
- Affect ongoing mission work (such as excess facilities located nearby ongoing mission work).

As explained above, if DOE were to accelerate the D&D of all of the facilities currently designated as higher risk, the ROM D&D cost as of March 2016 would be $11.6 billion. Additional funding would be needed for precursor and post D&D cleanup costs such as waste disposal costs or soil and groundwater remediation.

Alternatives

D&D could be accelerated either in a manner that is distributed at sites across the DOE complex, or it could be focused on addressing risks at a single location.

One alternative is a distributed approach; stabilizing, deactivating, or demolishing certain contaminated relatively higher-risk excess facilities in a manner that would be distributed across different DOE locations around the country. This approach would address buildings currently owned by various programs across a number of DOE labs and sites. Pursuing a mix of both full demolition and deactivation[8] of a number of the relatively higher-risk excess facilities identified in Appendix B would reduce risk without requiring funding for a full D&D of each facility. For instance, a distributed option could involve characterization and stabilization of the

---

[8] Deactivation includes, but is not limited to, de-inventorying the buildings of hazardous materials, which places the facilities into a safer, more stable condition while awaiting D&D.

Alpha 5 facility at Y-12 to reduce risk and MSRO costs, but would not fully D&D the facility, which could cost an estimated $400M more. Since some facilities might only be deactivated and not decommissioned under this approach, there would be less cost avoidance since some surveillance and maintenance costs would need to continue. In addition, although this approach lowers the risk from the facilities by stabilizing them and removing some contamination, it would not eliminate the risk.

A second alternative that focuses on accelerating D&D at a specific location – a site-specific approach – could have several benefits. First, a site-specific approach could be risk-based, by focusing on a site that houses a substantial portion of the relatively higher-risk facilities. Alternately, such an approach could focus on eliminating the substantial MSRO costs of maintaining the higher-risk facilities at a single location. As examples, 34 of the 44 "Tier 1" "higher risk" facilities reflected in Appendix B are located at Oak Ridge; five of the "Tier 1" facilities are located at Livermore; the estimated lifecycle costs (MSRO) to maintain the "higher risk" excess facilities at Portsmouth and Paducah are substantial.

Focusing efforts on a single location could provide additional benefits by utilizing a trained workforce and maximizing efficiencies of an integrated project. As a practical matter, D&D at crowded sites with ongoing mission work, such as Y-12, involves an integrated approach, as it is necessary to create space to conduct the D&D at some of the "higher risk" facilities. This could involve executing D&D at an adjacent lower-risk facility in order to facilitate the safe D&D of a higher-risk facility. A site-specific approach at location where there is ongoing mission work also could reduce impacts to those ongoing missions.

V. Plan for Transfer of Responsibility of Certain Facilities

Over the past 25 years, EM has completed the D&D of approximately 3,000 facilities previously owned by other Program Offices. In 2008 and 2009, EM reviewed over 300 facilities and found many to be appropriate for transfer pending the availability of funds to complete the D&D. Since that time, a number of these excess facilities were demolished under American Recovery and Reinvestment Act of 2009 (ARRA) and several additional process contaminated facilities have become excess. Because of competing regulatory and other compliance obligations and performance challenges in some areas, EM is unable to D&D all of the excess facilities already transferred from other programs at this time. In addition, the Joint Explanatory Statement accompanying the Consolidated Appropriations Act, 2016,[9] included the following:

> The Office of Environmental Management shall not accept ownership or responsibility for cleanup of any National Nuclear Security Administration facilities or sites without funding specifically designated for that purpose. The Department is directed to identify

[9] Public Law 114-113, Consolidated Appropriations Act, 2016, December 18, 2015.

all requests for transfers of facilities or projects from other DOE offices in its budget request justification in future years.

Per EM's Standard Operating Policies and Procedures number 34, for a facility to meet the requirements for transfer into the EM Program, the following must be true:

- The facility must no longer be needed for a DOE mission;
- The facility must be process contaminated with hazardous chemical and/or radioactive substances, such as plutonium, uranium, beryllium, or mercury. This does not include contaminants normally present in building materials and components, such as asbestos, lead-based paint, and equipment containing PCBs; and
- The facility must be an individual, self-contained facility, and not part of a larger complex.
- Specifically designated funds to disposition the facility must be available.

Also, after a facility is identified as acceptable for transfer to EM, it must meet the following general conditions before it can transfer:

- Wastes and materials removed;
- Facility hazards and conditions characterized;
- Site utilities isolated; and
- Facility condition is known and stable.

EM, in coordination with other DOE Program Offices, evaluates facilities identified for transfer to determine if these facilities meet the requirements. This evaluation includes an assessment of the facility, commonly referred to as a walk down. A team of subject matter experts from EM and other DOE Program Offices conducts the walk down and evaluates the facility; this serves as the basis of EM's decision regarding whether the facility meets the conditions of transfer or identifies the conditions that must be met prior to transferring the facility.

DOE is developing a plan for walk downs at all process-contaminated excess facilities evaluated as higher risk. These walk downs will establish a specific set of conditions for each facility that must be met for transfer so that Program Offices can plan for the necessary activities to meet them. DOE will prioritize the walk downs based on relative risk, with the relatively higher-risk facilities at Lawrence Livermore National Laboratory (LLNL) and Y-12 being walked down in FY 2016 and the remaining facilities to be walked down starting in FY 2017.

VI. Accomplishments and Planned Activities

DOE is committed to disposing of excess properties, making more efficient use of real property assets, and reducing its total square footprint in support of the Administration's Reduce the Footprint initiative.[10] As part of this effort, DOE is engaged in a number of ongoing activities to D&D and otherwise reduce the risk associated with excess facilities. DOE used the recently

---

[10] OMB, National Strategy for the Efficient Use of Real Property, Spring 2015.

collected data to identify appropriate projects that will reduce risk. Much of the ongoing or planned work described below addresses specific risks identified in the GAO and IG reports.

VI.A Recent Accomplishments and Planned Activities

EM

From 2010 to 2015 EM completed D&D of approximately 630 facilities, including the entombment of 16 facilities, and characterized, reduced risk, deactivated, or prepared another 22 facilities. This work was facilitated by $6 billion received under ARRA. Significant completions under ARRA included the following:

- Entombment of P- and R-Reactors at SRS, the Experimental Breeder Reactor-II (EBR-II) and certain facilities at the Idaho Nuclear Technology and Engineering Center (INTEC) at the Idaho National Laboratory (INL);
- Partial in-situ decommissioning of U Plant Canyon at Hanford;
- Partial deactivation and cleanout of NNSA's Alpha 5 at Y-12 (although still one of the highest-risk facilities as identified in recent GAO and IG Reports);
- Risk reduction at building 235-F at SRS;
- Continued deactivation of the West Valley Main Plant Process Building and removal of ancillary facilities; and
- Completion of facility D&D of certain facilities at Idaho Nuclear Technology and Engineering Center (INTEC) and Material and Fuels Complex (MFC).

FY 2016 EM work includes the ongoing D&D of the Plutonium Finishing Plant (PFP) at Hanford, continued risk reduction and partial deactivation of 235 F at SRS, and continued deactivation of the Main Plant Process Building at West Valley.

EM UED&D Program activities in FY 2016 include the following:

- Deactivation and completion of removal of contaminated process gas equipment at the Portsmouth Process Facility (X-326), preparation for deactivation of the X-333 Process Building, and continue construction of the On-Site Waste Disposal Facility;
- Deactivation and preparation for uranium deposit removals from Paducah Process Facilities (C337 and C337A) and complete facility modifications in Buildings C-335 and C-310 in support of uranium deposit removals; and
- Completion of D&D of K-31 GDP and beginning demolition of K-27, which is the fifth and final GDP at ETTP.

Also in FY 2016, the Oak Ridge Environmental cleanup program received $68 million in additional funding for work on contaminated excess facilities at Oak Ridge. EM and NNSA are working in concert to develop an integrated approach that addresses the most urgent needs in and around the relatively higher-risk facilities. This entails characterizing and abating hazards and stabilizing the condition of the facilities while they await demolition. This work will improve worker safety and reduce the costs and complexity of future cleanup by removing potential threats and helping prevent further migration of contaminants. The planned work includes:

- EM Building 9201-04 (Alpha 4)
  - Deactivation including characterization of COLEX equipment located on the West and East exterior sides of the building in preparation for equipment removal.
  - Risk reduction on high-risk equipment with potential mercury contamination and roof repairs to prevent water intrusion and contamination migration. This work will complement NNSA's FY 2016 planned roof repairs for Alpha-5 and Beta-4 resulting in stabilization of roofs for all former uranium processing buildings where mercury was used and is a major contaminant.
- EM Building 3026 risk reduction (one of SC's highest mission priorities) for the hot cell, including removal of the 3026 Wind Enclosure and covering 3026 C & D Pads, universal waste removal; fogging; grouting process drains; air gapping electric; and, limited surveying and coring behind stainless liners;
- EM ORNL Building 7500 characterization and hazard abatement;
- EM Building 3038 risk reduction and cleanout to allow downgrading the facility hazard categorization to less than Hazard Category 3, which will reduce MSRO costs;
- EM Buildings 3029 and 3028 risk reduction to mitigate the potential for migration of radiological contamination; and
- SC Biology Complex characterization and planning. This allows Oak Ridge to begin abatement and D&D of the high priority SC Biology Complex at Y-12 (Building 9207).

NNSA

Beginning in FY 2014 NNSA began directly funding the D&D of relatively higher priority facilities. The initial funding amount in FY 2014 was $13 million, increasing to $15.4 million in FY 2015 and $58 million in FY 2016.

In FY 2014, NNSA accomplished the following disposition and risk reduction activities:

- Demolition of the significantly degraded building 9744 at Y-12;
- Priority roof repairs at Y-12's Alpha 5;
- Preparation of the Bannister Road Complex in Kansas City for transfer to the private sector for redevelopment;
- Demolition of 17 buildings and 28 trailers at the Los Alamos National Laboratory (LANL); and
- Demolition by Sandia National Laboratories (SNL) of two buildings in California and seven trailers in New Mexico.

In FY 2015, these activities included:

- Demolition of the significantly degraded building 9808 at Y-12;
- Demolition of eleven buildings and nine trailers at LANL, including the Sheba Critical Building in TA-18 and a chemistry lab in TA-54;
- Disposal by Sandia of nine small facilities in New Mexico;
- Continued preparation of the Bannister Road Complex in Kansas City for transfer to the private sector for redevelopment; and
- Demolition of trailer 8710 at LLNL.

In FY 2016, Congress provided NNSA an additional $25 million to reduce the risk posed by its higher-risk excess facilities at Y-12 and LLNL. NNSA is executing work funded by that increase and other efforts through the following activities:

- Disposal by Sandia of 17 small facilities in New Mexico;
- Complete preparation of the Bannister Road Complex in Kansas City for transfer to the private sector for redevelopment;
- Demolition of SNL buildings at the Tonopah Test Range;
- Extensive roof repair work and addressing the flooded basement at Y-12's Alpha-5 to reduce risks identified by the GAO and IG;
- Extensive roof repair work and installation of a temporary electrical distribution system at Y-12's Beta-4 to address risks identified by the GAO and IG;
- Roof maintenance and de-inventorying to lower Material at Risk at Y-12's Building 9206;
- Demolition of Casa 2 and 3 complexes at LANL;
- Initial characterization of buildings 280, 292, 251, and 175 at LLNL to assess risks identified by the IG and GAO and prepare for transfer to EM; and
- Roof life extension of buildings 292, 251, and 175 at LLNL to address risks identified by the GAO and IG.

SC

In FY 2014, SC disposition and risk reduction activities included:

- Demolition of Building 589 and trailers at Brookhaven National Laboratory (BNL); and
- Demolition of several small structures at Argonne National Laboratory (ANL), ORNL and Stanford Linear Accelerator Center (SLAC).

In FY 2015, these activities included:

- Continued de-inventory of transuranic waste from the Alpha-Gamma-Hot-Cell-Facility (AGHCF) at ANL (identified in GAO and IG Reports);
- Demolition of contaminated Buildings 810 and 811 at BNL; and
- Removal of miscellaneous small structures and equipment at various SC laboratories.

In FY 2016, SC plans to continue these activities, including:

- Continued de-inventory of transuranic waste from the AGHCF at ANL;
- Demolition of Building 180 at BNL;
- Demolition of Buildings 2643 and 7751, and several small structures at ORNL;
- Removal of miscellaneous small structures and equipment at SC laboratories; and
- Ongoing phase 1 deactivation and continued D&D of LBNL (Old Town) buildings 5, 16, and 16A using Congressional funding within the EM Program.

NE

In FY 2014, NE demolished three guardhouses (B21-606, B27-602, B8-602), a water chemistry building (CF-1605), and an office building (CF-629) at INL.

In FY 2015, NE demolished a Naval Proving Ground (NPG) Officers Garage (CF-632), Fuel Oil Pump House (MFC-755), a Cold Storage Building (TRA-669), several other small facilities, and conducted remediation of the Technical Center Buildings (CF-688, CF-689). NE also accepted the return of the Paducah GDP from the United States Enrichment Corporation back into DOE responsibility and then transferred responsibility for cleanup and D&D of the Paducah GDP to the EM Program in FY 2015.

In FY 2016 NE will continue remediation of asbestos in the NPG buildings (CF-606, 607, and 613) and initiate other disposition activities for those buildings.

VI.B. Plans for FY 2017 D&D

EM

In FY 2017, EM plans to complete the following:

- D&D of three nuclear facilities, including the Vitrification Facility and Vaults, and 4 radiological facilities at West Valley; and
- Continuing deactivation and D&D at West Valley of remaining facilities.

EM expects to D&D PFP to slab-on-grade and complete installation of a cap over the slab.

In FY 2017, the EM UED&D program plans include completing deactivation of Portsmouth Building X-326 (the first process building to be declared demolition ready), and continuing site infrastructure upgrades and site preparations for construction of the On-Site Disposal Facility. At Paducah, uranium deposit removals will continue in C-337 and will begin in the C-333 Process Building, and design activities will continue for the first expansion cell of the On-Site Waste Disposal Facility. At ETTP, demolition and disposal of the K-27 GDP will be completed and demolition of the balance of site facilities will continue. At Oak Ridge, regulatory analysis will continue for the proposed new On-Site Waste Disposal Facility, and design will continue for the Outfall 200 Mercury Treatment Facility.

NNSA

In FY 2017, NNSA plans to provide nearly $250 million to continue reducing the risk posed by excess facilities and demolishing buildings. NNSA plans to complete the following work:

- Transfer of the Bannister Road Complex in Kansas City to the private sector for redevelopment;
- Continued risk reduction at Y-12's Alpha-5 and Beta-4, including de-inventory of equipment and material to reduce risks identified by the GAO and IG;
- Demolition of the HE Pressing Complex in TA-16 and the Press Building in TA-03 at LANL;
- Final characterization of the hazards and contamination at building 280 at LLNL to assess risk and prepare building for D&D; and
- Demolition of buildings 9111 and 9112 at Y-12.

SC

In FY 2017, SC plans include:

- Initiation of Phase 2 facility D&D of the facilities at LBNL (Old Town);
- Continue the de-inventory of the Alpha Gamma Hot Cell Facility at ANL to reduce risks identified by the GAO and IG;
- Initiate the de-inventory of the New Brunswick Laboratory at ANL;
- Demolish Building 134 at BNL;
- Continue removal of miscellaneous small facilities and equipment at SC laboratories;
- Demolish Building 7701 and several small structures at ORNL; and
- Demolish the Mod VI trailers at Princeton Plasma Physics Laboratory.

NE

In FY 2017, NE will continue the disposition of the NPG buildings and initiate the disposition of the Radiological Environmental Laboratory CF-690 and the Scoville Ordnance Offices (CF-633).

VII. Conclusion

DOE is continuously improving its enterprise-wide assessment, planning, and prioritization of excess facilities in order to address the potential risks these excess facilities pose to DOE's mission, workers, the public, and the environment. DOE's disposition priorities are to stabilize degraded higher-risk facilities, characterize their hazards and conditions, remove hazardous materials, and place them in a lower risk condition until the risk is eliminated by demolishing the facility and disposing of the resulting waste.

The recent efforts to define the scope of the excess facilities challenge identified over 2,300 excess facilities as of March 2016, with a ROM estimate to D&D of $32 billion, not including related costs such as waste disposal cells or treatment facilities. Approximately nine percent of these facilities were identified as higher risk and these higher-risk facilities represent over 36 percent of the total estimated D&D cost. Moreover, in the next ten years an estimated 1,000 additional facilities may be designated as excess, adding to the number of facilities to D&D and the associated costs.

Going forward, DOE will continue to address the challenges of managing contaminated excess facilities through the following steps:

- Conduct walk downs of the highest-risk facilities starting in FY 2016 to assess risks and to clarify conditions of transfer to EM, if funding is available.
- Update guidance for use by the Program Offices that builds on enterprise-wide expectations for excess facilities management and disposition and can be tailored for specific program needs. Items to be addressed include:
    - Planning and executing projects in a logical and cost effective manner;
    - Identifying and planning for additional resources that may be needed to support disposition, such as new waste treatment, handling, or disposal facilities;
    - Placing excess facilities in safe, stable, and lower cost conditions through deactivation while awaiting D&D;
    - Evaluating the physical condition of facilities annually to determine increased risk that may be associated with those conditions, and changes in priorities for addressing those risks; and
    - Ensuring DOE remains focused on the higher-risk facilities as a management priority.
- Improve the data collection used to track and report progress on the D&D of excess facilities.
- Evaluate strategies that increase efficiencies for D&D, such as streamlining requirements where appropriate and investing in technology research and development.
- Implement the CRENEL recommendations on excess facilities and infrastructure, as reflected in the DOE February 2016 response to the CRENEL report.

Appendix A: Assessment Guide for Prioritization

MISSION	PUBLIC HEALTH/ENVIRONMENTAL STEWARDSHIP	SAFETY
No Impact - Retention of the facility that has no impact on Site mission.	No Impact – Over the retention period of the facility, the facility and its contents are not expected to pose radiological, chemical, or hazardous material release to the environment that could impact local employees, site visitors, and/or public health. Compliant with environmental requirements, slight probability for near term non-compliances.	No Impact – Facility condition poses no safety concerns to Site employees.
Minor Impact - Retention of the facility that has minor impact on Site mission. Mission can be achieved with minor adjustments to scientific/programmatic schedule and cost operations.	Minor Impact – over the retention period of the facility, if not actively managed, the facility and its contents could present minor radiological, chemical, or hazardous material release to the environment that could impact local employee health. Occasional minor deviation of environmental compliance requirements.	Minor Impact – Facility condition poses minor safety concerns to Site employees due to deterioration/deferred maintenance.
Major Impact - Retention of the facility has major impact on Site mission. Mission can be achieved with major adjustments to scientific/programmatic schedule and cost operations.	Major Impact – over the retention period of the facility, if not actively managed, the facility and its contents could present a significant radiological, chemical, or hazardous material release to the environment that could impact site employees and visitors, along with local employee health. Frequent minor violations of environmental compliance requirements.	Major Impact – Facility condition poses major safety concerns to Site employees due to deterioration/deferred maintenance.
Significant Impact - Retention of the facility has significant impact and is preventing the achievement/progress of specific Site mission goals.	Significant Impact – over the retention period of the facility, if not actively managed, the facility and its contents could present a very significant radiological, chemical, or hazardous material release to the environment that could impact off-site public, site employees and visitors, along with local employee health. Serious frequent violations of environmental compliance requirements.	Significant Impact – Facility condition is unsafe for any access as a result of deterioration/deferred maintenance.

Appendix B: Higher-Risk DOE Excess Facilities as of March 2016

Notes:

- The list of numbers is for reference and do not indicate a priority ranking. As described in the preceding report, all excess facilities on this list are relatively higher risk with those listed as Tier I being higher risk than Tier II. All excess facilities on this list have either processed-related or industrial-related contamination.
- The EM total lifecycle ROM D&D costs for the higher risk excess facilities in this Appendix is $9.3 billion. This cost represents a subset of the total EM D&D direct program ROM cost estimate of $29 billion and is not broken out on a facility-by-facility level. The "ROM Costs" cell for the EM facilities is shaded light blue.
- The gray shaded rows indicate disposition of the facility is included in a NNSA's five-year planning/budget profile.

Higher Risk Contaminated Excess Facilities									
List #	Priority Tier	Site Name	PSO	Property ID	Property Name	ROM Costs ($M)	Estimated Disposition Year	Avoided MSRO Costs ($M)	
								Annual MSRO Costs	Lifecycle MSRO Costs[11]
1	Tier I	ETTP	EM	1037	Materials Lab		2021	9.7	58.4
2	Tier I	ETTP	EM	1037-C	Smelter House		2021	0.01	0.1
3	Tier I	ETTP	EM	131	Maintenance Shop		2019	0.6	2.3
4	Tier I	ETTP	EM	1435-D	Incinerator Facility		2021	1.3	7.9
5	Tier I	ETTP	EM	1435-C	Tnk Farm & Drum Strg -- >Tnker Unload		2021	0.1	0.4

[11] Determined by multiplying Annual MSRO (maintenance, surveillance, repair, and operations) costs by the number of years until facility is dispositioned, or 25 years if estimated disposition year is unknown at this time.

Higher Risk Contaminated Excess Facilities									
List #	Priority Tier	Site Name	PSO	Property ID	Property Name	ROM Costs ($M)	Estimated Disposition Year	Avoided MSRO Costs ($M)	
								Annual MSRO Costs	Lifecycle MSRO Costs[11]
6	Tier I	ETTP	EM	27-402-01	Process Building 402-1		2018	1.4	4.2
7	Tier I	ETTP	EM	27-402-02	Process Building 402-2		2018	1.4	4.2
8	Tier I	ETTP	EM	27-402-03	Process Building 402-3		2018	1.4	4.2
9	Tier I	ETTP	EM	27-402-04	Process Building 402-4		2018	1.4	4.2
10	Tier I	ETTP	EM	27-402-05	Process Building 402-5		2018	1.4	4.2
11	Tier I	ETTP	EM	27-402-06	Process Building 402-6		2018	1.4	4.2
12	Tier I	ETTP	EM	27-402-07	Process Building 402-7		2018	1.4	4.2
13	Tier I	ETTP	EM	27-402-08	Process Building 402-8		2018	1.4	4.2
14	Tier I	ETTP	EM	27-402-09	Process Building 402-9		2018	1.4	4.2
15	Tier I	ETTP	EM	633	Demonstration Facility		2019	0.2	0.9
16	Tier I	LLNL	EM[12]	280	Livermore Pool Type Reactor	52.2	TBD	0.01	0.1
17	Tier I	LLNL	NNSA	175	MARS E-Beam Facility	16	TBD	0.1	3.4
18	Tier I	LLNL	NNSA	241	Pluto Project Testing and Fabrication Facility	5.4	TBD	0.1	1.6
19	Tier I	LLNL	NNSA	251	Heavy Elements Facility	62	TBD	0.1	1.4

[12] While EM is the owner in DOE's Facilities Information Management System, NNSA maintains Building 280 at LLNL.

Higher Risk Contaminated Excess Facilities									
List #	Priority Tier	Site Name	PSO	Property ID	Property Name	ROM Costs ($M)	Estimated Disposition Year	Avoided MSRO Costs ($M)	
								Annual MSRO Costs	Lifecycle MSRO Costs[11]
20	Tier I	LLNL	NNSA	292	Rotating Target Neutron Source	52	TBD	0.1	2.4
21	Tier I	ORNL (X-10)	EM	7025	Tritium Target Preparation Facility		2033	0.01	0.2
22	Tier I	ORNL (X-10)	EM	7512	Stack (For 7503)		2043	0.01	0.2
23	Tier I	ORNL (X-10)	EM	3038	Radioisotope Laboratory		2026	0.2	1.7
24	Tier I	ORNL (X-10)	EM	3121	Vessel Off Gas Filter House for 3019A		2037	0.1	1.2
25	Tier I	ORNL (X-10)	EM	7500	Nuclear Safety Pilot Plant		2041	0.1 M	2.6 M
26	Tier I	RL	EM	324	Waste Technology Engineering Laboratory		2024	2 M	18 M
27	Tier I	RL	EM	242B	Radioactive Particle Research Laboratory		2047	0.01	0.2
28	Tier I	RL	EM	224B	Concentration Facility		2022	0.3	2.1
29	Tier I	SRS	EM	221000	F-Canyon		2038	10.8	248.3
30	Tier I	SRS	EM	235000	Metallurgical Building		2035	7	140
31	Tier I	Y-12	NNSA	9206	Production	188.7	TBD	1	25
32	Tier I	Y-12	NNSA	9201-05	Production (Alpha 5)	520.5	TBD	1	25
33	Tier I	Y-12	NNSA	9204-04	Production (Beta 4)	321.9	TBD	1	25
34	Tier I	Y-12	SC	9201-02	Fusion Energy Building	237.3	TBD	0.6	15

Higher Risk Contaminated Excess Facilities									
List #	Priority Tier	Site Name	PSO	Property ID	Property Name	ROM Costs ($M)	Estimated Disposition Year	Avoided MSRO Costs ($M)	
								Annual MSRO Costs	Lifecycle MSRO Costs[11]
35	Tier I	Y-12	EM	9213	Development/Offices		2033	0.1	2.3
36	Tier I	Y-12	EM	9201-04	Environmental Management (Alpha-4)		2032	3	51.2
37	Tier I	Y-12	SC	9207	Biology	56.1	TBD	0.6	15
38	Tier I	Y-12	SC	9210	Mammalian Genetics	14.2	TBD	0.6	15
39	Tier I	Y-12	SC	9422	Helium Compressor Building	5.8	TBD	0.01	15
40	Tier I	Y-12	SC	9204-01	Fusion Energy-Eng Tech	171.9	TBD	1	25
41	Tier I	Y-12	SC	9207A	9207 Annex	1.4	TBD	0.01	0.25
42	Tier I	Y-12	SC	9732-02	Storage Building	0.3	TBD	0.01	0.25
43	Tier I	Y-12	SC	9743-02	Pigeon Quarters	0.9	TBD	0.01	0.25
44	Tier I	Y-12	SC	9770-02	Radiation Source Bldg.	0.5	TBD	0.01	0.25
45	Tier II	BNL	SC	491	Medical Research Reactor	8.1	TBD	0.01	0.1
46	Tier II	BNL	SC	650	Former Custodial Storage	11.5	TBD	0.1	1.4
47	Tier II	BNL	SC	701	Former BGRR Project Offices	33.5	TBD	0.1	1.4
48	Tier II	BNL	SC	Reactor - BMRR	Medical Reactor	24.4	TBD	0.01	0.1
49	Tier II	BNL	SC	Reactor - HFBR	HFBR	129.1	TBD	0.1	2.5

Higher Risk Contaminated Excess Facilities									
List #	Priority Tier	Site Name	PSO	Property ID	Property Name	ROM Costs ($M)	Estimated Disposition Year	Avoided MSRO Costs ($M)	
								Annual MSRO Costs	Lifecycle MSRO Costs[11]
50	Tier II	ETTP	EM	1407-H	Central Neutralization Fac		2021	0.1	0.4
51	Tier II	KCP	NNSA	1	Manufacturing Building[13]	228	2017		
52	Tier II	LANL	NNSA	18-0032	Critical Assembly Bldg (Casa 2)	1.3	2016	0	0
53	Tier II	LANL	NNSA	18-0116	Critical Assembly Bldg Casa 3	2.4	2016	0	0
54	Tier II	LANL	NNSA	16-0430	He Pressing	6.1	2019	0	0
55	Tier II	LANL	NNSA	03-0016	Ion Beam Facility	53.4	TBD	0	0
56	Tier II	LANL	NNSA	16-0280	Inspection Bldg	2.4	TBD	0	0
57	Tier II	LANL	NNSA	16-0306	Plastics Bldg	14.7	TBD	0	0
58	Tier II	LBNL	SC	016	Laboratories and Research Offices	11.8	2016	0.1	0.1
59	Tier II	LBNL	SC	005	Laboratories & Research Offices	7.3	2016	0.1	0.1
60	Tier II	LBNL	SC	016A	Storage	0.3	2016	0.01	0.01
61	Tier II	LBNL	SC[14]	007	Assembly, Offices & Labs (ALS Support)	21.4	2018	0.6	1.7
62	Tier II	LBNL	SC	073A	Utility Equipment Bldg. (red-tagged)	0.1	TBD	0.01	0.1

[13] The ROM cost estimate for the Kansas City Plant includes the cost of all facilities included in the project to transfer the Bannister Road Complex to the private sector for redevelopment.

[14] While SC is identified as the responsible HQ Program Office for building B007 and B007C, EM is funding the D&D of Old Town.

Higher Risk Contaminated Excess Facilities									
List #	Priority Tier	Site Name	PSO	Property ID	Property Name	ROM Costs ($M)	Estimated Disposition Year	Avoided MSRO Costs ($M)	
								Annual MSRO Costs	Lifecycle MSRO Costs[11]
63	Tier II	LBNL	SC	073	Previously Labs/Shops/Office (red-tagged)	1.3	TBD	0.1	1.4
64	Tier II	LLNL	NNSA	221	Chemistry Facility	9	TBD	0.004	0.1
65	Tier II	LLNL	NNSA	326	Material Science Testing Facility	1	TBD	0.01	0.2
66	Tier II	LLNL	NNSA	343	Explosives and High Pressure Testing Facility	6	TBD	0.05	1.1
67	Tier II	LLNL	NNSA	OS212	Accelerator Facility	22	TBD	0	0
68	Tier II	ORNL (X-10)	EM	4507	High Level Chemical Dev Lab		2033	0.2	3.9
69	Tier II	ORNL (X-10)	EM	7503	MSRE Building		2043	0.4	10.8
70	Tier II	ORNL (X-10)	EM	7511	Filter Pit (For MSRE 7503)		2043	0.02	0.4
71	Tier II	ORNL (X-10)	EM	7514	Filter House For 7503		2043	0.01	0.1
72	Tier II	ORNL (X-10)	EM	3002	Filter House for Graphite Reactor - 3001		2033	0.3	7.7
73	Tier II	ORNL (X-10)	EM	3005	Low-Intensity Test Reactor Facility		2033	0.04	1
74	Tier II	ORNL (X-10)	EM	3010	Bulk Shielding Reactor		2033	0.04	1
75	Tier II	ORNL (X-10)	EM	3029	Radioisotope Production Lab-B		2030	0.1	1.5
76	Tier II	ORNL (X-10)	EM	3042	Oak Ridge Research Reactor (ORRR)		2033	0.3	6.7

Higher Risk Contaminated Excess Facilities									
List #	Priority Tier	Site Name	PSO	Property ID	Property Name	ROM Costs ($M)	Estimated Disposition Year	Avoided MSRO Costs ($M)	
								Annual MSRO Costs	Lifecycle MSRO Costs[11]
77	Tier II	ORNL (X-10)	EM	3107	25 Meter Target House		2033	0.003	0.1
78	Tier II	ORNL (X-10)	EM	3126	Charcoal Filt (Nog) Orr		2030	0.002	0.1
79	Tier II	ORNL (X-10)	EM	3139	Cell Ventilation Filters-ORR		2030	0.02	0.4
80	Tier II	ORNL (X-10)	EM	3515	Fission Product Lab No 1		2032	0.02	0.5
81	Tier II	ORNL (X-10)	EM	3517	Fission Products Development Laboratory		2032	0.5	13.5
82	Tier II	ORNL (X-10)	EM	3005-R	3005 Low Intensity Test Reactor (X900005)		2042	0.3	8
83	Tier II	ORNL (X-10)	EM	3010-RP	3010 Swim'G Pool Reactor (X900004)		2042	0.3	6.9
84	Tier II	ORNL (X-10)	EM	3010-RS	3010 Bulk Shield'G Reactor (X900007)		2042	0.1	1.8
85	Tier II	ORNL (X-10)	EM	3019B	High Level Radiation Analytical Lab		2033	4.9	122.7
86	Tier II	ORNL (X-10)	EM	3026D	Dismantling & Examination Hot Cells		2030	0.7	18.1
87	Tier II	ORNL (X-10)	EM	3042-R	Oak Ridge Research Reactor (X900042)		2035	2.8	70.4
88	Tier II	ORP	EM	216A	Valve Control Facility		2028	0	0
89	Tier II	ORP	EM	291AR	Exhaust Air Filter Stack Building		2044	0.005	0.1
90	Tier II	ORP	EM	242A702	Turbine Building		TBD	0.01	0.2

Higher Risk Contaminated Excess Facilities									
List #	Priority Tier	Site Name	PSO	Property ID	Property Name	ROM Costs ($M)	Estimated Disposition Year	Avoided MSRO Costs ($M)	
								Annual MSRO Costs	Lifecycle MSRO Costs[11]
91	Tier II	ORP	EM	2713S	Lab Office Building		TBD	0.2	4.4
92	Tier II	ORP	EM	6241V	Vent Station and Support Building		2044	0.2	7.2
93	Tier II	PAD	EM	C-310	Purge and Product Building		2040	0.6	15
94	Tier II	PAD	EM	C-310-A	Product Withdrawal Building		2040	0.02	0.4
95	Tier II	PAD	EM	C-315	Surge and Waste Building		2040	0.1	2.1
96	Tier II	PAD	EM	C-331	Process Building		2040	12.4	310
97	Tier II	PAD	EM	C-333	Process Building		2040	11.4	284.3
98	Tier II	PAD	EM	C-333-A	Feed Vaporization Facility		2040	0.04	1.1
99	Tier II	PAD	EM	C-335	Process Building		2040	5.5	137.3
100	Tier II	PAD	EM	C-337	Process Building		2040	11.4	284.3
101	Tier II	PAD	EM	C-337-A	Feed Vaporization Facility		2040	0.05	1.1
102	Tier II	PAD	EM	C-400	Cleaning Building		2040	0.5	12.5
103	Tier II	PAD	EM	C-409	Stabilization Building		2040	0.1	2.5
104	Tier II	PORTS	EM	X-326	GDP Process Building		2029	11.8	165
105	Tier II	PORTS	EM	X-330	GDP Process Building		2029	9.6	134
106	Tier II	PORTS	EM	X-333	GDP Process Building		2029	9.3	130

Higher Risk Contaminated Excess Facilities									
List #	Priority Tier	Site Name	PSO	Property ID	Property Name	ROM Costs ($M)	Estimated Disposition Year	Avoided MSRO Costs ($M)	
								Annual MSRO Costs	Lifecycle MSRO Costs[11]
107	Tier II	PORTS	EM	X-342A	Feed, Vaporization and Sampling Facility		2029	0.2	2.8
108	Tier II	PORTS	EM	X-343	Feed, Vaporization and Sampling Facility		2029	0.2	2.8
109	Tier II	PORTS	EM	X-344A	UF6 Sampling Facility		2029	1	14
110	Tier II	PORTS	EM	X-345	SNM Storage Building		2029	0.1	1.4
111	Tier II	PORTS	EM	X-710	Technical Services Building		2029	1.4	19.6
112	Tier II	PORTS	EM	X-744G	Bulk Storage Building		2029	0.3	4.2
113	Tier II	PORTS	EM	X-232C-2	Tie Line No. 2, X-330 to X-326		2029	0	0
114	Tier II	PORTS	EM	X-232C-4	Tie Line No. 2, X-326 to X-330		2029	0	0
115	Tier II	RL	EM	2711S	Stack Gas Monitoring Station		2016	0.0003	0.01
116	Tier II	RL	EM	2718S	Equipment/Lead Shielding Storage Shed		2016	0.0003	0.01
117	Tier II	RL	EM	234-5Z	PFP and Storage		2017	0	0
118	Tier II	RL	EM	105C	Cocooned Reactor Building		2050	0.01	0.4
119	Tier II	RL	EM	105DR	Cocooned Reactor Building		2050	0.01	0.3
120	Tier II	RL	EM	105F	Cocooned Reactor Building		2050	0.01	0.4
121	Tier II	RL	EM	105H	Cocooned Reactor Building		2050	0.02	0.5

Higher Risk Contaminated Excess Facilities									
List #	Priority Tier	Site Name	PSO	Property ID	Property Name	ROM Costs ($M)	Estimated Disposition Year	Avoided MSRO Costs ($M)	
								Annual MSRO Costs	Lifecycle MSRO Costs[11]
122	Tier II	RL	EM	105KW	Reactor Building		2050	0.1	2.1
123	Tier II	RL	EM	105KE	Reactor Building		2050	0.1	2.1
124	Tier II	RL	EM	105N	Cocooned Reactor		2050	0.1	2.8
125	Tier II	RL	EM	213A	Fission Product Load-in Station		2027	0.001	0.01
126	Tier II	RL	EM	218 E14 & E15	PUREX Plant Storage Tunnels 1 and 2		TBD	0.001	0.03
127	Tier II	RL	EM	276C	Solvent Handling Building		2023	0.005	0.04
128	Tier II	RL	EM	291AB	Exhaust Air Sampler House 1		2027	0.003	0.04
129	Tier II	RL	EM	203A	Acid Pump House		2026	0.002	0.02
130	Tier II	RL	EM	206A	Vacuum Acid Fractionator Building		2030	0.003	0.1
131	Tier II	RL	EM	212A	Fission Product Load-out Station		2030	0.001	0.02
132	Tier II	RL	EM	212B	Fission Products Load Out Station		2024	0.01	0.1
133	Tier II	RL	EM	291AC	Exhaust Air Sampler House 2		2027	0.0001	0.001
134	Tier II	RL	EM	293A	Off-Gas Treatment Facility		2027	0.004	0.1
135	Tier II	RL	EM	294A	Off Gas Treatment and Monitoring Station		2027	0.001	0.02
136	Tier II	RL	EM	221BB	Process Steam and Condensate Building		2023	0.001	0.01

Higher Risk Contaminated Excess Facilities									
List #	Priority Tier	Site Name	PSO	Property ID	Property Name	ROM Costs ($M)	Estimated Disposition Year	Avoided MSRO Costs ($M)	
								Annual MSRO Costs	Lifecycle MSRO Costs[11]
137	Tier II	RL	EM	221BC	SWP Change House		2022	0.001	0.01
138	Tier II	RL	EM	221BD	Laundry Storage Building		2022	0.001	0.01
139	Tier II	RL	EM	221BF	Condensate Effluent Discharge Facility		2023	0.004	0.03
140	Tier II	RL	EM	222B	Office Building		2023	0.01	0.1
141	Tier II	RL	EM	271B	B Plant Support Building		2024	0.1	0.5
142	Tier II	RL	EM	2716B	Radiation Monitoring Checkout Station		2025	0.0004	0.004
143	Tier II	RL	EM	291AD	Ammonia Off-Gas Building		2027	0.001	0.01
144	Tier II	RL	EM	291B	Exhaust Air Control House, Sand Filter		2024	0.01	0.1
145	Tier II	RL	EM	291BB	Instrument Building		2023	0.0003	0.002
146	Tier II	RL	EM	291BD	Instrument Building and Filter Vault		2026	0.004	0.04
147	Tier II	RL	EM	291BF	Instrument Building and Filter Vault		2025	0.003	0.03
148	Tier II	RL	EM	292AA	Plutonium Recovery Stack Sample House		2041	0.0002	0.01
149	Tier II	RL	EM	291BA	Exhaust Air Sample House		2022	0.0001	0.001
150	Tier II	RL	EM	295AA	SCD Sample and Pumpout Station		2041	0.0002	0.004
151	Tier II	RL	EM	2711A	Air Compressor Building		2026	0.001	0.01

Higher Risk Contaminated Excess Facilities									
List #	Priority Tier	Site Name	PSO	Property ID	Property Name	ROM Costs ($M)	Estimated Disposition Year	Avoided MSRO Costs ($M)	
								Annual MSRO Costs	Lifecycle MSRO Costs[11]
152	Tier II	RL	EM	292B	Stack Monitor Station		2023	0.001	0.005
153	Tier II	RL	EM	295A	Ammonia Scrubber/Discharge Sample		2027	0.0002	0.002
154	Tier II	RL	EM	295AD	SWL Sample Station		2041	0.0003	0.01
155	Tier II	RL	EM	295AB	PDD Sample Station		2026	0.001	0.01
156	Tier II	RL	EM	291BK	Instrument Building		2024	0.0002	0.002
157	Tier II	RL	EM	291U	Exhaust Fan Control House, Sand Filter		2023	0.01	0.1
158	Tier II	RL	EM	292T	Fission Products Release Laboratory		2044	0.02	0.6
159	Tier II	RL	EM	292U	Stack Monitoring Station		2023	0.001	0.002
160	Tier II	RL	EM	292S	Jet Pit House		2046	0.001	0.03
161	Tier II	RL	EM	293S	Acid Recovery and Off Gas Treatment Bldg		2046	0.003	0.1
162	Tier II	RL	EM	405	FFTF Reactor Containment Building		2031	0.1	1.1
163	Tier II	RL	EM	4717	Reactor Service Building		2032	0.1	1.6
164	Tier II	RL	EM	491S	HTS Service Building, South		2028	0.02	0.3
165	Tier II	RL	EM	291AJ	Sample Station 3		2027	0.0001	0.002
166	Tier II	RL	EM	291BG	Instrument Building and Filter Vault		2023	0.003	0.02

Higher Risk Contaminated Excess Facilities									
List #	Priority Tier	Site Name	PSO	Property ID	Property Name	ROM Costs ($M)	Estimated Disposition Year	Avoided MSRO Costs ($M)	
								Annual MSRO Costs	Lifecycle MSRO Costs[11]
167	Tier II	RL	EM	292AB	Purex Gas Effluent Monitoring Building		2041	0.003	0.07
168	Tier II	RL	EM	295AC	Chemical Sewer Line Sample Station		2026	0.0002	0.002
169	Tier II	RL	EM	291AH	Ammonia Off Gas Sample Station		2027	0.0001	0.001
170	Tier II	RL	EM	291AK	Tunnel Spray Enclosure and Caissons		2032	0.0004	0.01
171	Tier II	RL	EM	276A	Cold Solvent Storage Building, R Cell		2030	0.03	0.5
172	Tier II	RL	EM	242BL	Cask Loading Building		2046	0.001	0.03
173	Tier II	RL	EM	291A	PUREX Main Exhaust System		2041	0.02	0.4
174	Tier II	RL	EM	291BC	Access Control Building, Filter Vaults		2026	0.01	0.1
175	Tier II	RL	EM	291BJ	Instrument Building and 6th Filter Vault		2023	0.01	0.1
176	Tier II	RL	EM	241CX40	Grout Removal Building		2023	0.001	0.01
177	Tier II	RL	EM	291U001	221 U Main Stack		2019	0.003	0.01
178	Tier II	RL	EM	202A	PUREX Canyon and Service Facility		2032	0.6	9.4
179	Tier II	RL	EM	202S	Redox Canyon And Service Facility		2048	0.7	21.5
180	Tier II	RL	EM	221B	B Plant Canyon		2027	0.8	9.6

Higher Risk Contaminated Excess Facilities									
List #	Priority Tier	Site Name	PSO	Property ID	Property Name	ROM Costs ($M)	Estimated Disposition Year	Avoided MSRO Costs ($M)	
								Annual MSRO Costs	Lifecycle MSRO Costs[11]
181	Tier II	RL	EM	224T	Transuranic Storage and Assay Facility		2043	0.3	8.4
182	Tier II	RL	EM	231Z	Materials Engineering Laboratory		2019	0.5	2
183	Tier II	RL	EM	276S	Cold Solvent Storage and Makeup Building		2046	0.01	0.2
184	Tier II	SRS	EM	221001	F-Canyon A Line		2035	0.6	11.1
185	Tier II	SRS	EM	292001	Vessel Vent Fan House		2034	0.001	0.03
186	Tier II	SRS	NNSA	232000	Manufacturing Building	31.7	TBD	0.1	2.5
187	Tier II	SRS	NNSA	232001	Shop & Storage Building	4	TBD	0.01	0.3
188	Tier II	WVDP	EM	NA	Main Plant Process Building		2020	2	8
189	Tier II	WVDP	EM	NA	Vitrification Facility		2020	2	8
190	Tier II	WVDP	EM	NA	Low-Level Radiological Wastewater Treatment Facility		2018	0.6	1.8
191	Tier II	WVDP	EM	NA	Chemical Process Cell- Waste Storage Facility		2019	0.6	2.4
192	Tier II	WVDP	EM	NA	Vitrification Vault (Corral)		2019	0.6	2.4
193	Tier II	WVDP	EM	NA	High Level Waste Tank Pumps Storage Vaults		2019	0.6	2.4
194	Tier II	WVDP	EM	NA	Administrative Building		2018	0.6	2.4
195	Tier II	WVDP	EM	NA	Radwaste Treatment System Drum Cell		TBD	0.1	2.5

Higher Risk Contaminated Excess Facilities									
List #	Priority Tier	Site Name	PSO	Property ID	Property Name	ROM Costs ($M)	Estimated Disposition Year	Avoided MSRO Costs ($M)	
								Annual MSRO Costs	Lifecycle MSRO Costs[11]
196	Tier II	WVDP	EM	NA	Equipment Shelter and Condensers		2018	0.1	0.3
197	Tier II	WVDP	EM	NA	Warehouse Bulk Oil Storage Unit		2019	0.6	2.4
198	Tier II	WVDP	EM	NA	Liquid Pretreatment System Building		2019	0.6	2.4
199	Tier II	Y-12	NNSA	9720-17	Warehouse/Industrial	1	TBD	0.1	1.3
200	Tier II	Y-12	NNSA	9720-22	Storage	3.3	TBD	0.1	1.3
201	Tier II	Y-12	NNSA	9720-24	Classified Tool Storage	0.8	TBD	0.01	0.1
202	Tier II	Y-12	SC	9767-06	Utilities	0.2	TBD	0.01	0.25
203	Tier II	Y-12	SC	9767-07	Utilities	0.2	TBD	0.01	0.25

THE STATE OF GENERAL PURPOSE INFRASTRUCTURE AT THE DEPARTMENT OF ENERGY

REPORT OF THE DOE INFRASTRUCTURE EXECUTIVE COMMITTEE
TO THE LABORATORY OPERATIONS BOARD

NOVEMBER 2016

TABLE OF CONTENTS

Figures

1 Purpose

The Department of Energy (DOE) is responsible for a vast portfolio of infrastructure that consists of world-leading scientific and production tools and the general purpose infrastructure needed to enable the use of those tools. DOE has the fourth largest inventory of real property in the Federal government by square footage, and its complex includes seventeen DOE National Laboratories, National Nuclear Security Administration (NNSA) plants, and Environmental Management (EM) cleanup sites. This portfolio of land, facilities, and other assets is the foundation of DOE's ability to conduct its mission, and represents one of America's premier assets for science, technology, innovation, and security.

DOE INFRASTRUCTURE

10,095 buildings totaling 119 million square feet (owned and leased)

36 years – average facility age

39 years – average support structure (utilities, roads, bridges, etc.) age

2 million acres

$131 billion Total Replacement Plant Value

$2 billion in annual operating and maintenance costs

$5.4 billion in deferred maintenance (operational facilities)

Source: FY 2015 Facility Information Management System snapshot

However, modernization of DOE's infrastructure has not kept up in all areas with evolving mission needs in science and technology. This infrastructure portfolio has been developed over the past 70 years, with origins in the Manhattan Project. The average age of DOE's facilities is 36 years and its utilities is 39 years. While the Department has made significant investments in world class experimental facilities, much of the supporting, or "general purpose" infrastructure – such as office space, general laboratory spaces, shops and utilities – that enables the mission and forms the backbone of the DOE enterprise is in need of greater attention. Modern, reliable general purpose infrastructure is critical to support DOE in successfully and efficiently executing its missions both today and in the years ahead.[1]

Based on updated Department-wide infrastructure assessments, the Department is facing a systemic challenge of degrading infrastructure. To help address this challenge, the Department, through the Laboratory Operations Board, established an integrated plan to conduct site-wide assessments of general purpose infrastructure across all 17 National Laboratories as well as NNSA plants and environmental management activities, for the first time using common standards and definitions. The assessments provided a detailed, uniform

[1] The Department's 2014-2018 Strategic Plan recognizes this in Strategic Objective 9, which is to manage assets in a sustainable manner that supports the DOE mission.

analysis of facilities and other infrastructure and information for decisions on future investments.

In its first year, the data developed as a result of this initiative provided the basis for over $100 million requested and appropriated in FY 2016, targeted for general purpose infrastructure projects. In order to build on the success of that effort, an Infrastructure Executive Committee (IEC) comprised of line managers and facilities experts from across the complex was charged with providing an annual update to the Secretary and other senior DOE leadership on the state of general purpose infrastructure. This report, prepared by the Infrastructure Executive Committee and presented to the LOB, is the first such update. This report is intended to provide a leadership-level assessment of the DOE infrastructure portfolio, and in so doing, provide information that decision-makers can use to improve infrastructure stewardship – including future investments and improvements to management processes.

2 Background

In 2013, the Secretary of Energy formed the Laboratory Operations Board (LOB) to provide an enterprise-wide forum to engage the Laboratories and DOE's programs in a joint effort to identify opportunities to improve effectiveness and efficiency. One of the transformational opportunities identified by the LOB was the need to focus on revitalizing the general purpose infrastructure across the DOE enterprise to better support mission activities today and in the future. Beginning in the fall of 2013 and under the leadership of the LOB, the Department began making significant improvements to its stewardship of general purpose infrastructure – those physical assets such as utilities and general office buildings or laboratory spaces that are used on a broad basis to enable the mission of the entire plant, site, and laboratory. These efforts were developed and executed by DOE headquarters, site office, laboratory, and plant employees, as a partnership across the complex. Notable outcomes include:

- The Department's processes for assessing the condition of its assets was overhauled to more directly measure whether the asset is physically able to support the mission it is intended to fulfill.
- Clear and consistent guidance for conducting those assessments was developed through the LOB infrastructure process and issued across the Department; approximately 80% of DOE's infrastructure[2] has been evaluated using the methodology.
- The Department established an IEC as a subcommittee of the LOB. The IEC includes senior leadership from across the Department and is co-chaired by line programs on a

[2] The "DOE infrastructure" included in this document is for the following DOE programs/offices and the respective laboratories, plants, and sites stewarded by those offices: Office of Energy Efficiency & Renewable Energy, Office of Environmental Management, Office of Fossil Energy, Office of Nuclear Energy, Office of Science, and the National Nuclear Security Administration. See Appendix. Of this infrastructure portfolio, 80% has been assessed using the new criteria.

one-year rotating basis. NNSA led the Committee in FY 2015, followed by the Office of Science in FY 2016. Nuclear Energy and the Office of Management will co-chair the Committee for FY 2017. The IEC is charged with preparing this report annually as well as presenting enterprise-wide, prioritized investment recommendations in infrastructure.

- The Department's FY 2017 Budget requests additional funding to address infrastructure challenges, including a 36% increase over FY 2016 in the Department's request for General Plant Projects (GPP) and similar projects to improve general purpose infrastructure.
- The Office of Science Operations Improvement Council partnered with other programs to develop a framework and guiding principles to foster consistency among DOE sites in accounting for repair needs and deferred maintenance – two measures that are important indicators of investment needs.
- NNSA has expanded its Asset Management Program, which uses supply chain management economies-of-scale to provide a more centralized and efficient procurement approach to replacing mission-critical aging infrastructure systems that are common throughout the enterprise, such as roof and HVAC systems.
- EM is pursuing coordination, analysis and concurrence of EM site submissions for infrastructure reporting, such as the Integrated Facilities Infrastructure Crosscut Budget and five-year plans.
- Within individual program offices, infrastructure planning is now included as an integral component of the annual planning and evaluation process. This has enhanced integration of infrastructure and mission planning and raised the visibility of infrastructure and its mission impact. For example, building from the Office of Science planning model, NNSA is deploying its Master Asset Plan which is a strategic, enterprise-wide, risk-informed, long-range view (25+ years) of NNSA infrastructure that will be updated on an annual basis.

3 Current State of DOE Infrastructure

This annual report is structured around seven questions that help to assess the current state of DOE infrastructure and, proceeding forward, the progress made in revitalizing that infrastructure. These measures of performance are included in DOE's recently-updated Real Property Asset Management Order (Order 4301.C), and are as follows:

- Is the percent of adequate facilities and other structures increasing?
- Is deferred maintenance decreasing?
- Is the square footage of underutilized space decreasing?
- Are excess space/buildings being eliminated?
- Are the costs of carrying excess facilities declining?

- Did the Department make the investments in general purpose infrastructure that it committed to make?
- Are fewer core capabilities at risk due to infrastructure deficiencies?

Many of the metrics discussed in this report will provide more insight into infrastructure condition and management as year-over-year trends, rather than a single data point in time. A focus for this first annual report is to establish methods to gather and evaluate these metrics consistently across the enterprise. As a result, this report establishes a baseline and future annual reports will provide additional information to evaluate trends and improve infrastructure stewardship.

3.1 Is the percent of adequate facilities and other structures increasing?

The LOB assessment process, commenced in 2014, indicated that one half of the Department's assessed infrastructure portfolio (by Replacement Plant Value) is rated "substandard" or "inadequate" to accomplish its intended mission objective. The asset condition categories developed through the LOB assessment process are defined in the chart below:

Asset Condition Definitions

Adequate: Fully capable of performing its current mission with only minor deficiencies that can be corrected within normal operating budgets.
Substandard: Deficiencies limit performance of the mission and refurbishment is required to return the asset to adequate condition.
Inadequate: Major deficiencies that significantly impair performance of the mission; major refurbishment is required.

Figure 1 shows the asset condition of DOE facilities at the end of FY 2015, with more than half rated as inadequate or substandard to meet the mission. [3] Figure 2 shows the condition of the Department's core non-facility assets (primarily utilities). As with facilities, many non-facility assets were rated at the end of FY 2015 as inadequate or substandard to meet the mission.

[3] Figures 1, 2, and 3 reflect percentages using Replacement Plant Value for the assets. Replacement Plant Value, or RPV, is defined as the funding needed to replace existing infrastructure assets at today's cost and standards.

Figure 1. FY 2015 Facility Condition

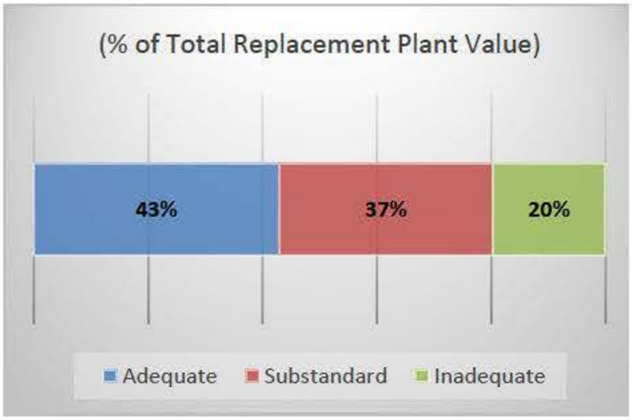


Figure 2. FY 2015 Non-Facility Condition

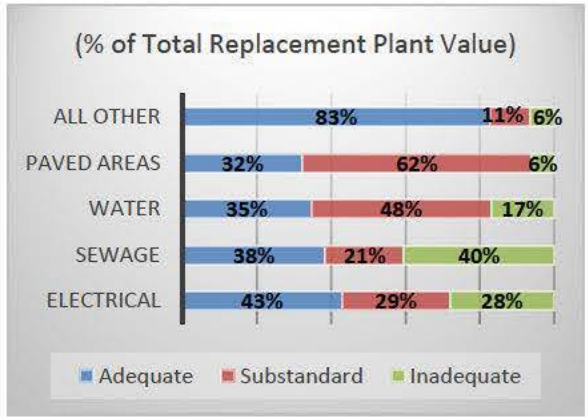
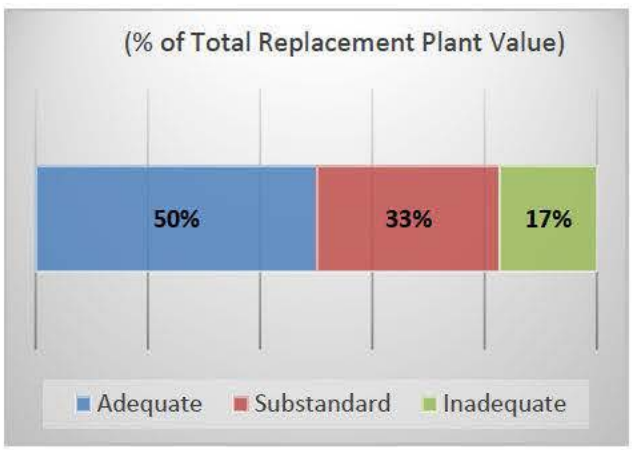


Figure 3 is an aggregate chart which shows the Department's Real Property Asset Condition for assessed assets around the DOE complex. As this chart reflects, as of FY 2015, 50% of DOE assessed assets (those that are owned by DOE, and active – not excess) were rated as "adequate" to meet the mission, 33% were rated as substandard, and 17% were rated as inadequate.

Figure 3. FY 2015 Real Property Asset Condition



Next Steps

The Department is focused on improving the condition of its assets to meet mission need and address potential risks to safety, security, and programmatic objectives. To track this progress, DOE has established an Agency Priority Goal for FY 2016-2017 that aims to increase the percentage of assets rated as adequate.

Agency Priority Goal: Deliver the highest quality R&D and production capabilities, strengthen partnerships with DOE headquarters, and improve management of the physical infrastructure of the National Laboratories to enable efficient leadership in science, technology, and national security.

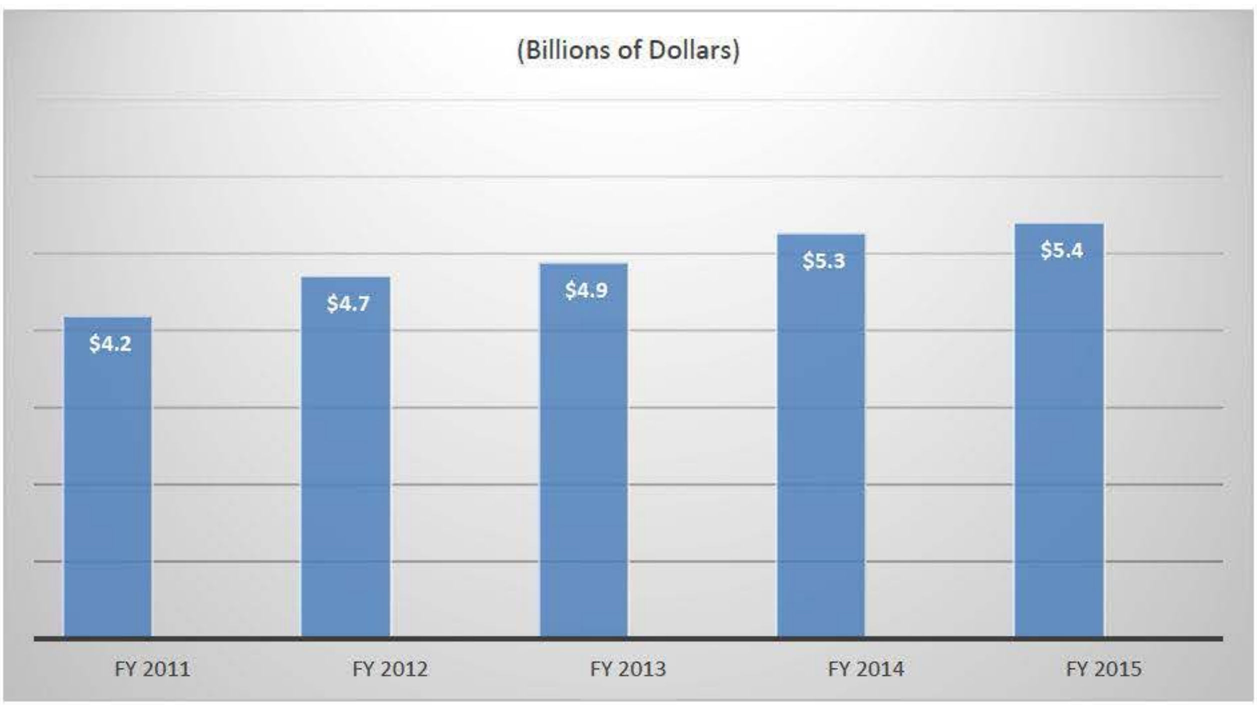
Strategy: By the end of FY 2017, the percentage of assessed DOE laboratory facilities categorized as "adequate" will increase by 2 percentage points from the FY 2015 baseline.

Going forward, the IEC will track year-over-year trends for infrastructure condition – both at the aggregate basis as reflected in Figure 3, and at the facility and non-facility asset level as reflected in Figures 1 and 2 – with the objective of increasing the percentage of assets rated as "adequate."

3.2 Is deferred maintenance decreasing?

When needed maintenance on a facility or utility system is postponed, it is referred to as "deferred maintenance." Increases in deferred maintenance could indicate aging infrastructure and associated challenges, such as those relating to reliability, mission readiness, and health and safety. Figure 4 shows the deferred maintenance trend for DOE since FY2011. As the chart shows, deferred maintenance for active, DOE owned assets has increased by almost 30% from $4.2 billion in FY 2011 to $5.4 billion in FY 2015.

Figure 4. Deferred Maintenance



Next Steps

Beginning with the FY 2016 Budget Request, and related to the LOB/IEC infrastructure effort, Secretary Moniz directed that each program's annual proposed investments in infrastructure should halt the growth of deferred maintenance. The Department is making other efforts to halt the increase of deferred maintenance. For instance, the annual laboratory planning efforts will include an assessment of deferred maintenance. In addition, the IEC will clarify data reporting in this area, including "deferred maintenance" and "repair needs," to better understand the mission impact of deferred maintenance and whether the Department's proposed investments in infrastructure are halting the growth of deferred maintenance.

3.3 Is the square footage of underutilized space decreasing?

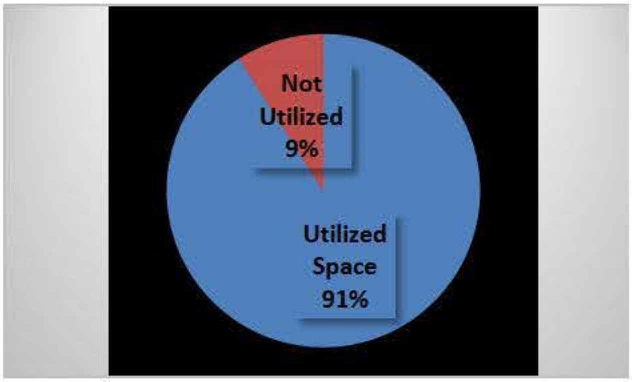
The Department is committed to maximizing the use of its space and assets. Identifying assets that are underutilized provides opportunities to either find ways to more fully utilize the space, or divest of it so it no longer requires resources to maintain. In addition to redefining asset condition, the LOB infrastructure assessment effort also re-defined metrics associated with utilization. Table 1 summarizes how space utilization is defined.

Table 1. Space Utilization Criteria

Utilization Rating	Office	High Bay, Ventilation Intensive, Power Intensive, General Space (Wet), General Space (Dry)	Storage
Over-utilized	95%	>85%	>80%
Fully Utilized	75%-95%	60%-85%	50%-80%
Under-utilized	<75%	30%-60%	10%-50%
Not Utilized		<30%	<10%

As these criteria were first used in the 2014 LOB assessments, annual trending data is not yet available; however, Figure 5 shows results from the end of FY 2015 indicating that 9% of the space measured is not utilized. This "not utilized" space includes whole facilities in some cases, but also can include portions of an otherwise utilized facility. "Not utilized" space is a candidate to be declared "excess" if there are no plans for future use.

Figure 5. FY 2015 Not Utilized Space



Next Steps

The IEC will continue to measure this data, ensuring that the assessments are uniform. Future years' reports will contain year-to-year data to indicate trends in this area. This data will be available for DOE to target investments to maximize the use of space, including reusing or repurposing infrastructure where possible to meet current mission needs.

3.4 Are excess space/buildings being eliminated?

In addition to its active infrastructure portfolio, DOE leads the largest nuclear cleanup effort in the world. The disposition of contaminated excess[4] facilities is an important part of this cleanup mission. Since the Office of Environmental Management (EM) was established in 1989, DOE's other Program Offices have transferred thousands of contaminated excess facilities for deactivation and decommissioning (D&D). EM has made substantial progress in D&D of these legacy contaminated excess facilities, having completed almost 3,000 facilities over the past 25 years.

Excess contaminated facilities are a drain on DOE's infrastructure resources, and can pose a risk to safety, security, and programmatic objectives. The Department faces a significant challenge with the number of aging excess facilities throughout the complex and the limited resources to deactivate, decontaminate, decommission, and demolish those facilities in the near term. As various DOE Program Secretarial Offices (PSOs) identify excess facilities they no longer need, they typically plan to request that contaminated excess facilities be transferred to EM. Until such transfer is formally completed, stewardship (management, surveillance and maintenance) responsibilities are retained with the owning PSO. Excess process contaminated facilities once accepted into the EM program are prioritized for deactivation as well as final disposition. However, as several external reports have recognized,[5] EM is unable to D&D all of the excess contaminated facilities already transferred in a timely manner or take in additional aging excess contaminated facilities from other PSOs in the foreseeable future.

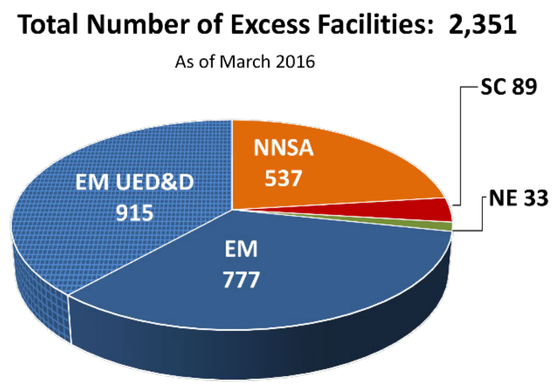
[4] For the purpose of this report, the term "excess" is synonymous with "nonoperational" and refers to a facility for which DOE no longer has a mission need.

[5] See Report of the DOE Office of Inspector General, "The Department of Energy's Management of High-Risk Excess Facilities," January 2015; report of the Commission to Review the Effectiveness of the National Energy Laboratories (CRENEL), October 2015.

In 2015, Secretary Moniz directed the establishment of an Excess Contaminated Facilities Working Group (ECFWG). The working group developed and executed an enterprise-wide data collection effort to obtain information on potential risk and updated rough order of magnitude cost estimates to D&D excess facilities. The ECFWG used the updated data to define the scope of the challenge and to propose risk-informed approaches for addressing DOE's contaminated excess facilities.

As of March 2016, DOE has over 2,300 excess facilities. Figure 6 reflects the excess facilities across the Department, broken out by the program that currently has responsibility for the facility.[6]

Figure 6. Excess Facility Inventory



Next Steps

The ECFWG is updating and validating data gathered by the working group's efforts, and finalizing a report on its work, to include a discussion of actions that DOE has taken or is planning to take to demolish specific facilities and to mitigate risks at existing contaminated facilities awaiting disposal. This report will be issued in 2016 in response to a requirement of the 2016 National Defense Authorization Act, and will be updated every two years. Additional information on excess contaminated facilities will be provided in that report. Over the next year, the IEC will work to integrate its efforts with those of the ECFWG.

3.5 Are the costs of carrying excess facilities declining?

The information gathered as part of the ECFWG efforts included ROM costs for D&D; cost ranges for maintenance, surveillance, repairs, and operations (MSRO); and an assessment of

[6] The Energy Policy Act of 1992 authorized annual contributions to the Uranium Enrichment Decontamination and Decommissioning (UED&D) Fund, which came from both a special assessment on domestic nuclear utilities and annual Congressional appropriations, to support the EM responsibilities at the nation's three Gaseous Diffusion Plants (GDPs) at Portsmouth, Ohio; Paducah, Kentucky; and Oak Ridge, Tennessee.

potential risk to public health and the environment, worker safety, and mission. When the report of this work is issued in 2016, it will contain information on these factors – to include estimated MSRO, or carrying costs.

As a general matter, for the higher risk excess contaminated facilities, MSRO costs can run into the millions of dollars per year to keep the facilities safe and stable. These costs are avoided when a facility is demolished. In addition to incurring ongoing MSRO costs, delaying D&D may:

- Expose individuals and the environment to increasing levels of risk;
- Escalate disposition costs, especially if a building degrades while awaiting D&D; and
- Impede ongoing mission work (due to excess facilities located near ongoing mission work).

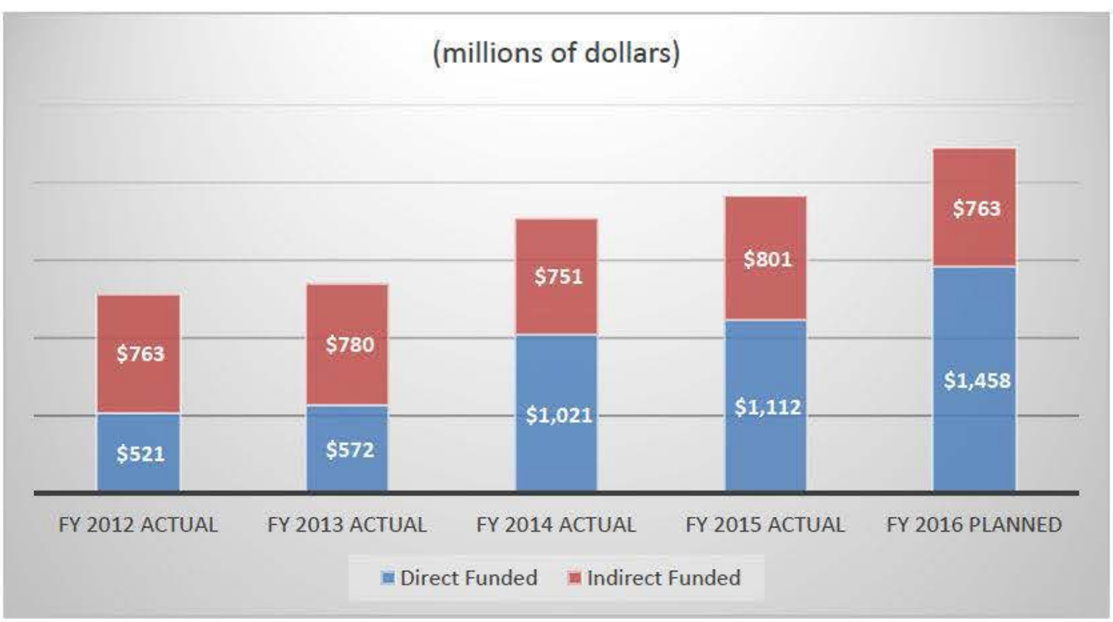
Next Steps

Over the next year, the IEC will work with the ECFWG to establish uniform measures and data validation in this area.

3.6 Did the Department make the investments it committed to make?

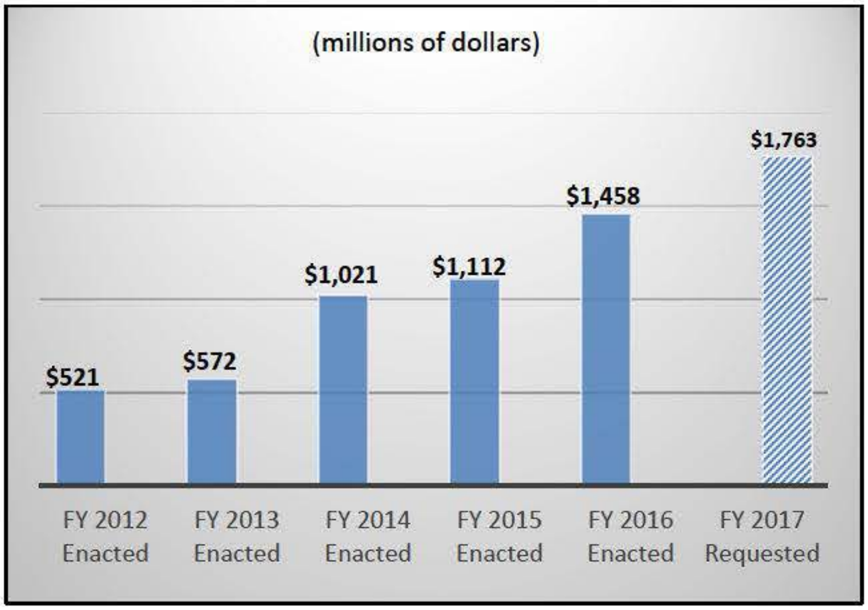
To evaluate the state of general purpose infrastructure, the IEC tracks what investments have been made to maintain and improve that infrastructure. Over the past five years (from FY 2012-FY 2016), more than $8 billion has been invested in general purpose infrastructure, either directly by the Department or through laboratory overhead (indirect investments). Over this period, investments in this area have steadily increased, rising by nearly 75% (Figure 7).

Figure 7. Investments in General Purpose Infrastructure



Stewardship of DOE infrastructure is a partnership between the federal line programs that oversee a laboratory or site (e.g., NNSA, EM, the Office of Science) and the individual laboratories, plants, and sites. This partnership is evident in Figure 7, which shows that infrastructure investments are a mix of direct-funded and indirect-funded activities, averaging 55% direct and 45% indirect when aggregated over FY 2012 through FY 2015.

Figure 8. Direct-Funded General Purpose Infrastructure Investments



Direct-Funded Investments

The direct-funded general purpose infrastructure investments include:

- Line item projects, which are capital improvements totaling greater than $10M;
- General Plant Projects, which are capital improvements of less than $10M;
- Excess Facilities Disposition Projects that are funded by direct appropriations; and
- Maintenance and Repair activities that are funded by direct appropriations.

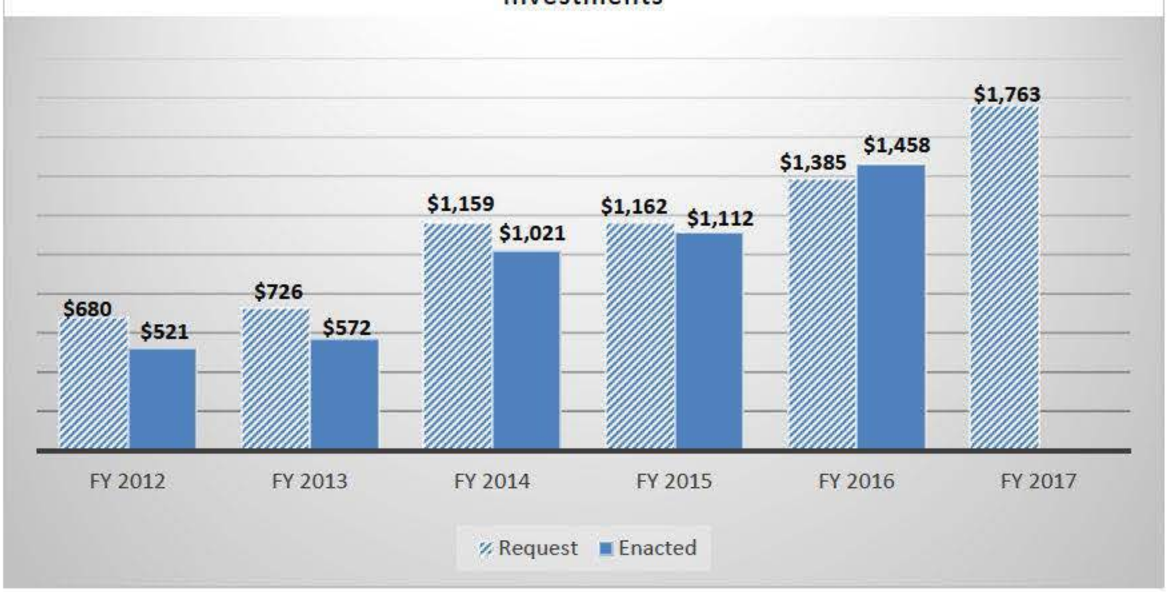
Figure 8 shows that direct investments in general purpose infrastructure have steadily increased over recent years. The increase in investments for FY 2016 is a result of LOB efforts to identify and prioritize investments in critical general purpose infrastructure projects, following the condition assessments. Table 2 shows some of the work supported by the FY 2016 appropriations to target critical general purpose infrastructure projects. The Department's FY 2017 request proposes further investments to arrest the decline in aging infrastructure and support mission activities.

TABLE 2. FY 2016 General Purpose Infrastructure Crosscut Investments

Fiscal Year	Funding ($M)	Work Scope
Enacted in 2016 - $109.9M	$12.3	Replacement of failing Heating, Ventilation, and Air Conditioning (HVAC) systems at several facilities across Lawrence Livermore National Laboratory
	$8	Replacement of critical mission equipment at the Kansas City National Security Campus
	$1.7	Upgrade of safety systems and waste disposal capabilities at Los Alamos National Laboratory
	$6.5	Upgrade of fire protection, electrical, and other core infrastructure systems at the Nevada Nuclear Security Site
	$5.8	Replacement of the Gas Laboratory at Pantex, as well as additional electrical and mechanical upgrades on site
	$5.5	Relocation of the Reservoir Storage Vault and replacement of glovebox oxygen monitors at the Savannah River Nuclear Security Site
	$8	Replacement of components of electrical and dehumidification systems at Y12
	$13.4	Replacement of core electrical infrastructure at SLAC National Accelerator Laboratory and Argonne National Laboratory
	$9	Renovation of 2 floors of Wilson Hall at Fermi National Accelerator Laboratory
	$16.5	Upgrades to the Savannah River National Laboratory firewater system, and replacement of hot cell windows and associated electrical control systems
	$23.2	Utility upgrades at Idaho National Laboratory, including power distribution infrastructure and control systems

Figure 9 shows enacted funding levels versus requested funding levels since FY 2012. Overall, DOE has been appropriated more than 90% of the direct-funded investments requested for general purpose infrastructure since FY 2012.

Figure 9. Requested and Enacted Direct-Funded General Purpose Infrastructure Investments



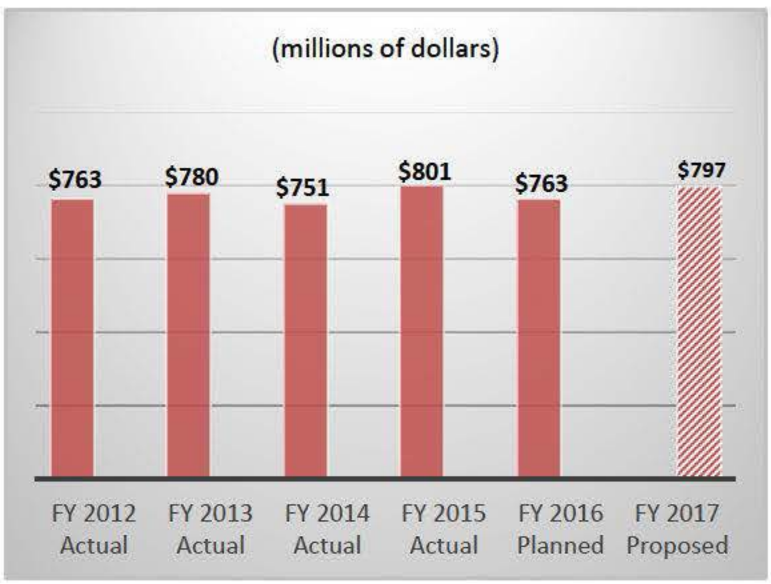
Indirect-Funded Investments

Indirect-funded general purpose infrastructure investments include:

- Institutional GPP, which are capital improvements of less than $10M that are of general benefit across the site;
- Excess Facilities Disposition Projects that are funded by site overhead; and
- Maintenance and Repair funded by site overhead.

Figure 10 shows that indirect investments have remained relatively steady over the past five years. These investment levels are largely managed by the individual laboratories and sites, and vary from program to program.

Figure 10. Indirect-Funded General Purpose Infrastructure Investments



Next Steps

In FY 2017, the IEC will again present enterprise-wide prioritized investments in infrastructure to senior DOE leadership.

3.7 Are fewer core capabilities at risk due to infrastructure deficiencies?

The IEC is focused on ensuring that general purpose infrastructure can continue to support each laboratory and site's core capabilities and contribute to the Nation's energy, environmental and nuclear security. The data and metrics in this report are intended to provide insight into the general question of whether fewer of those core capabilities are at risk due to infrastructure deficiencies.

Because many of the initiatives described at the outset of this report are new, and the data reflects a first year's effort to assemble this information in a uniform manner, this question will be addressed in future reports. The Department is committed to addressing the challenges posed by its aging infrastructure. This will involve attention from senior leadership, with guidance by the Laboratory Operations Board, and stewardship from the Infrastructure Executive Committee. A safe, reliable, and modern infrastructure is vital to supporting the critical work of the Department and the success of its mission.

4 Next Steps for Infrastructure Executive Committee

To sustain ongoing improvements to DOE's general purpose infrastructure, the IEC plans to accomplish the following actions in FY 2017:

- Draft the second annual State of General Purpose Infrastructure at the Department of Energy, to be issued by the end of FY 2017.
- Present proposed enterprise-wide prioritized investments in infrastructure to senior DOE leadership.
- Track year-over-year trends for infrastructure condition to determine whether the percent of facilities and other structures rated as "adequate" is increasing.
- Clarify data reporting, including "deferred maintenance" and "repair needs," to better understand the mission impact of deferred maintenance and whether the Department's proposed investments in infrastructure are halting the growth of deferred maintenance.
- Continue uniform assessments of space utilization to evaluate whether year-to-year trends demonstrate a decrease in the percentage of underutilized and not utilized space.
- Integrate efforts with the ECFWG to: assess whether excess space/buildings are being eliminated; assess whether the costs of carrying excess facilities are declining; and establish uniform measures and data validation in this area.
- Address in future reports whether fewer core capabilities are at risk due to infrastructure deficiencies.

Appendix: Data Source for Figures Presented in this Report

The “DOE infrastructure” included in this document is for the following DOE programs/offices and the respective laboratories, plants, and sites stewarded by those offices: Office of Energy Efficiency & Renewable Energy, Office of Environmental Management, Office of Fossil Energy, Office of Nuclear Energy, Office of Science, and the National Nuclear Security Administration. Data from the Power Marketing Administrations, Naval Reactors, Office of Legacy Management, and the Federal Energy Regulatory Commission is not included.

DOE Infrastructure Summary Box: Facilities and Information Management System (FIMS) Historical Report for FY 2015 with the following parameters – DOE Owned and Leased Assets, GSA Owned and Leased Assets, Permits and Withdrawn Land; all Laboratories and sites; Buildings, Trailers, Land, and Other Structures and Facilities (OSFs); all programs except Power Marketing Administrations; includes all assets.

Figure 1. Facility Condition: FIMS Ad Hoc Historical Report for FY 2015 with the following parameters – DOE-Owned Assets Only; all Laboratories and Sites; Buildings, Trailers and OSFs; Programs EE, EM, FE, NE, NNSA, and SC; excludes assets with Excess “Y” (Yes) Indicators; percentage calculation of total Replacement Plant Value (RPV) of those assets assessed.

Figure 2. Non-Facility Condition: April 1, 2016, FIMS Ad Hoc Historical Report for FY 2015 with the following parameters – DOE-Owned Assets Only; all Laboratories and Sites; Buildings Trailers, and OSFs; Programs EE, EM, FE, NE, NNSA, and SC; excludes assets with Excess “Y” Indicators; percentage calculation of total RPV of those assets assessed.

Figure 3. Real Property Asset Condition: April 1, 2016, FIMS Ad Hoc Historical Report for FY 2015 with the following parameters – DOE-Owned Assets Only; all Laboratories and Sites; Buildings, Trailers and OSFs; Programs EE, EM, FE, NE, NNSA, and SC; excludes assets with Excess “Y” Indicators; percentage calculation of total RPV of those assets assessed.

Figure 4. Deferred Maintenance: Actuals from April 1, 2016, FIMS Ad Hoc Historical Reports for FY 2011-FY 2015 with the following parameters – DOE-Owned Assets Only; all Laboratories and Sites; Buildings, Trailers, and OSFs; programs included are EE, EM, FE, NE, NNSA, and SC; includes operating facilities only. Projected data provided by program offices.

Figure 5. Not Utilized Space: September 1, 2016, FIMS Ad Hoc Historical Report for FY 2015 with the following parameters – DOE-Owned Assets Only; all Laboratories and Sites; Buildings,

Trailers and OSFs; Programs EE, EM, FE, NE, NNSA, and SC; excludes assets with Excess "Y" Indicators.

Figure 6. Excess Facility Inventory: Data from ECFWG assessment efforts; total as of March 2016. Data includes excess and non-operational facilities. Non-operational facilities status in FIMS includes the following: D&D in Progress; Deactivation; Operating Pending D&D; Shutdown Pending D&D; and Shutdown Pending Disposal.

Figure 7. Investments in General Purpose Infrastructure: Prior Year Enacted Appropriations and Integrated Facilities and Infrastructure Crosscut submissions for Congressional Requests; data as provided by the programs.

Figure 8. Direct-Funded General Purpose Infrastructure Investments: Prior year enacted appropriations and FY 2017 Congressional Request Submissions; data provided by the programs.

Figure 9. Requested and Enacted Direct-Funded General Purpose Infrastructure Investments: prior year Congressional Request Submissions, prior year Enacted Appropriations, and FY 2017 Congressional Request Submissions; data provided by the programs.

Figure 10. Indirect-Funded General Purpose Infrastructure Investments: Prior year IFI Crosscut submissions for Congressional Requests; data provided by the programs.

46. Can you provide a list of all current open job postings and the status of those positions?

Response: DOE had 571 positions in the hiring process, as of December 9, 2016. The attached spreadsheet provides a list of each open position, with the exception of non-executive NNSA positions, and its status in the hiring process. Also attached is a summary of job postings across DOE.

Servicing HR Office	Org	Position Title	Pay Plan	Occ. Series	Grade	Hiring Process Phase
M&P HR SSC	ARPA-E	Grants Management Specialist	GS	1109	09/13	Candidate Selection
M&P HR SSC	AU	Health Physicist	GS	1306	14	Announcement Open
M&P HR SSC	AU	Administrative Support Specialist	GS	301	09	Applicant Evaluation
M&P HR SSC	AU	Security Specialist	GS	080	13	Applicant Evaluation
M&P HR SSC	AU	General Engineer	GS	801	15	Applicant Evaluation
M&P HR SSC	AU	General Engineer	GS	801	15	Applicant Evaluation
M&P HR SSC	AU	Personnel Security Specialist	GS	080	09/11	Applicant Evaluation
M&P HR SSC	AU	Quality Assurance Specialist	GS	1910	13	Candidate Selection
M&P HR SSC	AU	Physical Security Specialist	GS	080	14	Candidate Selection
M&P HR SSC	AU	Supv. Criminal Investigator	GS	1811	15	Candidate Selection
M&P HR SSC	AU	Employee Concerns Program Manager	GS	340	15	Candidate Selection
M&P HR SSC	AU	Criminal Investigator	GS	1811	09/11	Candidate Selection
OCEM	AU	Nuclear Engineer	EJ	0840	05	Entry on Duty
M&P HR SSC	AU	Lead Personnel Security Specialist	GS	080	14	Job Acceptance
M&P HR SSC	AU	Personnel Security Specialist	GS	080	09/11	Job Acceptance
M&P HR SSC	AU	Criminal Investigator	GS	1811	09/11	Job Acceptance
M&P HR SSC	AU	Criminal Investigator	GS	1811	09/11	Job Acceptance
BPA HR SC	BPA	Facilities Maintenance Worker	BB	4749	00	Announcement Open
BPA HR SC	BPA	EVP Information Technology & Chief Info Officer	ES	2210	00	Announcement Open
OCEM	BPA	Director, Human Resources Service Center	ES	0201	00	Announcement Open
BPA HR SC	BPA	Safety & Occupational Health S	GS	0018	12	Announcement Open
BPA HR SC	BPA	Electrical Engineer	GS	0850	12	Announcement Open
BPA HR SC	BPA	Electrical Engineer	GS	0850	12	Announcement Open
BPA HR SC	BPA	Electronics Engineer	GS	855	12	Announcement Open
BPA HR SC	BPA	Project Management Coordinator	GS	0301	12	Announcement Open
BPA HR SC	BPA	Account Specialist	GS	1101	12	Announcement Open
BPA HR SC	BPA	Land Surveyor (Office-Mapping Group)	GS	1373	12	Announcement Open
BPA HR SC	BPA	Electrical Engineer	GS	0850	13	Announcement Open
BPA HR SC	BPA	Hydro O&M Program Manager	GS	1101	13	Announcement Open
BPA HR SC	BPA	Interdisciplinary Engineer (Civil/Mechancial/Electrical)	GS	810/830/850	13	Announcement Open
BPA HR SC	BPA	IT Specialist	GS	2210	13	Announcement Open
BPA HR SC	BPA	IT Specialist	GS	2210	13	Announcement Open
BPA HR SC	BPA	Public Utiltities Specialist	GS	1130	13	Announcement Open
BPA HR SC	BPA	Electrical Engineer	GS	850	13	Announcement Open
BPA HR SC	BPA	Supervisory IT Specialist	GS	2210	14	Announcement Open
BPA HR SC	BPA	Supervisory Electronics Engineer	GS	0855	14	Announcement Open
BPA HR SC	BPA	Supvy Public Utilities Specialist	GS	1130	14	Announcement Open
BPA HR SC	BPA	Public Utiltities Specialist	GS	1130	14	Announcement Open
BPA HR SC	BPA	Operations Research Analyst	GS	1515	14	Announcement Open
BPA HR SC	BPA	Real Time Operations Director	GS	1101	15	Announcement Open
BPA HR SC	BPA	Director, Corporate Strategy	GS	340	15	Announcement Open
BPA HR SC	BPA	HMEM	GS	5803	00	Applicant Evaluation
BPA HR SC	BPA	Secretary (OA)	GS	318	08	Applicant Evaluation
BPA HR SC	BPA	Support Services Specialist	GS	0342	11	Applicant Evaluation
BPA HR SC	BPA	IT Specialist	GS	2210	12	Applicant Evaluation
BPA HR SC	BPA	Physical Scientist (Power Ops)	GS	1301	12	Applicant Evaluation
BPA HR SC	BPA	Industry Economist	GS	0110	12	Applicant Evaluation
BPA HR SC	BPA	Management and Program Analyst	GS	0343	12	Applicant Evaluation
BPA HR SC	BPA	IT Specialist	GS	2210	12	Applicant Evaluation
BPA HR SC	BPA	IT Specialist (INFOSEC)	GS	2210	12	Applicant Evaluation
BPA HR SC	BPA	Civil/Mechanical Engineer	GS	810	12	Applicant Evaluation
BPA HR SC	BPA	Public Utilities Specialist	GS	1130	12	Applicant Evaluation
BPA HR SC	BPA	Management and Program Analyst	GS	343	13	Applicant Evaluation
BPA HR SC	BPA	Lead NERC Compliance Specialist	GS	1101	13	Applicant Evaluation
BPA HR SC	BPA	Electrical Engineer	GS	850	13	Applicant Evaluation
BPA HR SC	BPA	Supervisory IT Spec (InfoSec)	GS	2210	14	Applicant Evaluation
BPA HR SC	BPA	Executive Manager, Fish and Wildlife	GS	340	15	Applicant Evaluation
BPA HR SC	BPA	Line Equipment Operator	BB	2810	00	Candidate Selection
BPA HR SC	BPA	Lineman	BB	2810	00	Candidate Selection

Servicing HR Office	Org	Position Title	Pay Plan	Occ. Series	Grade	Hiring Process Phase
BPA HR SC	BPA	Security Officer	GS	80	09	Candidate Selection
BPA HR SC	BPA	Financial Analyst	GS	1160	11	Candidate Selection
BPA HR SC	BPA	Accountant	GS	510	11	Candidate Selection
BPA HR SC	BPA	IT Specialist (INFOSEC)	GS	2210	12	Candidate Selection
BPA HR SC	BPA	Electrical Engineer	GS	850	12	Candidate Selection
BPA HR SC	BPA	Business Analyst	GS	1101	12	Candidate Selection
BPA HR SC	BPA	Accountant	GS	510	12	Candidate Selection
BPA HR SC	BPA	Inventory Management Specialist	GS	2010	12	Candidate Selection
BPA HR SC	BPA	Physical Scientist (Environmental)	GS	1301	12	Candidate Selection
BPA HR SC	BPA	Management and Program Analyst	GS	343	13	Candidate Selection
BPA HR SC	BPA	Management and Program Analyst	GS	343	13	Candidate Selection
BPA HR SC	BPA	Supervisory Land Surveyor	GS	1373	13	Candidate Selection
BPA HR SC	BPA	IT Specialist (SYSADMIN/CUSTSPT)	GS	2210	13	Candidate Selection
BPA HR SC	BPA	Deputy Executive VP. Business Transformation	GS	340	13	Candidate Selection
BPA HR SC	BPA	IT Specialist (SYSADMIN/CUSTSPT)	GS	2210	13	Candidate Selection
BPA HR SC	BPA	Civil/Mechanical Engineer	GS	810	13	Candidate Selection
BPA HR SC	BPA	Management and Program Analyst	GS	343	13	Candidate Selection
BPA HR SC	BPA	Outage Tracking Public Utlities Specialist	GS	1130	14	Candidate Selection
BPA HR SC	BPA	Outage Supervisor	GS	1101	14	Candidate Selection
BPA HR SC	BPA	Supervisory Electronic Engineer	GS	850	14	Candidate Selection
BPA HR SC	BPA	Supervisory Public Utilities Specialist	GS	1130	14	Candidate Selection
BPA HR SC	BPA	Supervisory Electrical Engineer	GS	850	14	Candidate Selection
BPA HR SC	BPA	Building Management Specialist	GS	1176	14	Candidate Selection
BPA HR SC	BPA	Lead Human Resources Specialist	GS	201	15	Candidate Selection
BPA HR SC	BPA	Director, Enterprise Arch	GS	1130	15	Candidate Selection
BPA HR SC	BPA	Director, EPMO	GS	1130	15	Candidate Selection
BPA HR SC	BPA	Financial Analyst	GS	1160	15	Candidate Selection
BPA HR SC	BPA	HMEM	BB	5803	00	Entry on Duty
OCEM	BPA	Chief Operating Officer	ES	0340	00	Entry on Duty
BPA HR SC	BPA	Human Resources Specialist	GS	201	12	Entry on Duty
BPA HR SC	BPA	Electrical Engineer	GS	850	12	Entry on Duty
BPA HR SC	BPA	Auditor	GS	511	12	Entry on Duty
BPA HR SC	BPA	Substation Operations Specialist	GS	1601	13	Entry on Duty
BPA HR SC	BPA	Public Utilities Specialist (Analyst)	GS	1130	13	Entry on Duty
BPA HR SC	BPA	Public Affairs Specialist	GS	1035	13	Entry on Duty
BPA HR SC	BPA	Human Resources Specialist (ER)	GS	201	12	Job Acceptance
BPA HR SC	BPA	Public Utilities Specialist (Revnue Analyst)	GS	1130	12	Job Acceptance
BPA HR SC	BPA	Electrical Engineer	GS	850	12	Job Acceptance
BPA HR SC	BPA	HMEM	BB	5803	00	Tentative Job Offer
BPA HR SC	BPA	HMEM	BB	5803	00	Tentative Job Offer
BPA HR SC	BPA	Electrician	BB	2810	00	Tentative Job Offer
BPA HR SC	BPA	Management Associate 1	GS	301	09	Tentative Job Offer
BPA HR SC	BPA	Contract Specialist	GS	1102	11	Tentative Job Offer
BPA HR SC	BPA	Human Resources Specialist (ER/PM)	GS	201	11	Tentative Job Offer
BPA HR SC	BPA	Financial Analyst	GS	1160	11	Tentative Job Offer
BPA HR SC	BPA	Human Resources Specialist (Recruit/Class)	GS	201	12	Tentative Job Offer
BPA HR SC	BPA	Machinist	GS	3414	12	Tentative Job Offer
BPA HR SC	BPA	Operations Research Analyst	GS	1515	12	Tentative Job Offer
BPA HR SC	BPA	Public Utilities Specialist (Revenue)	GS	1130	12	Tentative Job Offer
BPA HR SC	BPA	Electrical Engineer	GS	850	12	Tentative Job Offer
BPA HR SC	BPA	Electronics Engineer	GS	850	12	Tentative Job Offer
BPA HR SC	BPA	Procurement Analyst	GS	1102	13	Tentative Job Offer
BPA HR SC	BPA	Mechanical Engineer	GS	830	13	Tentative Job Offer
M&P HR SSC	CF	Accountant	GS	0510	07/12	Applicant Evaluation
M&P HR SSC	CF	Budget Analyst	GS	0560	13	Candidate Selection
M&P HR SSC	CF	Budget Analyst	GS	0560	09/11/12	Candidate Selection
M&P HR SSC	CF	Budget Analyst	GS	0560	13/14	Candidate Selection
M&P HR SSC	CF	Accountant	GS	0510	14	Job Acceptance
M&P HR SSC	CF	Supervisory Accountant	GS	0510	15	Job Acceptance

Servicing HR Office	Org	Position Title	Pay Plan	Occ. Series	Grade	Hiring Process Phase
M&P HR SSC	CF	IT Specialist (Applications Software)	GS	2210	15	Job Acceptance
M&P HR SSC	CF	Supervisory Accountant	GS	0510	15	Job Acceptance
M&P HR SSC	CF	Information Technology Specialist	GS	2210	7/9/11	Job Acceptance
M&P HR SSC	CF	Accountant	GS	0510	07/12	Job Acceptance
M&P HR SSC	CF	Accountant	GS	0510	07/12	Tentative Job Offer
M&P HR SSC	CI	Director of Intergovernmental & External Affairs	GS	301	15	Job Acceptance
M&P HR SSC	EA	Nuclear Engineer	GS	0840	14/15	Applicant Evaluation
M&P HR SSC	EA	Security Specialist	GS	0080	15	Candidate Selection
M&P HR SSC	EA	Safety Engineer	GS	0801	13/14	Candidate Selection
M&P HR SSC	EA	General Engineer/Physical Scientist	GS	801/1301	14/15	Candidate Selection
M&P HR SSC	EA	General Engineer	GS	801	14/15	Candidate Selection
M&P HR SSC	ED	Supervisory Attorney Advisor (Civil Rights)	GS	0905	12	Announcement Open
M&P HR SSC	ED	Equal Employment Opportunity Specialist	GS	0260	09/11/12	Announcement Open
M&P HR SSC	ED	Business Program Manager	GS	1101	14	Applicant Evaluation
M&P HR SSC	ED	Attorney Adviser (Civil Rights)	GS	0905	11/12	Candidate Selection
M&P HR SSC	ED	Equal Employment Specialist	GS	0260	09/11	Entry on Duty
M&P HR SSC	ED	Attorney-Adviser (Civil Rights)	GS	0905	11/12	Job Acceptance
M&P HR SSC	ED	Equal Employment Specialist	GS	260	12/13	Job Acceptance
M&P HR SSC	ED	Operations Research Analyst	GS	1515	14	Tentative Job Offer
S&E HR SSC	EE	Summer Aid Intern (Trainee)	GS	303	04	Applicant Evaluation
S&E HR SSC	EE	Communications Specialist	GS	0301	13	Applicant Evaluation
S&E HR SSC	EE	General Engineer	GS	0801	14	Applicant Evaluation
S&E HR SSC	EE	General Engineer	GS	0801	14	Applicant Evaluation
S&E HR SSC	EE	Attorney Advisor (General)	GS	0905	12/13/14	Applicant Evaluation
S&E HR SSC	EE	General Engineer/Physical Scientist	GS	0801/1301	12/13	Applicant Evaluation
S&E HR SSC	EE	Energy Technology Program Specialist	GS	0301	12/13	Applicant Evaluation
S&E HR SSC	EE	Management and Program Analyst	GS	0343	12/13	Applicant Evaluation
S&E HR SSC	EE	Interdisciplinary General Engineer/Physical Scientist	GS	1301/0801	12/13	Applicant Evaluation
S&E HR SSC	EE	General Engineer (MARINE & HYDRKINETIC)	GS	0801	13/14	Applicant Evaluation
S&E HR SSC	EE	Budget Analyst	GS	0560	13	Candidate Selection
S&E HR SSC	EE	Management and Program Analyst	GS	0343	13	Candidate Selection
S&E HR SSC	EE	Management and Program Analyst	GS	0343	13	Candidate Selection
S&E HR SSC	EE	Budget Analyst	GS	0560	14	Candidate Selection
S&E HR SSC	EE	Management and Program Analyst	GS	0343	14	Candidate Selection
S&E HR SSC	EE	Energy Technology Program Specialist	GS	0301	14	Candidate Selection
S&E HR SSC	EE	Supervisory Safety & Occupational Health Manager	GS	0018	14	Candidate Selection
S&E HR SSC	EE	Management and Program Analyst	GS	0343	15	Candidate Selection
S&E HR SSC	EE	Supervisor, Workforce and Talent Management	GS	0301	15	Candidate Selection
S&E HR SSC	EE	Supervisory Management and Program Analyst	GS	0343	15	Candidate Selection
S&E HR SSC	EE	Management Analyst	GS	0343	15	Candidate Selection
S&E HR SSC	EE	General Engineer/Physical Scientist	GS	0801/1301	12/13	Candidate Selection
S&E HR SSC	EE	Management and Program Analyst	GS	343	12/13	Candidate Selection
S&E HR SSC	EE	Supervisory, Energy Technology Program Specialist	GS	0301	14/15	Candidate Selection
S&E HR SSC	EE	General Engineer	GS	801	13	Entry on Duty
S&E HR SSC	EE	Interdisciplinary General Engineer/Physical Scientist	GS	0801/1301	13/14	Entry on Duty
S&E HR SSC	EE	General Engineer/Physical Scientist	GS	0801/1301	14	Job Acceptance
S&E HR SSC	EE	General Engineer	GS	0801	14	Job Acceptance
S&E HR SSC	EE	Supervisory General Engineer/Physical Scientist	GS	801/1301	15	Job Acceptance
S&E HR SSC	EE	Legislative Analyst	GS	0301	11/12	Job Acceptance
S&E HR SSC	EE	Policy Advisor	GS	301	12/13	Job Acceptance
S&E HR SSC	EE	General Engineer	GS	801	12/13	Job Acceptance
S&E HR SSC	EE	Energy Technical Project Specialist	GS	0301	12/13	Job Acceptance
S&E HR SSC	EE	Interdisciplinary General Engineer/Physical Scientist	GS	0801/1301	12/13	Job Acceptance
S&E HR SSC	EE	Information Technology Specialist	GS	2210	14/15	Job Acceptance
S&E HR SSC	EE	Energy Technology Program Specialist EEID#273 Stakeholder Engage	GS	301	13	Tentative Job Offer
S&E HR SSC	EE	Management and Program Analyst (OSP EEID273)	GS	343	13	Tentative Job Offer
S&E HR SSC	EE	Grants Management Specialist	GS	1109	09/11/12	Tentative Job Offer
S&E HR SSC	EE	Contract Specialist	GS	1102	09/11/12	Tentative Job Offer
OCEM	EERE	Director, Building Technologies Office	ES	0340	00	Entry on Duty

Servicing HR Office	Org	Position Title	Pay Plan	Occ. Series	Grade	Hiring Process Phase
OCEM	EERE	Director, Budget Office	ES	0340	00	Qualifications Review Board
OCEM	EERE	Director, Water Power Technologies Office	ES	0340	00	Qualifications Review Board
OCEM	EERE	Deputy Director, Solar Energy Technology Office	ES	0340	00	Qualifications Review Board
OCEM	EI	Director, Office of Web Management	EJ	0340	04	Announcement Open
OCEM	EI	CIO/Director, Office of Information Technology	ES	2210	00	Announcement Open
S&E HR SSC	EI	Lead Chemical Engineer	GS	893	14	Applicant Evaluation
S&E HR SSC	EI	Industry Econoist	GS	110	09/11/12	Applicant Evaluation
S&E HR SSC	EI	Macroeconomist	GS	0110	09/11/12	Applicant Evaluation
S&E HR SSC	EI	Operations Research Analyst/Industry Economist	GS	110/1515	09/11	Applicant Evaluation
S&E HR SSC	EI	Survey/Math Statistician	GS	1529/1530	09/11	Applicant Evaluation
S&E HR SSC	EI	General Engineer	GS	1529/1530	09/11	Applicant Evaluation
S&E HR SSC	EI	Operations Research Analyst	GS	1515	7/9/11/12	Applicant Evaluation
S&E HR SSC	EI	industry Economist/Operation Research Analyst	GS	110/1515	13	Candidate Selection
S&E HR SSC	EI	Math/Survey Statistician	GS	1529/1530	13	Candidate Selection
S&E HR SSC	EI	General Engineer	GS	801	13	Candidate Selection
S&E HR SSC	EI	General Engineer	GS	00801	09/11	Candidate Selection
S&E HR SSC	EI	Operations Research Analyst/Industry Economist	GS	1515/110	09/11	Candidate Selection
S&E HR SSC	EI	Interdisciplinary Mathematical Statistician/Survey Statistician	GS	1529/1530	7/9/11/12	Candidate Selection
S&E HR SSC	EI	Operations Research Analyst	GS	1515	7/9/11/12	Candidate Selection
S&E HR SSC	EI	Industry Economist	GS	0110	12	Entry on Duty
S&E HR SSC	EI	Supervisory IT Specialist	GS	2210	15	Entry on Duty
S&E HR SSC	EI	Survey Statistician/Mathematical Statistician	GS	1529/1530	09/11	Entry on Duty
S&E HR SSC	EI	General Engineer	GS	0801	7/9/11/12	Entry on Duty
OCEM	EI	Director, Office of Petroleum and Biofuels Statistics	ES	0340	00	Qualifications Review Board
S&E HR SSC	EI	Industry Economist/Operations Rearch Analsyt	GS	110/1515	13	Tentative Job Offer
OCEM	EM	BUDGET OFFICER	EJ	0560	04	Announcement Open
OCEM	EM	NUCLEAR ENGINEER, SAFETY ADVISOR	EK	801	04	Announcement Open
OCEM	EM	ASSISTANT MANAGER FOR TANK FARMS	ES	801	00	Announcement Open
OCEM	EM	PROGRAM MANAGER	ES	0340	00	Announcement Open
OCEM	EM	DIRECTOR, OFFICE OF COMMUNICATIONS	ES	0340	00	Announcement Open
OCEM	EM	DEPUTY CHIEF FOR FIELD OPERATIONS	ES	0340	00	Applicant Evaluation
OCEM	EM	ASSOCIATE DEPUTY DIRECTOR, PROJECT EXECUTION AND TECHNICA	EJ	0340	04	Candidate Selection
OCEM	EM	DIRECTOR, PROJECT MANAGEMENT	EJ	0340	04	Candidate Selection
OCEM	EM	CHIEF COUNSEL	ES	0905	00	Candidate Selection
OCEM	EM	DIRECTOR FOR REGULATORY, INTERGOVERNMENTAL AND STAKEHOLDER E	ES	0340	00	Candidate Selection
OCEM	EM	DIRECTOR FOR BUDGET AND PLANNING	ES	0340	00	Candidate Selection
OCEM	EM	DEPUTY CHIEF FOR REGULATORY AND POLICY AFFAIRS	ES	0340	00	Candidate Selection
OCEM	EM	ASSOCIATE DEPUTY ASSISTANT SECRETARY FOR ACQUISITION AND PROJECT	ES	0340	00	Candidate Selection
OCEM	EM	DEPUTY CHIEF FOR CORPORATE SERVICES	ES	0340	00	Candidate Selection
OCEM	EM	DEPUTY ASSISTANT SECRETARY FOR WASTE AND MATERIALS MANAGEMEN	ES	0340	00	Candidate Selection
OCEM	EM	DEPUTY MANAGER, CARLSBAD FIELD OFFICE	ES	0340	00	Qualifications Review Board
M&P HR SSC	EM	Lead IT Specialist (INFOSEC)	GS	2210	14	Announcement Open
M&P HR SSC	EM	Management Analyst (Executive Officer)	GS	0343	15	Announcement Open
M&P HR SSC	EM	Nuclear Engineer	GS	0840	13/14	Announcement Open
M&P HR SSC	EM	Management Analyst	GS	0343	09/13	Applicant Evaluation
M&P HR SSC	EM	Public Affairs Specialist	GS	1035	11/13	Applicant Evaluation
M&P HR SSC	EM	Program Analyst	GS	0343	11	Candidate Selection
M&P HR SSC	EM	Program Analyst	GS	0343	11	Candidate Selection
M&P HR SSC	EM	Environmental Protection Specialist (NEPA)	GS	0028	13	Candidate Selection
M&P HR SSC	EM	Industrial Hygienist	GS	0690	13	Candidate Selection
M&P HR SSC	EM	General Engineer or Physical Scientist	GS	0801/1301	13	Candidate Selection
M&P HR SSC	EM	Procurement Analyst	GS	1102	13	Candidate Selection
M&P HR SSC	EM	Env Protect Spec(Permitting and Compliance Manager)	GS	0028	14	Candidate Selection
M&P HR SSC	EM	Program Analyst (Performance Assurance)	GS	0343	14	Candidate Selection
M&P HR SSC	EM	Quality Improvement Specialist	GS	1910	09/11/12	Candidate Selection
M&P HR SSC	EM	Nuclear Engineer	GS	0840	13/14	Candidate Selection
M&P HR SSC	EM	Gen Eng/Physical Scientist FRs	GS	0801/1301	13/14	Candidate Selection
M&P HR SSC	EM	General Engineer (Quality Assurance)	GS	0801	13/14	Candidate Selection
M&P HR SSC	EM	General Engineer or Physical Scientist (FRs)	GS	0801/1301	13/14	Candidate Selection

Servicing HR Office	Org	Position Title	Pay Plan	Occ. Series	Grade	Hiring Process Phase
M&P HR SSC	EM	Nuclear Engineer	GS	0840	13/14	Candidate Selection
M&P HR SSC	EM	Quality Assurance Specialist (Software QA)	GS	1910	13	Job Acceptance
M&P HR SSC	EM	Attorney Advisor (General)	GS	0905	14	Job Acceptance
M&P HR SSC	EM	Lead Equal Employment Specialist	GS	0260	14	Job Acceptance
M&P HR SSC	EM	Health Physicist	GS	1306	15	Job Acceptance
M&P HR SSC	EM	Fire Protection Engineer	GS	0804	14/15	Job Acceptance
M&P HR SSC	EM	Contract Specialist	GS	1102	13	Tentative Job Offer
M&P HR SSC	EM	Health Physicist	GS	1306	13	Tentative Job Offer
M&P HR SSC	EM	Facility Area Engineer	GS	0801	07/09	Tentative Job Offer
M&P HR SSC	EP	Policy Analyst	GS	0301	12/13	Applicant Evaluation
M&P HR SSC	EP	Budget Analyst	GS	0560	13/14	Applicant Evaluation
M&P HR SSC	EP	Policy Analyst	GS	0301	12	Candidate Selection
M&P HR SSC	EP	Policy Analyst	GS	0301	12	Candidate Selection
M&P HR SSC	EP	Policy Analyst	GS	0301	12/13	Candidate Selection
M&P HR SSC	EP	Physical Scientist	GS	1301	13	Entry on Duty
M&P HR SSC	EP	Physical Scientist	GS	1301	13	Job Acceptance
OCEM	EPSA	Chief Operating Officer	ES	0340	00	Entry on Duty
S&E HR SSC	FE	Acquisition Support Assistant (OA)	GS	0303	06	Announcement Open
S&E HR SSC	FE	Supervisory Public Affairs Specialist	GS	1035	14	Announcement Open
S&E HR SSC	FE	Safety & Occupational Health Manager	GS	0018	12/13	Announcement Open
S&E HR SSC	FE	Business Management Specialist	GS	1101	12	Applicant Evaluation
S&E HR SSC	FE	Interdisciplinary: Research General Engineer/Physical Scientist	GS	0801/1301	13	Applicant Evaluation
S&E HR SSC	FE	Executive Assistant	GS	0301	09/11	Applicant Evaluation
OCEM	FE	Process Systems Engineer	EJ	0801	05	Candidate Selection
S&E HR SSC	FE	Accounting Technician (Travel)	GS	525	06	Candidate Selection
S&E HR SSC	FE	Supv General Engineer	GS	0801	15	Candidate Selection
S&E HR SSC	FE	Supervisory Information Technology Specialist	GS	2210	15	Candidate Selection
S&E HR SSC	FE	Administrative Specialist	GS	0301	07/09	Candidate Selection
OCEM	FE	Deputy Director, Science and Technology Strategic Plans and Programs	ES	1301	00	Entry on Duty
S&E HR SSC	FE	Information Technology Specialist (infosec)	GS	2210	12	Entry on Duty
S&E HR SSC	FE	Supervisory Environmental, Safety & Health Specialist	GS	0301	14	Entry on Duty
S&E HR SSC	FE	Purchasing Agent	GS	1105	05/06	Entry on Duty
S&E HR SSC	FE	Environmental Protection Specialist	GS	0028	12/13	Entry on Duty
S&E HR SSC	FE	General Engineer	GS	0801	14	Job Acceptance
S&E HR SSC	FE	Environmental Engineer	GS	0819	14	Job Acceptance
S&E HR SSC	FE	General Engineer	GS	0801	13	Tentative Job Offer
OCEM	GC	Assistant General Counsel for Technology Transfer and Intellectual Propert	ES	905	00	Candidate Selection
M&P HR SSC	GC	Law Clerk	GS	904	09	Job Acceptance
M&P HR SSC	GC	General Engineer	GS	0801	13	Job Acceptance
M&P HR SSC	GC	General Engineer	GS	0801	13	Job Acceptance
M&P HR SSC	GC	Patent Attorney	GS	1222	14	Entry on Duty
M&P HR SSC	GC	Trial Attorney	GS	905	14	Job Acceptance
M&P HR SSC	GC	Attorney-Adviser (Contract)	GS	905	14	Job Acceptance
M&P HR SSC	GC	Attorney-Adviser (Contract)	GS	905	14	Job Acceptance
M&P HR SSC	GC	Trial Attorney	GS	905	15	Entry on Duty
M&P HR SSC	GC	Chief Counsel, Golden Field Office	GS	905	15	Entry on Duty
M&P HR SSC	GC	Attorney-Adviser (Contract)	GS	905	15	Job Acceptance
M&P HR SSC	GC	Paralegal Specialist	GS	0950	09/11	Job Acceptance
M&P HR SSC	HC	Human Resources Specialist (Benefits)	GS	0201	11	Candidate Selection
S&E HR SSC	HC	Human Resources Specialist (Benefits)	GS	0201	11	Candidate Selection
PMA HR SSC	HC	Supvry Human Resources Spclst (Trng/Dvlp)	GS	0201	13	Candidate Selection
PMA HR SSC	HC	Human Resources Specialist (Business Partner)	GS	0201	13	Candidate Selection
M&P HR SSC	HC	Communications Specialist	GS	0301	14/15	Candidate Selection
OCEM	HC	Director, M&P HR Shared Service Cente	ES	0340	00	Entry on Duty
M&P HR SSC	HC	Supervisory Human Resources Specialist	GS	0201	13	Job Acceptance
M&P HR SSC	HG	Supervisory Attorney-Advisor (General)	GS	0905	15	Candidate Selection
OCEM	IA	Deputy Assistant Secretary for Asia and the Americas	ES	0340	00	Entry on Duty
M&P HR SSC	IA	International Relations Specialist	GS	0131	13	Job Acceptance
M&P HR SSC	IM	Information Technology Specialist (SYSADMIN)	GS	2210	14	Candidate Selection

Servicing HR Office	Org	Position Title	Pay Plan	Occ. Series	Grade	Hiring Process Phase
M&P HR SSC	IM	Supervisory IT Specialist	GS	2210	15	Candidate Selection
OCEM	IM	Associate CIO for Strategic Computing	EJ	1550	04	Entry on Duty
M&P HR SSC	IM	Management Analyst	GS	0343	09/11	Entry on Duty
M&P HR SSC	IM	Management Analyst	GS	0343	14	Job Acceptance
M&P HR SSC	IM	Management Analyst	GS	0343	15	Job Acceptance
OCEM	IN	Deputy Director for Cyber Intelligence	ES	0340	00	Announcement Open
M&P HR SSC	IN	Program Analyst	GS	0343	14	Announcement Open
M&P HR SSC	IN	Intelligence Research Specialist	GS	0132	13/14	Announcement Open
M&P HR SSC	IN	Intelligence Operations Specialist	GS	0132	12/13	Entry on Duty
M&P HR SSC	IN	Intelligence Research Specialist	GS	0132	13/14	Entry on Duty
M&P HR SSC	IN	Intelligence Research Specialist	GS	0132	12	Job Acceptance
M&P HR SSC	IN	Procurement Specialist	GS	1101	14	Job Acceptance
M&P HR SSC	IN	Intelligence Research Specialist	GS	0132	14	Job Acceptance
M&P HR SSC	IN	Supervisory, Security Specialist	GS	0080	15	Job Acceptance
M&P HR SSC	IN	Intelligence Research Specialist	GS	0132	12/13	Tentative Job Offer
M&P HR SSC	LM	Quality Assurance Specialist	GS	1910	13/14	Applicant Evaluation
OCEM	LM	DIRECTOR	ES	301	00	Candidate Selection
M&P HR SSC	LM	Reality Specialist	GS	1170	11/12	Candidate Selection
M&P HR SSC	LM	Physical Scientist	GS	1301	12	Job Acceptance
M&P HR SSC	LM	Physical Scientist	GS	1301	13	Job Acceptance
M&P HR SSC	LM	General Engineer	GS	801	13	Job Acceptance
M&P HR SSC	LM	Physical Scientist	GS	1301	13	Job Acceptance
M&P HR SSC	LM	Interdiscipllinary General Engineer/Physical Scientist	GS	801/1301	09/11/12	Job Acceptance
M&P HR SSC	LM	Facility & Personal Property Manager	GS	1101	12/13	Tentative Job Offer
M&P HR SSC	LM	Asset Manager	GS	1101	14/15	Tentative Job Offer
M&P HR SSC	LP	Loan Specialist	GS	1165	09/11	Applicant Evaluation
M&P HR SSC	LP	Loan Specialist	GS	1165	11/12	Applicant Evaluation
M&P HR SSC	LP	Investment/Credit Analyst	GS	1101	11/12	Applicant Evaluation
M&P HR SSC	LP	Loan Specialist	GS	1165	13/14	Applicant Evaluation
M&P HR SSC	LP	General Engineer (Recent Grad)	GS	0801	11	Candidate Selection
M&P HR SSC	LP	Loan Specialist	GS	1165	13/14	Candidate Selection
M&P HR SSC	LP	General Engineer	GS	0801	13/14	Candidate Selection
M&P HR SSC	LP	Attorney-Advisor	GS	0905	15	Job Acceptance
M&P HR SSC	LP	Attorney-Advisor	GS	0905	15	Job Acceptance
M&P HR SSC	LP	Attorney-Advisor	GS	0905	15	Job Acceptance
M&P HR SSC	LP	Loan Specialist	GS	1165	13/14	Job Acceptance
M&P HR SSC	LP	Loan Specialist	GS	1165	13/14	Job Acceptance
M&P HR SSC	MA	Contract Specialist (Team Leader)	GS	1102	14	Applicant Evaluation
M&P HR SSC	MA	Contract Specialist	GS	1102	12/13	Applicant Evaluation
M&P HR SSC	MA	Contract Specialist	GS	1102	12/13	Applicant Evaluation
M&P HR SSC	MA	Facility Ops Specialist	GS	1640	12	Candidate Selection
M&P HR SSC	MA	Contract Specialist	GS	1102	13	Candidate Selection
M&P HR SSC	MA	Supervisory Budget Analyst	GS	0560	14	Candidate Selection
M&P HR SSC	MA	Interdisciplinary	GS	0800	5/7/9/11	Candidate Selection
M&P HR SSC	MA	Contract Specialist (Team Leader)	GS	1102	14	Job Acceptance
M&P HR SSC	MA	Information Technology Specialist	GS	2210	14	Job Acceptance
M&P HR SSC	MA	Procurement Analyst	GS	1102	15	Job Acceptance
M&P HR SSC	MA	Fire Protection Engineer	GS	0804	13/14	Job Acceptance
M&P HR SSC	MA	Supervisory Contract Specialist	GS	1102	15	Tentative Job Offer
M&P HR SSC	MP	Supervisory Human Resources Specialist	GS	0201	13	Candidate Selection
S&E HR SSC	NE	Budget Analyst	GS	560	13	Applicant Evaluation
S&E HR SSC	NE	Nuclear Engineer	GS	840	15	Applicant Evaluation
S&E HR SSC	NE	Contract Specialist	GS	1102	11/12/13	Applicant Evaluation
S&E HR SSC	NE	Records and Information Management Specialist	GS	0308	11/12	Applicant Evaluation
S&E HR SSC	NE	Budget Analyst	GS	0560	12/13	Candidate Selection
OCEM	NE	Deputy Manager, Idaho Operations Office	ES	0340	00	Entry on Duty
S&E HR SSC	NE	Supervisory General Engineer/Physical Scientist	GS	0801/1301	14	Entry on Duty
S&E HR SSC	NE	Attorney-Adviser (General)	GS	0905	13/14	Job Acceptance
OCEM	NNSA	Associate ADA for Defense Nuclear Nonproliferation R&D	ES	1301	00	Candidate Selection

Servicing HR Office	Org	Position Title	Pay Plan	Occ. Series	Grade	Hiring Process Phase
OCEM	NNSA	Director, Regulatory Affairs	ES	0840	00	Entry on Duty
OCEM	NNSA	Director, Information Technology Management	ES	2210	00	Qualifications Review Board
OCEM	NNSA	Director, Advanced Submarine Systems Division	ES	0840	00	Qualifications Review Board
S&E HR SSC	OE	Supervisory Communications Specialist	GS	0301	14	Candidate Selection
S&E HR SSC	OE	Electrical Engineer	GS	850	7/9/11	Tentative Job Offer
M&P HR SSC	PA	Public Affairs Specialist	GS	1035	14	Applicant Evaluation
M&P HR SSC	PA	Administrative Support Specialist	GS	301	13	Job Acceptance
OCEM	SC	Director, Advanced Computing Technologies Division	ES	1301	00	Announcement Open
OCEM	SC	Associate Director, Advanced Scientific Computing Research	ES	1550	00	Announcement Open
S&E HR SSC	SC	Physicist	GS	1310	15	Announcement Open
S&E HR SSC	SC	Physicist	GS	1310	15	Announcement Open
S&E HR SSC	SC	Telecommunications Specialist	GS	0391	12	Applicant Evaluation
S&E HR SSC	SC	Technical Information Specialist	GS	1412	12	Applicant Evaluation
S&E HR SSC	SC	Information Technology Specialist	GS	2210	12	Candidate Selection
S&E HR SSC	SC	Program Analyst (Transportation Safety)	GS	0343	13	Candidate Selection
S&E HR SSC	SC	Physical Scientist	GS	1301	15	Candidate Selection
S&E HR SSC	SC	Chemist	GS	1320	15	Candidate Selection
OCEM	SC	Laboratory Director, New Brunswick Laboratory / Supervisory Physic	EJ	1301	04	Entry on Duty
OCEM	SC	Director, Chemical Sciences, Geoscience, and Bioscience Division	ES	1320	00	Entry on Duty
S&E HR SSC	SC	General Engineer / Physical Scientist	GS	801/1301	14	Entry on Duty
OCEM	SC	Deputy Manager, Oak Ridge Office	ES	0801	00	Qualifications Review Board
PMA HR SSC	SWPA	Human Resources Specialist (ER/LR)	GS	0201	13	Candidate Selection
S&E HR SSC	TT	Senior Communications Specialist (Supervisor)	GS	0301	14	Candidate Selection
S&E HR SSC	TT	Management and Program Analyst (CEIC Senior Advisor)	GS	0343	15	Candidate Selection
PMA HR SSC	WAPA	Power System Dispatcher (Lead/Tech Writer)	AD	0303	05	Announcement Open
PMA HR SSC	WAPA	Real Time Electrical Engineer	AD	850	AD-3/4	Announcement Open
PMA HR SSC	WAPA	Contract Specialist	GS	1102	12	Announcement Open
PMA HR SSC	WAPA	IT Specialist (SysAdmin)	GS	2210	12	Announcement Open
PMA HR SSC	WAPA	IT Specialist (SYSANALYSIS/APPSW)	GS	2210	13	Announcement Open
PMA HR SSC	WAPA	IT Specialist (SYSANALYSIS/APPSW)	GS	2210	13	Announcement Open
PMA HR SSC	WAPA	Supvsry Facility & Property Mngmnt Spclst	GS	1601	13	Announcement Open
PMA HR SSC	WAPA	Vegetation Program Manager	GS	0401	13	Announcement Open
PMA HR SSC	WAPA	Electrical Engineer	GS	0850	13	Announcement Open
PMA HR SSC	WAPA	Sudent Intern (PUS Tech)	GS	1101	03/04	Announcement Open
PMA HR SSC	WAPA	Heavy Equipment Operator	WB	5716	00	Announcement Open
PMA HR SSC	WAPA	EEC - Foreman II	WB	2610	00	Announcement Open
PMA HR SSC	WAPA	Electrician	WB	2810	00	Announcement Open
PMA HR SSC	WAPA	Meter & Relay Craftsman	WB	2610	00	Announcement Open
OCEM	WAPA	CHIEF FINANCIAL OFFICER	ES	0505	00	Applicant Evaluation
PMA HR SSC	WAPA	Maintenance Manager	GS	0340	15	Applicant Evaluation
PMA HR SSC	WAPA	Electrical Engineer	GS	850	05/07	Applicant Evaluation
PMA HR SSC	WAPA	Safety and Occupational Health Specialist	GS	0018	11/12	Applicant Evaluation
PMA HR SSC	WAPA	Power System Dispatcher	AD	303	04	Candidate Selection
PMA HR SSC	WAPA	Real Time Electrical Engineer	AD	0850	03/04	Candidate Selection
PMA HR SSC	WAPA	Accounting Technician	GS	0525	07	Candidate Selection
PMA HR SSC	WAPA	Emergency Management Specialist	GS	0080	12	Candidate Selection
PMA HR SSC	WAPA	IT Specialist (InfoSec)	GS	2210	13	Candidate Selection
PMA HR SSC	WAPA	Supvsry Accountant	GS	0510	13	Candidate Selection
PMA HR SSC	WAPA	EPTC Manager	GS	301	14	Candidate Selection
PMA HR SSC	WAPA	Risk and Reliability Compliance Manager	GS	1101	15	Candidate Selection
PMA HR SSC	WAPA	Public Utilities Spclst	GS	1130	09/11	Candidate Selection
PMA HR SSC	WAPA	Construction Control Rep	GS	809	10/11	Candidate Selection
PMA HR SSC	WAPA	Electrical Engineer	GS	0850	11/12	Candidate Selection
PMA HR SSC	WAPA	Electronic Equipment Craftsman	WB	2610	00	Candidate Selection
PMA HR SSC	WAPA	Electrician CIT	WB	2810	00	Candidate Selection
PMA HR SSC	WAPA	Power System Dispatcher	AD	0303	04	Entry on Duty
PMA HR SSC	WAPA	Power System Dispatcher (Lead/Tech Writer)	AD	303	05	Entry on Duty
PMA HR SSC	WAPA	Financial Program Analyst	GS	0501	12	Entry on Duty
PMA HR SSC	WAPA	Supvy Budget Analyst	GS	0560	13	Entry on Duty

Servicing HR Office	Org	Position Title	Pay Plan	Occ. Series	Grade	Hiring Process Phase
PMA HR SSC	WAPA	Public Utilities Spclst (Portfolio Mngr)	GS	1130	13	Entry on Duty
PMA HR SSC	WAPA	Electrical Engineer	GS	850	05/07	Entry on Duty
PMA HR SSC	WAPA	Lineman	WB	2801	00	Entry on Duty
PMA HR SSC	WAPA	Natural Resources Spclst (NEPA Coord)	GS	0401	12	Job Acceptance
PMA HR SSC	WAPA	Supvry Construction Control Rep	GS	0809	13	Job Acceptance
PMA HR SSC	WAPA	Electrician	WB	2810	00	Job Acceptance
PMA HR SSC	WAPA	Student Trainee (Information Technology)	GS	2299	04	Tentative Job Offer

47. Can you provide a list of outstanding M&O contracts yet to be awarded for all DOE facilities and their current status?

Response: Yes, attached is a list of outstanding M&O contracts yet to be awarded for all DOE facilities and their current status.

DOE/NNSA Management and Operating Contracts

Contract Title	Program	Contractor	Composition of Contractor	Business Model	FY Competed	Award Date	Current Contract End date	Options/Award Term Remaining	Ultimate Potential Contract End Date
National Renewable Energy Laboratory (NREL)	EERE	Alliance for Sustainable Energy (ASE)	Battelle Memorial Institute, MRIGlobal	FFRDC M&O	2008	7/29/2008	9/30/2018		9/30/2018
Idaho National Laboratory (INL)	NE	Battelle Energy Alliance LLC	Battelle Memorial Institute	FFRDC M&O	2005	11/9/2004	9/30/2019		9/30/2019
Pacific Northwest National Laboratory (PNNL)	SC	Battelle Memorial Institute	Battelle Memorial Institute	FFRDC M&O	1965	12/30/2002	9/30/2022		9/30/2022
Brookhaven National Laboratory (BNL)	SC	Brookhaven Science Associates (BSA), LLC	Battelle Memorial Institute, The Research Foundation for The State University of New York Stony Brook University (SUNY RF)	FFRDC M&O	2015	12/22/2014	1/4/2020	14 years Award Term available	1/4/2035
Fermi National Accelerator Center (FNAL)	SC	Fermi Research Alliance, LLC	University of Chicago, Universities Research Association, Inc	FFRDC M&O	2007	11/1/2006	12/31/2019	5 years Award Term available	12/31/2025
Ames Laboratory (Ames)	SC	Iowa State University	Iowa State University	FFRDC M&O	2007	12/4/2006	12/31/2021	5 years Award Term available	12/31/2026
Thomas Jefferson National Accelerator Facility (TJNAF)	SC	Jefferson Science Associates, LLC	Southeastern Universities Research Association (SURA), Inc., Pacific Architects and Engineers (PAE) Applied Technologies, LLC	FFRDC M&O	2006	4/14/2006	5/31/2019	5 years Award Term available	5/31/2024
Lawrence Livermore National Laboratory (LLNL)	NNSA	Lawrence Livermore National Security, LLC	Bechtel National, Univ of California, Babcock & Wilcox, AECOM	FFRDC M&O	2007	10/1/2007	9/30/2019	7 years Award Term available	9/30/2026
Los Alamos National Lab M&O (LANL)	NNSA	Los Alamos National Security, LLC	University of California, Bechtel National, Babcock & Wilcox Technical Services, AECOM	FFRDC M&O	2006	6/1/2006	9/30/2018		9/30/2018
Sandia National Laboratories (Sandia/SNL)*	NNSA	Sandia Corporation	Lockheed Martin Corporation	FFRDC M&O	1994	10/15/1993	4/30/2018		4/30/2018

As of: 12/21/2016

DOE/NNSA Management and Operating Contracts

Contract Title	Program	Contractor	Composition of Contractor	Business Model	FY Competed	Award Date	Current Contract End date	Options/Award Term Remaining	Ultimate Potential Contract End Date
Savannah River Site (SRS) Savannah River National Laboratory (SRNL)	EM/NNSA	Savannah River Nuclear Solutions (SRNS), LLC	Fluor Corporation, Newport News Nuclear, Honeywell International Inc.	FFRDC M&O	2008	1/10/2008	7/31/2018		7/31/2018
SLAC National Accelerator Laboratory (SLAC)	SC	Stanford University	Stanford University	FFRDC M&O	N/A	11/1/1962	9/30/2017		9/30/2017
Lawrence Berkeley National Laboratory (LBNL)	SC	The Regents of the University of California	University of California	FFRDC M&O	2005	4/19/2005	5/31/2020	4 years Award Term available	5/31/2025
Princeton Plasma Physics Laboratory (PPPL)	SC	The Trustees of Princeton University	Princeton University	FFRDC M&O	2009	4/1/2009	3/31/2019		3/31/2019
Argonne National Laboratory (ANL)	SC	UChicago Argonne LLC	University of Chicago	FFRDC M&O	2006	7/31/2006	9/30/2020	6 years Award Term available	9/30/2026
Oak Ridge National Laboratory (ORNL)	SC	UT-Battelle, LLC	University of Tennessee, Battelle Memorial Institute	FFRDC M&O	1999	10/18/1999	3/31/2020		3/31/2020
Bettis/Knolls Atomic Power Laboratory (Bettis KAPL)	NNSA	Bechtel Marine Propulsion	Bechtel National Inc.	M&O non-FFRDC	2009	9/18/2008	9/30/2018		9/30/2018
NNSA Production Office (NPO) Pantex Plant and Y-12 National Security Complex	NNSA	Consolidated Nuclear Security LLC	Bechtel National Inc., Lockheed Martin Services, Inc., ATK Launch Systems, Inc., SOC LLC	M&O non-FFRDC	2012	3/3/2014	6/30/2019	3 Option Periods available (5 years in total)	6/30/2024
Strategic Petroleum Reserve Office (SPRO)	FE	Fluor Federal Petroleum Operations	Fluor Federal Petroleum Operations	M&O non-FFRDC	2014	4/1/2014	3/31/2019	5 year Option Period available	3/31/2024
National Security Complex (formerly Kansas City Plant (KCP))	NNSA	Honeywell Federal Manufacturing & Technologies LLC	Honeywell International Inc	M&O non-FFRDC	2015	7/9/2015	9/30/2020	5 Option Periods available	9/30/2025

As of: 12/21/2016

DOE/NNSA Management and Operating Contracts

Contract Title	Program	Contractor	Composition of Contractor	Business Model	FY Competed	Award Date	Current Contract End date	Options/Award Term Remaining	Ultimate Potential Contract End Date
Nevada National Security Site (NNSS)*	NNSA	National Security Technologies (NSTec) LLC	Northrop Grumman, CH2M Hill, AECOM, Babcock & Wilcox Company	M&O non-FFRDC	2006	3/28/2006	1/31/2017		1/31/2017
Waste Isolation Pilot Plant (WIPP)	EM	Nuclear Waste Partnership LLC	AECOM, BWXT Technical Services Group	M&O non-FFRDC	2012	4/20/2012	9/30/2017	1 year Option Period and 4 year Option Period available	9/30/2022

*NNSA is conducting follow-on acquisitions for Sandia National Laboratories and the Nevada National Security Site. Both are in the pre-award acquisition phase and have not yet been awarded.

As of: 12/21/2016

48. What secretarial determinations/records of decisions are pending?

Response: In terms of National Environmental Policy Act compliance, the term "record of decision" (ROD) applies to the Federal decision made following completion of a Final Environmental Impact Statement (EIS). There is no ROD following completion of an Environmental Assessment. The Department has 2 "pending" decisions, i.e., anticipated RODs in the near term:

1. Mark-18A Target Material Recovery Program at the Savannah River Site --Supplement Analysis (based on 2 EISs) completed in December 2016; Amended ROD anticipated to be issued by EM in January 2017.

2. TransWest Express Transmission Project, WY/CO/UT/NV--Final EIS (DOE and BLM co-leads) issued in May 2015; BLM ROD issued in December 2016; DOE/WAPA ROD anticipated in January 2017.

Information about all ongoing EISs is available in the Status Chart on the NEPA website: www.energy.gov/NEPA and updated monthly. The December 15 edition of the Status Chart showed the Mark18A Amended ROD anticipated in December; it is now anticipated in January. The TransWest ROD was shown as anticipated in January, which is still the case.

49. What should the incoming Administration do to balance risk, performance and ultimately completion in contracting?

Response: In fiscal year 2016, DOE awarded over $30 billion through the issuance of different types of contractual instruments. (b) (5)
(b) (5)

50. What should this Administration do differently to make sure there are the right incentives to attract qualified contractors?

Response: Fundamentally, assuring the integrity of the federal contracting process is key to attracting qualified contractors to invest resources in pursuing government contracting opportunities. Emphasis should be on improving government and industry engagement in the advance planning process to enhance opportunities for industry to provide input on the planned acquisition strategy, including industries' perspectives on the type of contract the government intends to award (e.g., cost-reimbursement or firm-fixed-price), and the kinds of incentives that will be used to drive contractor performance once a contract is awarded. This will also help to facilitate increased confidence by prospective contractors that the government's requirements and performance expectations are clearly defined and understood and that the selected contract type appropriately balances performance risk for both the government and the prospective awardee.

51. Can you provide a list of reports to Congress or other external parties that are due in 2017?

Response: Yes, attached is a list of reports to Congress or external parties that are due in 2017.

List of Reports to Congress or Other External Parties that are Due in 2017 as of December 20, 2016

Assigned Office	Statutory Due Date	Title
AR	3/14/2017	Annual Report, the Director shall provide to the relevant authorizing and appropriations committees of Congress a report describing projects supported by ARPA-E during the previous fiscal year.
AU	12/1/2017	Annual Report on Marshall Islands Medical Program
AU	2/9/2017	Annual Report of the Department of Energy Activities Relating to the Defense Nuclear Facilities Safety Board
AU	2/8/2017	Annual Report on DOE Special Access Programs
BPA	11/30/2017	Annual Report to Congress
CF	2/2/2017	Annual Report on Accounting for Fines and Penalties Imposed on DOE for Violations Involving Mixed Wastes
CF	3/1/2017	Annual Report on Uncosted Obligations/Carryover Balances
CF	12/31/2017	Annual Report to Congress on Laboratory-Directed Research & Development (LDRD) Expenditures
CF	4/2/2017	Annual Report on Homeland Security
CF	4/30/2017 and 9/30/2017	Semi-Annual Pension Report on current plan status, funding ratios, reimbursement levels, projected plan status at budgeted levels, and any updates to funding ratios and contributions with or as supplemental information to the budget request. This information should be updated in April and September of each year.
CF	2/1/2017	[Recurring in future budget justifications] Direction on Centers in Budget Request
CF	1/15/2017	[Quarterly] Sec. 301(b) report on grants under $1M

CF	6/15/2017	[Twice Yearly - Semi Annual Report] Sec. 502 semi-annual report on cross-agency transfers
EA	9/30/2017	Annual Report, the Office of Independent Enterprise Assessments is directed to provide to the Committee an annual report that provides an overview of its oversight activities, findings, and recommendations for the fiscal year.
ED	2/8/2017	Annual Report to the Secretary on the U.S. Department of Energy's Small Business
ED	3/29/2017	Annual Report on Notification and Federal Employee Antidiscrimination and Retaliation Act and the No Fear Act Report
ED	2/17/2017	Annual Report on Service Disabled Veteran Program
EE	8/16/2017	Annual Report to the President and the Congress on Federal Government Energy Management
EE	6/30/2017	Recurring Report (Twice) on evaluation of the success of voluntary commitments to reduce industrial energy intensity
EE	2/5/2017	Semi-Annual Report to Congress Regarding Energy Conservation Standards Activities
EE	12/31/2017	Annual Report on Federal Fleet Compliance
EE	4/4/2017	[One time report - no deadline] Smart Home Electronics Report - Annual
EE	5/26/2017	Annual - Transfer of Study of Electric Rates - Directs the Secretary to appoint a team of technical, policy and financial experts to develop an “energy action plan” for Puerto Rico that includes recommendations on how Puerto Rico can: (1)reduce use of foreign fuels (2)develop & utilize domestic fuel energy sources (3) improve performance of energy infrastructure & overall energy efficiency
EM	11/30/2017	Annual Report on all costs incurred in the previous fiscal year for the program for long-term management and storage of mercury

List of Reports to Congress or Other External Parties that are Due in 2017 as of December 20, 2016

EM	1/1/2017	[Semi-Annual Report] Report on WIPP Budget
EM	6/18/2017	Recurring Report - Not later than one year after enactment of the FY 2016 NDAA and every 180 days thereafter, owner's agent shall submit to the Secretary a report on advice provided by the owner's agent to the Secretary with respect to oversight of contract described in subsection(b). Secretary shall transmit to the congressional defense committees the report and any views he has on the report
FE	4/30/2017	Naval Petroleum Reserves Annual Report
FE	8/30/2017	Annual Report on Strategic Petroleum Reserve
HG	10/25/2017	Annual Report on the Investigations Undertaken of Whistleblower Protection Program Complaints
IG	4/30/2017	Semi-Annual IG Activities Report
IM	3/1/2017	Annual Security Review - FISMA
IM	4/30/2017	Annual Report - Federal Information Technology Acquisition Reform Act (FITARA) Implementation Plan to the Office of Management and Budget (OMB)
LP	4/15/2017	Quarterly Report, the Department is directed to report to the Congress not later than 30 days after enactment of this Act on the status of the Cape Wind conditional commitment. The Department shall updated this report quarterly through fiscal year 2016.
LP	3/30/2017	[Quarterly Report] Cape Wind quarterly report
MA	3/3/2017	Freedom of Information Activities Annual Report to the Department of Justice

List of Reports to Congress or Other External Parties that are Due in 2017 as of December 20, 2016

MA	2/27/2017	Annual Comprehensive Printing Program Plan
MA	7/2/2017	Annual List to OMB on Government Activities Not Inherently Governmental in Nature
MA	11/30/2017	Semi-Annual Commercial Printing Report
MA	4/13/2017	Plain Writing Act of 2010; Plain Language Implementation Plan Annual Compliance Report
MA	1/31/2017	Annual Report - OMB directs DOE to post on it's official website a list of DOE-sponsored conferences from the previous fiscal year where net expenses for the agency were in excess of $100k. For instances where the net expenses for an agency-sponsored conference exceeded $500k, include the agency head's waiver that identified the exceptional circumstances that necessitated exceeding the threshold
MA	6/30/2017	Annual Report - Strategic Sustainability Performance Plan (SSPP) to the White House Council on Environmental Quality and Office of Management and Budget
NNSA	3/2/2017	Annual Report to Congress on the Status of Nuclear Materials Protections, Control, and Accounting (NMPC&A) Program
NNSA	3/11/2017	Annual Report on Stockpile Assessments (ROSA). Report is to be submitted to Congress by the President.
NNSA	2/17/2017	Annual Report on Physical and Cyber Security Technical Management Plans
NNSA	9/30/2017	Annual Report on NNSA's footprint reduction plans, include accounting of the amount of square footage to be added or removed by facility & site. Account for existing banked excess square footage by site. Where facilities add square footage, rationale for enlarging footprint to conduct those operations should be clearly articulated & tied to a priority identified in the Stockpile Stewardship Plan
NNSA	9/30/2017	Annual Report and Certification on Status of the Security of the Nuclear Security Enterprise
NNSA	3/15/2017	Annual Report, Infrastructure Planning.—NR provided a ten-year facilities plan in October 2012, but the plan did not provide a site-by-site description of its real property and infrastructure requirements that were clearly linked to strategic programmatic goals and priorities. Not later than 60 days after enactment of this Act and annually thereafter.
NNSA	2/1/2017	Recurring Report through 2018, Description of Activities conducted by the Director of Cost Estimating and Program Evaluation (CEPE) during the calendar year preceding the submission of the report that are related to the duties and activities described in this section

NNSA	Trigger Report	Annual Report, In fiscal year 2015 and subsequent fiscal years, the Secretary of Energy shall submit to the congressional defense committees (as defined in U.S.C. 25 101(a)(16)) a report, on each major warhead refurbishment program that reaches the Phase 6.3 milestone, that provides an analysis of alternatives.
NNSA	3/1/2017	Recurring Report, Certification as to Plutonium Pit Production
NNSA	3/1/2017	Recurring Report, Certification regarding Phase 1 of UCRP
NNSA	3/1/2017	Recurring Report, Design and Use of Prototypes of Nuclear Weapons for Intelligence Purposes
NNSA	Trigger Report	One-Time Report, Advance notice on B61 LEP - Annual
NNSA	Trigger Report	One-Time Report, Delay for Plutonium Pit Production - Annual
NNSA	Trigger Report	One-Time Report, If delay in plan for Production of Nuclear Warhead for Long range Standoff Weapon - Annual
NNSA	2/1/2017	Recurring Report, 1043 Report
NNSA	2/1/2017	Annual Report - Concurrent with the submission to Congress of the President under section 1105(a) of title 31, United States Code, in each fiscal year, the Administrator shall submit to the congressional defense committees a five-year management for activities associated with the defense nuclear nonproliferation programs of the Administration titled Defense Nuclear Nonproliferation Management Plan
NNSA	3/31/2017	Annual Report - DOD and DOE will prepare and submit to the President an annual Joint Surety Report that assesses - at a minimum - nuclear weapon safety, security, control, emergency response, inspection, and evaluation programs, and the impact of budget constraints on required improvement programs. Report will primarily cover activities of the preceding fiscal year; due annually on March 31. (U)
NNSA	Quarterly - 2/23/2017	[Recurring report, every 90 days] Interagency Review of Applications for the Transfer of United States Civil Nuclear Technology
NNSA	2/1/2017	[Annual Report] Report on Compliance with Export control requirements of Covered Countries and End Users

List of Reports to Congress or Other External Parties that are Due in 2017 as of December 20, 2016

NNSA	2/16/2017	[One Time Report] Material Management and Minimization - Annual
NNSA	9/30/2017	Trigger Report - Notification to Congressional Committees whenever the Secretary or the Administrator terminates the employment of a covered employee or removes and reassigns a covered employee for cause, the Secretary or Administrator as the case may be, shall notify the appropriate congressional committee no later than 30 days after the date of such termination or reassignment - Annual
NNSA	3/1/2017	One-Time Report: NNSA is directed to commission the JASONs Defense Advisory Group to investigate the need for new radiographic capabilities, and determine whether there is adequate planning to justify investing in those capabilities; a report on the findings of the JASONs review shall be provided to the Committees of both Houses of Congress - Annual
NNSA	1/20/2017	One-time and Annually 5 years thereafter Report: Encouraging Reliable Supplies of Molybdenum-99 Produced without Highly Enriched Uranium
NNSA	12/30/2017	FY 2017 Selected Acquisition Reports (SARS)
NNSA	10/31/2017	Annual Report - Receipt and Use of International Contributions.
NNSA	9/30/2017	10 USC 179 requires the Nuclear Weapons Council to prepare a annual strategic plan to the President on the composition of the nuclear weapons stockpile (NWSP). This plan fulfills the requirements stated in the AEA of 1954 and 10 USC 179. The Secretaries of Defense and Energy are required to forward a NWS
NNSA	2/1/2017	ANNUAL REPORT (NOTIFICATION) - Notification of Employee Practices Affecting National Security
NNSA	Trigger Report	Trigger Report: Cost-Benefit Analyses for Competition of Management and Operating Contracts
NNSA	2/15/2017	Implementation of the MOX Facility Construction and Operation Plan

List of Reports to Congress or Other External Parties that are Due in 2017 as of December 20, 2016

NNSA	2/1/2017	Report on Transfers to All Foreign Countries
NNSA	5/25/2017	Annual Report on Transfer of Sensitive Items
NNSA	3/31/2017	Recurring Report (through 2019) Development of Strategy on Risks to Non Proliferation Caused by Additive Manufacturing
NNSA	5/1/2017	Annual Report - FY 2016 Aeronautics and Space Report of the President (NASA is the lead on this report to the President)
NNSA	Trigger Report	If the Secretary elects to establish a microlab pilot program, Report That Provides and Update on the Implementation of the Program
NNSA	Trigger Report	Report on the Microlab Program including findings and recommendations of the Secretary with Respect to the Program
NNSA	Trigger Report	Notification of Cost Overruns and SARs for Major Alteration Projects
NNSA	Trigger Certification	Certification that there is sufficient diversion control and such transfer presents a minimal risk of diversion of civil nuclear technology to a military program that would degrade the technical advantage of the United States
NNSA	Trigger Certification	Certification that a waiver of the prohibition on availability of funds for Development of Certain Nuclear Nonproliferation Technologies is in the national security interests of the United States

List of Reports to Congress or Other External Parties that are Due in 2017 as of December 20, 2016

NNSA	Trigger Report	Report containing notification and justification that a waiver on the prohibition on the availability of funds for provision of defense nuclear nonproliferation assistance to Russian Federation is in the national security interest of the United States
NNSA	Trigger Notification	Treatment of Contractors who engage in improper program management
NNSA	Trigger Notification	Exception
NNSA	Trigger Notification	Root Cause Analyses for Cost Overruns - submit to congressional defense committees an assessment of the root cause or causes of the growth in the total cost of the project
NNSA	Trigger Notification	Waiver on the limitation of payment of bonuses
OE	8/5/2017	Annual Report on study of economic dispatch: how generating facilities operate to produce electric energy at the lowest cost, & whether consumers benefit, in terms of reliability & cost, if non-utilities sell electricity to facilities
OTT	11/29/2017	Annual Report - Secretary shall submit to Congress a technology transfer execution plan; also request a submission of an updated execution plan each year after regarding progress towards meeting goals and funds expended

SC	7/17/2017	Annual Report, The Committee is concerned that the fusion energy program is not taking full advantage of high performance computing to address scientific and technical challenges on the path to fusion energy. The Committee directs the Office of Science to develop a plan on the use of these simulation capabilities based on the results of a 2-year planning effort recently funded by the Department.

Subject
FY12 Appropriation House Report 112-118 (p. 118) 42 U.S.C. §16538(h)(1)
The Palau Compact of Free Association Act of 11/14/86 (PL 99-658), Section104 (K). The statutory deadline is 12/01 annually.
Public Law 99-658, Section 104(k)
Atomic Energy Act of 1954 (PL 83-703, Section 316 (b) as amended by FY89 NDA (PL 100-456); - NDA FY 1991 (PL 101-510); and - for FY 1992 and FY 1993 (PL 102-190)
FY 2000 National Defense Authorization Act, P.L. 106-65, Section 3236, 50 USC, Section 2126
Bonneville Project Act of 1937 as amended (P.L. 75-329); as amended by (P.L. 89-561); as amended by (P.L. 96-501), Sec 4(h)(12)(b); as amended by (P.L. 101-576, Sec 306)
Federal Facilities Compliance Act of 1992 (P.L. 102-386, Section 110)
Energy Policy Act of 10/24/92 (P.L. 102-486, Section 2307(a)) (HR 776)
P.L. 104-201, Section 3136(b)
FY 2004 Energy and Water Development Appropriations (HR) Page 110 (CR) Page 137
FY12 Appropriations Conference Report Explanatory Statement (p. 20, 845)
House FY16 Energy and Water Appropriations Bill, Committee Report 114-91 (p. 79-80) DUE DATE: Not specific. this must be included in "future budget justifications." As such, the due date has been listed for the first day of February, 2017 when the budget normally is about to come out. While the fiscal year 2016 request provided more detail than before for the establishment of new research centers, the Committee expects the Department to provide a more detailed analysis in future requests. The Committee reiterates its previous direction for the Department to explicitly include in future budget justifications for all centers, hubs, institutes, facilities, and any other persistent, location based grantees; their current and proposed funding levels; expected out-year commitments; and details on their programmatic and technical goals.
Consolidated Appropriations Act, 2016, Section 301(b)(2) -- DUE DATE: Within 15 days of the conclusion of each quarter -- [Quarterly Sec. 301(b) report on grants under $1M] Sec. 301(b)(2) The Secretary of Energy shall submit to the Committees on Appropriations of both Houses of Congress within 15 days of the conclusion of each quarter a report detailing each grant allocation or discretionary grant award totaling less than $1,000,000 provided during the previous quarter.

Consolidated Appropriations Act, 2016, Section 502© -- [Sec. 502 semi-annual report on cross-agency transfers]. Sec. 502(c) The head of any relevant department or agency funded in this Act utilizing any transfer authority shall submit to the Committees on Appropriations of both Houses of Congress a semiannual report detailing the transfer authorities, except for any authority whereby a department, agency, or instrumentality of the United States Government may provide goods or services to another department, agency, or instrumentality, used in the previous 6 months and in the year-to-date. This report shall include the amounts transferred and the purposes for which they were transferred, and shall not replace or modify existing notification requirements for each authority.

House Report 113–486 (p.152)

13 CFR Part 125.2 (7) (e) (1) & (2), Page 60013 & 60014; and FAR 19.201(d)(11)(i).

2002 Notification and Federal Employee Antidiscrimination and Retaliation Act, P.L.107-174, Section 203 (a), and 5 CFR, Section 724.302 (No Fear Act)

Executive Order 13360

EO 12902, dtd 3/10/94, Secs 301 (b); 302 (a)(1T)&(b); 305;308 (a&b). Per EPACT (P.L. 104-66. Fed Energy Mgmt Improvement Act (P.L. 100-615 Secs 3 (a&b&d).

FY 2005 Energy Policy Act, Section 106(f)

FY 2005 Energy Policy Act, Section 141(b)

2005 EPACT, Section 701and EO 13423

House FY16 Energy and Water Appropriations Bill, Committee Report 114-91 (p. 88) -- DUE DATE: No specific due date, but DOE is directed to start the study within 8 months of enactment (August 2016). Subsequently, I have set the reporting due date to simply be one (1) year from enactment. -- The Committee directs the Department to work with its partner agencies, industry, and relevant university programs to initiate not later than eight months after the enactment of this Act a study of the potential benefits of ‘‘smart home’’ electronics. [See legislation for further specifics]

Amends Section 9 of the Consolidated and Further Continuing Appropriations Act of 2015 (48 U.S.C. 1492a) - Puerto Rico Oversight, Management, And Economic Stability (PROMESA) Act

Mercury Export Ban Act of 2008, P.L. 110-414, Section 5(c) (Prepare report 60 days after end of each fiscal year.)

List of Reports to Congress or Other External Parties that are Due in 2017 as of December 20, 2016

Senate FY16 Energy and Water Appropriations Bill, Committee Report 114-54 (p. 105) -- DUE DATE: Simply stated as Semi Annual. I have set the first of this series to be due in July such that reports will be due in January and in July each year moving forward. This can likely be changed at the request of the program, but must be discussed with ES, GC, CI, CFO. -- The Committee is disappointed with the lack of a detailed budget to adequately explain and justify the recovery work and ensure that the recovery is not delayed by funding issues. The Committee requests that the Department develop and maintain a detailed budget of the WIPP recovery plan and provide it to the Committee on a semi-annual basis to account for work and needed projects.

House Report 114-270 , Conference Report to accompany H.R. 1735 ---- With respect to the contract between the Office of River Protection of DOE and Bechtel National, Inc. or its successor relating to the Hanford Waste Treatment and Immobilization Plant contract number (DE-AC27-01RV14136) Subsection (d)(1) report- due within 1 year of enactment, and every 180 days thereafter, requires the *owner's agent* to report to the Secretary on advice provided. Subsection (d)(3) report- no due date specified, requires the Secretary to transmit to Congress the report from the owner's agent, along with any views the Secretary has on that report.

An Act to Codify Title 32 of U.S. Code, dtd 8/10/56 (PL 84-1028), Sec 7431(c) amended by Naval Pet. Reserves Production Act (PL 94-258), Sec 201 (13).
Energy Policy and Conservation Act of 12/22/75 (P.L. 94-163), Sec 165(a) amended by Omnibus Budget Reconciliation Act (P.L. 99-509), Sec 3203. ACTION PLAN REC'D.
Conference Report (H.R. 106-301, Sec. 3164 (m), Page 448 and Page 920) to the National Defense Authorization Act for FY 2000 (P.L. 106-60)
Inspector General Act of 10/12/78 (PL 95-452), Section 5(b) as amended by the Inspector General Act Amendments of 10/18/88 (PL 100-504), Section 106(b).
Federal Information Security Management Act (FISMA)
Section 831 of the National Defense Authorization Act for Fiscal Year 2015 (Public Law 113-291)

Omnibus Explanatory Statement, p. 44

FY16 Consolidated Appropriations Act, Explanatory Statement -- The Department is directed to continue to provide to the Committees on Appropriations of both Houses of Congress quarterly reports on the status of the Cape Wind conditional commitment, including an update on ongoing litigation and the risks this litigation poses to the success of the project.

5 U.S.C. 552(e)

List of Reports to Congress or Other External Parties that are Due in 2017 as of December 20, 2016

Joint Committee on Printing letter dated 9/23/85 (no authorization number provided) and letter dated 8/27/87 (JCP# 87197), which approved the annual 2/15 submittal date.

The Federal Activities Inventory Reform Act of 1998 (PL 105-270, Section 2 (a))

Government Printing and Binding regulations, Title IV, Section 49-1

Plain Writing Act of 2010; signed into law on October 13, 2010, requires a Plain Language Implementation Plan Annual Compliance Report

May 11, 2012 Memorandum (M-12-12) to Heads of Executive Departments and Agencies regarding "Promoting Efficient Spending to Support Agency Operations and September 21, 2011 Memorandum (M-11-35) to Heads of Executive Departments and Agencies regarding "Eliminating Excess Conference Spending and Promoting Efficiency in Government"

Goals established under E.O. 13514 " Federal Leadership in Environmental, Energy and Economic Performance," as well as the revised and new goals established under E.O. 13693 "Planning for Federal Sustainability in the Next Decade"

FY 2001 National Defense Authorization Act (Conference Rpt. H.R. 106-945, Section 3171)

FY 2003 National Defense Authorization, P.L. 107-314, Section 3141. Report is to be submitted to Congress by the President.

FY 2008 National Defense Authorization Act, P.L. 110-181, Section 3123

FY12 Appropriations House Report 112-118 (p. 125)

FY 2013, Section 3131(q)(amending section 4521 of the AEDA)

House Report 113-135 (p. 136) Became Public Law 1/17/2014, reporting requirement: 60 days after enactment, then annually thereafter

FY14 NDAA Section 3112

HR 83, Division D, p.484-486

H.R. 3979 FY 2015 NDAA Agreement p 1496
H.R. 3979 FY 2015 NDAA Agreement p 1504
H.R. 3979 FY 2015 NDAA Agreement p 1491

H.R. 3979 FY 2015 NDAA Agreement p 886
H.R. 3979 FY 2015 NDAA Agreement p 1496
H.R. 3979 FY 2015 NDAA Agreement p 1508

FY 12 NDAA
FY 16 NDAA (S. 1356, signed into law as P.L. 114-92) p. 1196-1203

PPD-35 (U) - This directive supersedes the following document, which is hereby rescinded: National Security Presidential Directive (PPD-28)

Every 90 days the Secretary of Energy shall submit to the appropriate congressional committees a report on the transfer of US civil nuclear technology to a covered foreign country in the preceding 90 days -- FY 16 NDAA Conference Report to Accompany S.1356 p. 1214-1223
FY 16 NDAA Conference Report to Accompany S.1356 p. 1214-1223 -- Concurrent with the submission to Congress of the budget of the President. GC has determined that this reporting requirement will be effective for transfers completed since the enactment of the FY 16 NDAA. First report will be due February 1, 2017. -- NA-20

Joint Explanatory Statement to FY 2016 Consolidated Appropriations Act (P.L. 114-113), Division D, H10106 -- Develop and submit a report that includes an evaluation of program risks and lifecycle cost estimate and schedule for the alternative -- NA-20 -- NOTE: There was no specific due date listed in the legislation when received by DOE. The due-date put into eDocs is simply one year (365 days) from the date of input. Should the program determine that more or less time is needed, they must consult with their proper POC in ES as well as with their proper POC in GC to determine if a change in due-date may be allowed.

FY 16 NDAA Conference Report to Accompany S.1356 p. 1154-1162

Draft legislation: H.R. 114-532: No set due date given

National Defense Authorization Act; FY 2013 (Public Law 112-239)

Update to existing SARS legislative: House FY16 Energy and Water Appropriations Bill, Committee Report 114-91 (p. 114)

FY 2007 National Defense Authorization Act, PL 109-163, Section 3114

Atomic Energy Act of 1954 and 10 USC 179

FY 16 NDAA Conference Report to Accompany S.1356 p. 1154-1162 - Due at or about the time that the President's budget is submitted to Congress

FY 13 NDAA (P.L. 112-239), as amended by Section 3124 of the FY 14 NDAA (P.L. 113-66), as amended by FY 16 NDAA Conference Report to Accompany S. 1356 p. 1209-1214

FY 2003 National Defense Authorization Act, Section 3182; incorporated into section 4306(a)(3) of AEDA; (50 U.S.C 2566) NLT February 15 each year, beginning 2004 and continuing for as long as the MOX facility is in use, the Secretary shall submit to Congress a report on the implementation of the plan required by paragraph (1). Each report after 2014 shall address whether the MOX production objective has been met; and assess progress toward meeting the obligations of the United States under the PMDA.

Concurrent with the submission to Congress of the budget of the President. GC has determined that this reporting requirement will be effective for transfers completed since the enactment of the FY 16 NDAA. First report will be due February 1, 2017. * Report may be waived if the Secretary determines an imminent radiological hazard exists and NLT 7 days after such determination submits a certification of that hazard, justification for the waiver and notification required by clause (i) of subparagraph (A) and the statement required by clause (ii) of that subparagraph. * The Secretary of Energy shall submit a report of intention to make the authorization for the transfer of such technology and a statement of whether any agency required to be consulted objected or sought conditions on the transfer. Due NLT 14 days before making an authorization.
FY 16 NDAA Conference Report to Accompany S.1356 p. 1214-1223 - NLT than 180 days after the date of the enactment of this Act, and annually thereafter, the President shall submit to the appropriate congressional committees a report describing the efforts of covered foreign countries to prevent the transfer of sensitive items, including efforts to improve the prevention of the transfer of such items and assessing the adequacy of such efforts
P.L. 114-92, FY 16 NDAA, Sec., 3139 - The President shall develop and pursue a strategy to address the risks to the goals and policies of the United States regarding nuclear nonproliferation that are caused by increased use of additive manufacture technology, including such technology that does not originate in the United States. NLT than March 31, 2016, and the end of each 120 day period thereafter through January 1, 2019, the President shall provide a briefing on the strategy developed
Sec. 206, P.L. 85-568, 72 Stat., 426. - Collaboration with NASA to provide to Congress a description of the programmed activities and the accomplishments of all agencies of the United States in the field of aeronautics and space activities.
FY 16 NDAA Conference Report to Accompany S.1356 p. 1184-1187 - NLT 120 days after implementation of the program
FY 16 NDAA Conference Report to Accompany S.1356 p. 1184-1187 - NLT One Year after the date of implementation of the program
FY 16 NDAA Conference Report to Accompany S.1356 p. 1168-1170 - NLT 30 days after establishing a cost and schedule baseline for each major alteration project
H. 1735 (H.R. 114-102)p. 385-386 - NLT than 14 days prior to the approval of any part 810 authorization for a covered foreign country
H. 1735 (H.R. 114-102) p. 386 - 15 days prior to carrying out the waiver.

FY 16 NDAA Conference Report to Accompany S.1356 p. 1187-1188 - Requires a period of 15 days to elapse following the date on which the Secretary submits the report.

If the Secretary of Energy or the Administrator determines that a covered contractor engaged in improper program management that resulted in a notification under section 4713 of the Atomic Energy Defense Act or significantly and detrimentally affected the cost, scope, or schedule associated with tithe approval of critical decision 3 in the acquisition process for a project, the Secretary or the Administrator, as the case may be, shall submit to the appropriate congressional committees an explanation as to whether termination of the contract is an appropriate remedy; a description of the terms of the contract regarding award fees and performance; and a description of how the Secretary or the Administrator, as the case may be, plans to exercise options under the contract.

P.L. 114-92, FY 16 NDAA, Sec., 3247 (b) - If the Secretary or the Administrator is not able to submit the information described in Sec., 3246 (a)(1-3) by reason of a contract enforcement action, the Secretary or the Administrator, as the case may be, may submit a notification of such contract enforcement action and the date on which the Secretary or the Administrator plans to submit the information described in Sec., 3247(a)(

P.L. 114-92, FY 16 NDAA, Sec., 3114 - Amends Section 4713(c) of the AEDA, as amended by section 3113. Adds, "submit to the congressional defense committees an assessment of the root cause or causes of the growth in the total cost of the project, including the contribution of any shortcomings in cost, schedule, or performance of the program, including the role, if any, of unrealistic performance expectations; unrealistic baseline estimates for cost or schedule; immature technologies or excessive manufacturing or integration risk; unanticipated design engineering manufacturing or technology integration issues arising during program performance; changes in procurement quantities; inadequate program funding or funding instability; poor performance by personnel of the Federal Government or contractor personnel responsible for program management; or any other matters.

P.L. 114-92, FY 16 NDAA, Sec., 3246 - The Secretary or the Administrator, as the case may be, may waive the limitation on the payment of a bonus on a case-by-case basis, if the Secretary or the Administrator, as the case may be, notifies the appropriate congressional committees of such waiver, and a period of 60 days elapses following such waiver.

FY 2005 Energy Policy Act, Section 1234

EPACT2005 Sec. 1001(e)(1)

Senate Report 113-47 (p.95)

Offices of Inspectors General
Statutorially Required Reports to Congress/OutSide Entities

Date	Statute	Title	Requirements	Associated Report(s)
1978	Public Law 95-452	Inspector General Act of 1978	The Inspector General Act provides the ***Office of Inspector General*** with the statutory authority to conduct audits and investigations of fraud, waste, and abuse of agency programs and operations.	Semiannual Report to Congress (Issued April and November)
1994	Public Law 103-356	Government Management Reform Act (GMRA) of 1994	The purpose of GMRA is to provide a more effective, efficient, and responsive government through a series of management reforms primarily for Federal human resources and financial management. The Act requires that all major Federal departments and agencies prepare a financial statement covering all accounts and associated activities of each office, bureau, and activity of the agency. The statement should conform to OMB guidance, and it should be audited by the agencies ***Office of Inspector General*** . The statement should reflect: the overall financial position of the offices, bureaus, and activities covered by the statement, including assets and liabilities thereof; and results of operations of those offices, bureaus, and activities. The majority of audit costs are funded by the Department, but the OIG provides technical oversight of the contract auditors.	Audit of the Department of Energy's Fiscal Year XXXX Consolidated Financial Statements Audit of the Fiscal Year XXXX Financial Statements of the Federal Energy Regulatory Commission Audit of the Fiscal Year XXXX Financial Statements of the Nuclear Waste Fund Audit of the Fiscal Year XXXX Combined Financial Statements of the Southwestern Federal Power System Audit of the Fiscal Year XXXX Combined Financial Statements of the Western Area Power Administration Management Letter on the Audit of the Department's Consolidated Financial Statements for Fiscal Year XXXX
2000	Public Law 106-531	Reports Consolidation Act of 2000	Annually, the ***Office of Inspector General*** summarizes what the OIG considers to be the most serious management and performance challenges facing the agency and briefly assesses the agency's progress in addressing those challenges.	Management Challenges at the Department of Energy - Fiscal Year XXXX
2010	Public Law 111-204	Improper Payments Elimination and Recovery Act of 2010 (amended Improper Payments Information Act of 2002)	The ***Inspector General*** of each agency shall determine annually whether the agency is in compliance with the Act and issue a report on that determination.	Audit of the Department of Energy's Improper Payment Reporting in the Fiscal Year XXXX Agency Financial Report
2010	Public Law 111-258	Reducing Over-Classification Act	The ***Inspector General*** of each department or agency of the United States with an officer or employee who is authorized to make original classifications, in consultation with the Information Security Oversight Office, shall carry out no less than two evaluations of that department or agency or a component of the department or agency— (A) to assess whether applicable classification policies, procedures, rules, and regulations have been adopted, followed, and effectively administered within such department, agency, or component; and (B) to identify policies, procedures, rules, regulations, or management practices that may be contributing to persistent misclassification of material within such department, agency or component.	Completed the first review entitled, "Review of Controls Over Department's Classification of National Security Information" and are currently conducting the second mandated review, entitled "Follow-up Review of Controls Over Department's Classification of National Security Information".
2012	Public Law 112-194	Government Charge Card Abuse Prevention Act of 2012	The ***Inspector General*** of each executive agency with more than $10M in travel card spending shall conduct periodic audits or reviews of travel card programs to analyze risks of illegal, improper, or erroneous purchases and payments. The findings of such audits or reviews along with recommendations to prevent improper use of travel cards shall be reported to the Director of the Office of Management and Budget and Congress. The ***Inspector General*** of each executive agency with more than $10M in purchase card spending shall submit a joint report with the agency to OMB on a semiannual basis of on violations of the purchase card program and actions taken as a result of the violations.	Complete the annual risk assessment and issue memo to OMB by the end of January each year covering the prior FY. The memo will state whether the risk assessment resulted in the need to perform an audit in the following FY.
2014	Public Law 113-101	Digital Accountability and Transparency Act of 2014	The ***Inspector General*** will review a statistically valid sampling of the spending data submitted under the Act by the agency and issue a report every other year assessing the completeness, timeliness, quality, and accuracy of the data sampled and the implementation and use of data standards by the agency.	The required date to issue this report has been delayed until November 2017. OIG issued an interim report on the Department's DATA Act readiness in November 2016.
2014	Public Law107-347	Federal Information Security Modernization Act of 2014	FISMA directs Federal agencies to conduct annual IT security reviews and ***Inspectors General*** (IGs) to perform annual independent evaluations of agency programs and systems and report their results to OMB and Congress.	The Department of Energy's Unclassified Cybersecurity Program - XXXX Federal Energy Regulatory Commission's Unclassified Cybersecurity Program - XXXX Information Technology Management Letter on the Audit of the Department of Energy's Consolidated Balance Sheet for Fiscal Year XXXX

Date	Statute	Title	Requirements	Associated Report(s)
2015	Public Law 114-53	Cybersecurity Act of 2015	Not later than 240 days after the date of enactment of this Act, the ***Inspector General*** of each covered agency shall submit to the appropriate committees of jurisdiction in the Senate and the House of Representatives a report, which shall include information collected from the covered agency for the contents regarding the Federal computer systems of the covered agency. Not later than 2 years after the date of the enactment of this Act and not less frequently than once every 2 years thereafter, the ***Inpsector General*** shall jointly submit to Congress an interagency report on the actions of the executive branch to carry out this title during the most recent 2-year period.	Initial report issued August 2016. The first biennial report will be issued in December 2017.

52. How can the DOE support existing reactors to continue operating as part of the nation's infrastructure?

Response: (b) (5)

(b) (5)

(b) (5)

53. What can DOE do to help prevent premature closure of plants?

Response: In May 2016, DOE convened a meeting of experts and stakeholders to discuss the economic challenges facing the existing nuclear fleet and the unintended consequences that could arise from premature plant closures. At the meeting, DOE identified potential policy options that can be pursued at federal and state levels to address these concerns, as well as technical options that utilities can use to improve the economic competitiveness of operating nuclear power plants. A summary report, as well as, a cost gap analysis are available at https://gain.inl.gov. From these interactions, DOE has two clear roles – development of technology to improve the economics of operating plants and technical assistance to develop and implement policies to enable the continued operation of the existing fleet.

As identified in the report, DOE can support research and development, jointly with industry, that can improve the performance and economics of the existing fleet. DOE currently has work ongoing in this area under the Light Water Reactor Sustainability Program, the Consortium for Advanced Simulation of Light Water Reactors (CASL), and associated with accident tolerant fuels that should result in improved economics for the existing fleet. However, much of this work is not expected to provide realized cost reductions in the next year or two.

As identified in the report and demonstrated by both Illinois and New York, much of the direct actions to prevent premature closure of plants rests outside DOE. DOE can though provide technical assistance to stakeholders that are addressing premature closures. DOE's systems analysis capabilities can be used to support the continued efficient operation of the existing fleet. Through this work, the value of the nuclear fleet to the stability and security of the energy sector and the economy of the United States can be assessed and recommendations developed to support continued operation of the existing fleet and further expansion of the technology. Technical assistance of this type, including potential policy recommendations, can be provided to states, the Federal Energy Regulatory Commission (FERC), and other policy makers.

Potential actions under consideration by states include power purchase agreements, tax credits, and clean energy standards. FERC is working on reconsideration of price formation—or how electricity prices are established to balance supply and demand. Improved price formation could ultimately help appropriately price the value nuclear plants offer, which could in turn help their economics. DOE can facilitate multiagency interactions and provide technical assistance to enable the development and implementation of policies at the state and federal level to ensure the continued efficient operation of the existing fleet.

54. How do you recommend continuing to supporting the licensing of Small Modular Reactors?

Response: The Department has been supporting the design development, certification, and licensing of Small Modular Reactor (SMR) technologies since 2012 by providing financial assistance awards (cost sharing) to industry partners focused on the near-term deployment of these safe, innovative reactor designs. The SMR Licensing Technical Support (LTS) program has been instrumental in accelerating the regulatory maturity of SMRs by supporting the completion of design certification and site licensing applications for the most promising designs and for the utility customers most likely to build SMR power into their clean energy portfolios. The Department's funding is currently focused on the NuScale Power SMR design, and also in support of site permitting and licensing actions being conducted by the Tennessee Valley Authority and Utah Associated Municipal Power Systems. Applications for all three projects are expected to be in the review process with the Nuclear Regulatory Commission by the end of 2017, or soon after. Fiscal Year 2017 will be the final year of SMR LTS program funding. While much will have been accomplished through the Federal investment to date, significant additional work will remain to complete the regulatory approvals, finalize the NuScale SMR design, and address the challenges for commercialization.

To assure that our nuclear industry is capable of achieving an appropriate level of economic competitiveness and commercial viability for domestic SMR technologies, the Department has been examining the potential for a follow-on program to assist industry to ultimately deploy the first SMRs in the U.S. DOE held an industry-focused workshop in June 2016 to elicit stakeholder opinions on where Department investment in SMRs would most effectively impact SMR commercialization (http://energy.gov/ne/downloads/doe-smr-workshop-pathway-smr-commercialization). Potential areas of investment identified as a result of the workshop included: 1) finalizing the SMR designs with the most direct line-of-sight to commercialization; 2) supporting combined construction and operating licenses for additional interested utilities; 3) conducting research, development and demonstration on fabrication technologies that have the highest potential to improve quality, cost and schedule for the output of SMR parts and components; and, 4) demonstrating enhanced market applications for SMRs. Taken in total, these activities would serve to develop the domestic SMR enterprise by incentivizing multiple SMR vendors and the factories required to supply major components. Such a program could provide the most direct path to assuring the safest, most secure, and economical SMR technologies are commercially available to both domestic and international utility customers for operation within the next decade, helping the U.S. to achieve our nuclear safety, economic, energy security goals.

In addition to support for design development, certification and licensing, and future potential follow-up programs to assist industry, Title XVII of the Energy Policy Act of 2005 (EPACT) authorized the DOE to issue loans or loan guarantees to nuclear power facilities including those that plan to utilize Small Modular Reactors. SMRs projects are consider eligible under Title XVII because nuclear power emits no greenhouse gases during operations and SMRs are not yet commercially deployed. The state-of-the-art design improvements that include areas of fuel technology, thermal efficiency, modularized construction, safety systems, and standardized design meet the "new and innovative technology" requirements of EPACT Title XVII and 10CFR609 - Loan Guarantees for Projects That Employ Innovative Technologies. DOE clarified that SMRs are eligible technologies when the "Advanced Nuclear Energy Project Solicitation" was issued on December 10, 2014 (https://energy.gov/sites/prod/files/2015/12/f27/DOE-LPO_ADV-NUCLEAR_Solicitation_10-Dec-2014.pdf) that made up to $10.5 billion available for SMR commercialization. Responding to industry requests for further clarifications, the "Second Supplement to the Loan Guarantee Solicitation Announcement" (https://energy.gov/sites/prod/files/2015/12/f27/DOE-LPO_ADV-NUCLEAR_Supplement-02_06-Nov-2015.pdf) was issued on November 6, 2015. The supplement clarified that projects could apply while under NRC licensing review and inserted a new Section IID "Early Upstream and Engineering Project Costs". The new section provided examples of development, permitting and engineering costs that could be eligible cost under a loan guarantee. The DOE's authority to make loans or loan guarantees is provided the Omnibus Appropriations Act, 2009, P.L. 111-8, as amended by Section 408 of the Supplemental Appropriations Act, 2009, P.L. No. 111-32 and the $10.5 billion is available until expended and this supports the long development cycles needed for nuclear projects. "

55. How best can DOE optimize its Advanced Reactor R&D activities to maximize their value proposition and work with investors to development and commercialize advanced reactors?

Response: DOE is optimizing Advanced Reactor R&D activities by focusing on accelerating the deployment of advanced reactor systems and directly addressing the technology and regulatory risks of the advanced reactor developers. The vision and strategy for this effort has been documented (http://www.energy.gov/ne/downloads/draft-vision-and-strategy-development-and-deployment-advanced-reactors) and feedback solicited from key stakeholders. This strategy includes the accelerated goal to be ready for deployment of advanced technologies by the early 2030s.

DOE accomplishes its mission through a number of methods, including specific private-public cost-shared partnerships, which leverage taxpayer resources with private sector funding. Recently, the Gateway for Accelerated Innovation in Nuclear (GAIN) initiative was established to provide the nuclear community with access to the technical, regulatory, and financial support necessary to move innovative nuclear energy technologies toward commercialization while ensuring the continued safe, reliable, and economic operation of the existing nuclear fleet. The GAIN initiative seeks to assist industry, academia and the entire nuclear technology development stakeholder community to address market and investment challenges by facilitating easier access to the experimental and computational capabilities, technical expertise, and knowledge of DOE National Laboratories to accelerate innovation and bring new U.S. technologies to market.

DOE is addressing the investment challenges by providing the nuclear community with a single point of access to the broad range of capabilities -- people, facilities, materials, and data -- across the DOE complex and its National Laboratories capabilities. However, there are challenges:

- the facilities needed to conduct the necessary research, development, and demonstration activities are very expensive to develop and maintain
- technology readiness levels vary among designers, requiring differing research and funding opportunities
- the regulatory process is uncertain for new nuclear technologies, and
- strong coordination between federal agencies, the research community, and technology developers has been lacking and is required to reach commercialization.

Thus, focused research opportunities and dedicated industry engagement are important components of DOE's Advanced Reactor Vision and Strategy and the GAIN initiative, ensuring that DOE-sponsored activities are impactful to companies working to realize the full potential of nuclear. GAIN integrates and facilitates efforts by private industry, universities and government research institutions to test, develop and demonstrate advanced nuclear technologies to accelerate the licensing and commercialization of these systems.

DOE is also working with the Nuclear Regulatory Commission to establish a reliable and efficient approach for licensing advanced reactor technologies. Uncertainty regarding the licensing process, timeframe and cost is one of the most significant risks facing investors or customers in deciding whether or not to deploy advanced nuclear technologies. In addition, GAIN expands upon this work by assisting technology developers through the regulatory process.

DOE also utilizes various advisory committees that include senior leaders in government, academia, industry, and the investment community to assess our goals, activities and priorities and provide recommendations that further enhance our ability to deliver the right technology solutions at the right time to meet market needs.

56. What is the Department's role with respect to JCPOA? Which office has the lead for the Department?

Response: DOE's role is to provide technical support and analysis throughout implementation of the JCPOA to help ensure that Iran carries out its commitments. NNSA, through NNSA's Office of Defense Nuclear Nonproliferation, has the lead for the Department. For example, NNSA participates in a U.S. interagency working group that supports the U.S. role in the JCPOA procurement channel by evaluating proposed nuclear-related transfers to Iran's nuclear and non-nuclear civilian industries. NNSA also provides technical expertise, equipment, and training to support the IAEA's ability to monitor implementation of the JCPOA. DOE will provide technical support and review of the modernized reactor design for the Arak facility to ensure that it conforms to the key attributes and characteristics of the modernized reactor as set forth in the JCPOA.

57. Can you provide a copy of any Participation Agreement under Section 1221 of EPAct signed by the Department?

Response: There are no Participation Agreements under Section 1221. However, the Participation Agreement under Section 1222 for the Plains and Eastern Clean Line Project is attached.

PARTICIPATION AGREEMENT

among

THE UNITED STATES DEPARTMENT OF ENERGY

and

PLAINS AND EASTERN CLEAN LINE HOLDINGS LLC,

ARKANSAS CLEAN LINE LLC,

PLAINS AND EASTERN CLEAN LINE OKLAHOMA LLC

and certain of their Affiliates (as set forth herein)

dated as of March 25, 2016

Table of Contents

LIST OF SCHEDULES

PARTICIPATION AGREEMENT

This PARTICIPATION AGREEMENT (this "Agreement"), dated as of March 25, 2016, is entered into by and among the UNITED STATES DEPARTMENT OF ENERGY (the "Department" or "DOE"), PLAINS AND EASTERN CLEAN LINE HOLDINGS LLC, a limited liability company organized under the laws of the State of Delaware ("Holdings"), ARKANSAS CLEAN LINE LLC, a limited liability company organized under the laws of the State of Delaware ("ACL"), PLAINS AND EASTERN CLEAN LINE OKLAHOMA LLC, a limited liability company organized under the laws of the State of Oklahoma ("PECL OK"), OKLAHOMA LAND ACQUISITION COMPANY LLC ("OLA"), a limited liability company organized under the laws of the State of Delaware, and, solely to the extent that any of the provisions set forth herein apply to the Clean Line Parties (as opposed to the Clean Line Entities, Holdings or any of the Project Subsidiaries), PLAINS AND EASTERN CLEAN LINE LLC, a limited liability company organized under the laws of the State of Arkansas ("PECL"). Capitalized terms used herein shall have the meanings set forth for such term in Section 1.1 of this Agreement.

RECITALS

WHEREAS, pursuant to Section 1222 of the Energy Policy Act of 2005 ("Section 1222"), the Secretary of the Department, acting through the Southwestern Power Administration ("SWPA"), has the authority to design, develop, construct, operate, maintain, own or otherwise participate with other Persons in designing, developing, constructing, operating, maintaining or owning new electric power transmission facilities and related facilities within any state in which SWPA operates and to accept third party funding for these purposes.

WHEREAS, pursuant to its authorities under, and in reliance upon, Section 1222, the Department is participating with the Clean Line Entities in the design, development, construction, operation, maintenance and ownership, as applicable, of approximately 705 miles of +/-600 kilovolt overhead, high voltage direct current ("HVDC") electric transmission facilities and related facilities with the capacity to deliver approximately 4,000 megawatts ("MW") (net) from renewable energy generation facilities located in the Oklahoma Panhandle and Texas Panhandle regions to the eastern state-line of Arkansas near the Mississippi River (the "Arkansas Connection Point") (collectively, the "Project").

WHEREAS, the Project shall include: (a) an AC/DC converter station and related facilities located in Texas County, Oklahoma (the "Converter Station Facility"), (b) an AC collection system of up to six AC transmission lines located in the Oklahoma Panhandle (the "AC Collection System"), (c) an intermediate AC/DC converter station and related facilities located in Pope County, Arkansas (the "Intermediate Converter Station") and (d) all transmission lines (including all structures and wires and related components) running from the Converter Station Facility to the Arkansas Connection Point and the AC transmission lines interconnecting the Converter Station Facility to the transmission system under the operational control of the Southwest Power Pool, Inc. ("SPP") and the Intermediate Converter Station to the transmission system under the operational control of the Midcontinent Independent System Operator ("MISO") (collectively, the "Transmission Line Facilities" and together with the Converter Station Facility, the AC Collection System, the Intermediate Converter Station and related facilities, the "Project Facilities"). The Project Facilities located in Oklahoma are hereinafter referred to as the "OK Facilities" and the Project Facilities located in Arkansas are hereinafter referred to as the "AR Facilities." The Project Facilities include all temporary and permanent structures, wires and related components in respect of the Project.

WHEREAS, the Clean Line Parties are separately developing transmission and related facilities in Tennessee that will interconnect with the Project at the Arkansas Connection Point and may develop facilities in the Texas Panhandle that would interconnect with the Project at the Texas-Oklahoma state-line.

WHEREAS, on June 10, 2010, the Department published a *Request for Proposals for New or Upgraded Transmission Line Projects Under Section 1222 of the Energy Policy Act of 2005* (75 Fed. Reg. 32940) (the "RFP") in the Federal Register. In July 2010, Clean Line Energy Partners LLC ("CLEP"), a limited liability company organized under the laws of the State of Delaware, submitted a proposal relating to the Project in response to the RFP and submitted a revised proposal in August 2011. In April 2012, the Department determined that CLEP's proposal was responsive to the RFP, and subsequently, on September 20, 2012, the Department and SWPA entered into an Advance Funding and Development Agreement (the "AFDA") with CLEP, PECL and PECL OK, which, among other things, provides for advance funding by CLEP, PECL and PECL OK to the Department and SWPA to commence necessary environmental reviews and other due diligence activities in order to assess whether the Project meets the criteria specified by Section 1222.

NOW, THEREFORE, in consideration of the mutual covenants contained herein and other valuable consideration, the receipt, adequacy and sufficiency of which are hereby acknowledged, the Parties hereto, intending to be legally bound, do hereby agree as follows:

ARTICLE I
DEFINED TERMS AND DEFINITIONS

1.1 Defined Terms. For purposes of this Agreement, the following words and expressions when initially capitalized shall have the meaning assigned to them below.

"Abandonment" means that (a) prior to the occurrence of Project Completion, development activities and construction activities (if construction has begun) in respect of the Project shall have ceased for any reason, other than as a result of the occurrence of Force Majeure or a Governmental Order that requires cessation of activities until compliance with the Governmental Order is achieved and the Clean Line Entity subject to such order is diligently pursuing compliance, for a period of ninety (90) consecutive days, (b) from and after the occurrence of Project Completion, the Project shall have ceased to operate, other than as a result of the occurrence of Force Majeure, for a period of ninety (90) consecutive days, or (c) at any time any Clean Line Entity shall have publicly declared that it intends not to continue with the development, design, engineering, construction, financing, ownership, operation, maintenance and management of the Project for any reason other than the occurrence of Force Majeure.

"AC" means alternating current.

"AC Collection System" has the meaning set forth in the recitals.

"Acceptable Counterparty" means any Person that either (a) owns and operates a renewable power generating facility located in any, all or some of the Oklahoma and Texas Panhandle regions and the State of Arkansas or (b) is a purchaser of renewable energy that is being delivered by the Project.

"Acceptable Form" means, with respect to any letter of credit, Guarantee, commitment, undertaking or other Contractual Obligation, that such letter of credit, Guarantee, commitment, undertaking or other Contractual Obligation is in form and substance reasonably acceptable or satisfactory to DOE; provided that it would be unreasonable for DOE not to accept or be satisfied with any such letter of credit, Guarantee, commitment, undertaking or other Contractual Obligation for purposes of satisfying any requirement, condition or other matter set forth in this Agreement to the extent such letter of credit, Guarantee, commitment, undertaking or other Contractual Obligation (a) is on customary market terms (to be determined taking into account the purpose for which such letter of credit, Guarantee, commitment, undertaking or other Contractual Obligation is being delivered or required under the terms of this Agreement), (b) does not contain any conditions precedent to any Person's obligations thereunder that could not reasonably be anticipated to be satisfied on a timely basis, (c) in the case of any Project Equity Commitment or Project Financing Commitment, such commitment is not predicated on the satisfaction of any general due diligence condition precedent, and (d) does not contain any unusual termination provisions (whether taking the form of an event of default, termination event, an event that gives rise to a right of acceleration or in any other form that gives rise to any of the foregoing) that could reasonably be anticipated to give rise to a termination of such letter of credit, Guarantee, commitment, undertaking of other Contractual Obligation or an acceleration of any applicable Clean Line Parties' obligations thereunder (excluding a termination based on a reasonable sunset date or date certain that in either case is consistent with the Project Schedule).

"Acceptable Guarantee" means an unconditional, irrevocable, direct-pay guarantee (a) that (i) is denominated in Dollars, (ii) provides that DOE is the beneficiary thereof, (iii) is issued by an Acceptable Support Provider, (iv) requires the issuer thereof to have waived all rights to make any claim against any Clean Line Party, DOE or the Collateral, whether for costs of maintaining the guarantee or reimbursement of amounts paid under the guarantee, or otherwise, and none of the Clean Line Parties shall be required to pay any fee to such issuer in respect of the issuance of such guarantee, in each case, except out of cash available for equity distributions or dividends to holders of Equity Interests in Holdings, (v) entitles DOE to make a demand for payment thereunder as contemplated by this Agreement, including under the circumstances contemplated by Section 11.5(a) and (vi) is otherwise in an Acceptable Form (including with respect to representations, covenants and requirements relating to posting of collateral support in instances where the issuer thereof ceases to be an Acceptable Support Provider) and (b) as to which DOE has received (i) such financial statements in respect of the issuer thereof as requested by DOE, (ii) customary legal opinions with respect to capacity, authority and enforceability of such guarantee and as to such other matters as reasonably requested by DOE from legal counsel acceptable to DOE, and (iii) corporate documents, resolutions, copies of any necessary consents and approvals and customary certificates by and in respect of the issuer thereof as reasonably required by DOE.

"Acceptable Letter of Credit" means an unconditional, irrevocable, direct-pay letter of credit that (a) is denominated in Dollars, (b) is issued in favor of DOE by an Acceptable Support Provider, (c) meets each of the following requirements and (d) is otherwise in Acceptable Form:

(i) the initial expiration date thereof shall be at least twelve (12) months beyond the date of issuance, and shall automatically renew upon its expiration (which renewal period shall be for at least twelve (12) months) unless, at least forty-five (45) days prior to any such expiration, the issuer thereof shall provide DOE with a notice of non-renewal of such letter of credit;

(ii) upon any failure to renew such letter of credit at least thirty (30) days prior to such expiration date, or if the issuer of such letter of credit shall cease to be an Acceptable Support Provider, the entire face amount thereof shall be drawable by DOE;

(iii) such letter of credit shall be drawable by DOE as contemplated by this Agreement, including under the circumstances contemplated by Section 11.5(a);

(iv) no Contractual Obligation executed or delivered in connection with such letter of credit shall provide the issuer thereof or any other Person with any claim against any Clean Line Party, DOE, or the Collateral, whether for costs of maintenance, reimbursement of amounts drawn under such letter of credit or otherwise (except if such letter of credit is provided as part of the Project Financing pursuant to the Project Financing Documents);

(v) such letter of credit shall be payable immediately, conditioned only on written presentment from DOE to the issuer thereof of a sight draft drawn on such letter of credit and a certificate stating that DOE has the right to draw under such letter of credit in the amount of the sight draft without the requirement to present the original letter of credit; and

(vi) such letter of credit shall allow for multiple draws.

"Acceptable Permitted Project Investment Commitment" means a binding Contractual Obligation entered into by one or more of the Clean Line Entities with an Acceptable Counterparty pursuant to which such Acceptable Counterparty has committed to make a Permitted Project Investment for fair market value in order to have the right to use a portion of the Electrical Capacity for the transmission of power from renewable energy sources related to such Acceptable Counterparty's purchase or sale of renewable energy or to enter into Acceptable Transmission Services Agreements with other third parties; provided that the obligation of such Acceptable Counterparty to make the applicable Permitted Project Investment shall only be subject to the satisfaction of the conditions precedent set forth on Part A of Schedule 14 hereto or shall otherwise be in an Acceptable Form.

"Acceptable Support Provider" means a Person that meets the following criteria:

(a) in the case of an Acceptable Letter of Credit or letter of credit provided in connection with any Project Equity Commitment, such Person (i) is either (A) a bank with a branch or representative office in New York, New York and is organized under or licensed as a branch or agency under the laws of the United States or any State thereof or (B) a corporation or limited liability company that is organized under the laws of the United States or any State thereof, (ii) has outstanding unguaranteed and unsecured long-term Indebtedness for Borrowed Money that is rated "A-" or better by S&P and "A3" or better by Moody's (with neither such rating being on negative watch) and (iii) has a combined capital and surplus of at least $500,000,000;

(b) in the case of an Acceptable Guarantee, such Person (i) is a corporation or limited liability company that is organized under the laws of the United States or any State thereof, (ii) has outstanding unguaranteed and unsecured long-term Indebtedness for Borrowed Money that is rated at least "BBB" by S&P and "Baa2" by Moody's (with neither such rating being on negative watch) and (iii) has a combined capital and surplus of at least $250,000,000; and

(c) in the case of a Project Equity Commitment, such Person is a corporation, limited partnership or limited liability company that is organized under the laws of the United States or any State thereof and such Person (i) has outstanding unguaranteed and unsecured long-term Indebtedness for Borrowed Money that is rated at least "BBB" by S&P and "Baa2" by Moody's (with neither such rating being on negative watch) or (ii) has a combined capital and surplus of at least $250,000,000.

"Acceptable Transmission Services Agreement" means a firm committed Transmission Services Agreement with an Acceptable Counterparty that (a) satisfies the following criteria; (i) the term of such Transmission Services Agreement is for not less than five years, (ii) the obligation of the Acceptable Counterparty thereto is only subject to the satisfaction of the conditions precedent set forth in Part A of Schedule 14 hereto, (iii) such Transmission Services Agreement contains only rights of termination on the part of the Acceptable Counterparty set forth in Part B of Schedule 14 hereto, and (iv) such Transmission Services Agreement cannot be terminated for convenience, whether by payment of a penalty or otherwise, or (b) is otherwise in an Acceptable Form.

"Account Collateral" has the meaning set forth in Section 11.6(a)(i).

"ACL" has the meaning set forth in the preamble.

"Acquisition by Condemnation" means any acquisition of Project Real Estate Rights by DOE through its powers of eminent domain or by condemnation.

"Acquisition Option" has the meaning set forth in Section 7.2(a).

"Action" means any (a) action, suit or proceeding of or before any Governmental Authority, (b) investigation by a Governmental Authority or (c) arbitral proceeding.

"Active Participation" means, in respect of any Key Person, that such Key Person (a) prior to the issuance of the Notice to Proceed, devotes substantially all of his business time and attention to the Clean Line Entities and CLEP (and its Subsidiaries) and the conduct of their business and (b) after the issuance of the Notice to Proceed and until Project Completion, such Key Person remains involved with the Clean Line Entities and the conduct of their business.

"Adverse DOE Impact" means a material adverse effect on (a) DOE's rights and remedies under the Transaction Documents, including each Covered Party's right to be indemnified for Covered Liabilities, (b) each Clean Line Party's ability to perform in a timely manner its obligations under this Agreement or any other Transaction Document, including such Clean Line Party's obligation to pay Covered Costs, (c) DOE's express third party beneficiary rights under any Material Project Contract, (d) the construction or operation of the Project, (e) DOE's obligations or liabilities in respect of any DOE Delegated Real Estate Rights or the AR Facilities, (f) the validity or enforceability of any material provision of this Agreement or any other Transaction Document, and (g) the validity or enforceability of the Performance Support or the validity, enforceability or priority of DOE's security interests in the Collateral and the continued effectiveness and enforceability of the Security Documents.

"Advance Funding Account" has the meaning set forth in Section 11.3(a).

"Advanced Funding Contingency Amount" means, as of any given date, a contingency amount equal to 10% of all Covered Costs estimated by DOE to be due and payable by DOE in the three (3) month period immediately succeeding such date of determination.

"AFDA" has the meaning set forth in the recitals.

"Affiliate" means with respect to any Person, any other Person that directly or indirectly Controls, or is under common Control with, or is Controlled by, such Person and, if such Person is an individual, any member of the immediate family of such individual and any trust whose principal beneficiary is such individual or one or more members of such immediate family and any Person who is Controlled by any such member or trust.

"Affiliated Lenders" means any Person that either (a) is an Affiliate of any Clean Line Party or (b) owns, directly or indirectly, more than five percent (5%) of the Equity Interests in any Clean Line Party.

"Aggregate Payments" means, with respect to a Contributing Subsidiary Guarantor as of any date of determination, an amount equal to (a) the aggregate amount of all payments and distributions made on or before such date by such Contributing Subsidiary Guarantor in respect of the Guarantee under Article IX, *minus* (b) the aggregate amount of all payments received on or before such date by such Contributing Subsidiary Guarantor from the other Contributing Subsidiary Guarantors as contributions under Section 9.2.

"Agreed Rate" means the "Prime rate" for the "U.S." as published in the "Money Rates" table of The Wall Street Journal from time to time.

"Agreement" has the meaning set forth in the preamble.

"AM Laws" means, with respect to any Person, all Applicable Laws concerning or relating to anti-money laundering.

"Anti-Corruption Laws" means, with respect to any Person, all Applicable Laws concerning or relating to bribery or corruption, including, the Foreign Corrupt Practices Act of 1977 (Pub. L. No. 95 213, §§101-104).

"Applicable Amount" means (a) from and after the Commencement Date but before DOE has issued the Notice to Proceed, $5,000,000 and (b) from and after the issuance of the Notice to Proceed, $50,000,000 *minus* the balance of any funds then on deposit in, or credited to, the Wind-Up Reserve Account; provided that the Applicable Amount, from and after the issuance of the Notice to Proceed, shall in no event be less than $10,000,000 at any time.

"Applicable Laws" means, with respect to any Person, any constitution, statute, law, rule, regulation, code, ordinance, treaty, judgment, order or any published directive, guideline, requirement, other governmental rule or restriction or Governmental Order which has the force of law, by or from a court, arbitrator or other of a Governmental Authority having jurisdiction over such Person or any of its Properties, whether in effect as of the date hereof or as of any date hereafter and including any applicable Environmental Laws.

"APSC" means the Arkansas Public Service Commission.

"APSC 2011 Order" has the meaning set forth in Section 12.1(t).

"AR Facilities" has the meaning set forth in the recitals.

"Arkansas Connection Point" has the meaning set forth in the recitals.

"Authorized Officer" means, (a) with respect to any Person that is a corporation, the chairman, chief executive officer, president, vice president, assistant vice president, treasurer, assistant treasurer, or any other financial officer of such Person, (b) with respect to any Person that is a partnership, each general partner of such Person or the chairman, chief executive officer, president, a vice president, an assistant vice president, treasurer, an assistant treasurer or any other financial officer of a general partner of such Person or (c) with respect to any Person that is a limited liability company, the manager, managing partner or duly appointed officer of such Person, the individuals authorized to represent such Person pursuant to the Organizational Documents of such Person, or the chairman, chief executive officer, president, vice president, assistant vice president, treasurer, assistant treasurer or any other financial officer of the manager or managing member of such Person.

"Bankruptcy Code" means Title 11 of the United States Code entitled "Bankruptcy", as amended.

"Bankruptcy Law" means the Bankruptcy Code and any similar federal, state or foreign law for the relief of debtors, conservatorship, bankruptcy, general assignment for the benefit of creditors, moratorium, rearrangement, receivership, insolvency, reorganization or similar debtor relief laws of the United States or other applicable jurisdictions from time to time in effect, and any similar federal, state or foreign law for the relief of debtors affecting the rights of creditors generally.

"Base Amount" means, as of any date of determination, the sum of: (a) the amount of all Covered Costs estimated by DOE to be due and payable by DOE in the three (3) month period immediately succeeding such date of determination *plus* (b) the sum of any future amounts payable from time to time by DOE pursuant to any Contractual Obligation entered into by DOE in connection with the Project (including any Real Estate Rights Agreements) (but subject in all cases to Section 11.3(g)) regardless of the time at which such amount is payable by DOE (for the avoidance of doubt, such amount shall include any amounts payable by DOE under any such Contractual Obligation for any future years occurring during the term of such Contractual Obligation).

"Base Case Projections" has the meaning set forth in Section 6.1(h).

"Base Contingency Amount" has the meaning set forth in the definition of "Contingency Amount".

"Biological Opinion" means the U.S. Fish and Wildlife's biological opinion issued on November 20, 2015 pursuant to Section 7 of the Endangered Species Act regarding the Project and Other Facilities, as amended or updated from time to time as required.

"Business Day" means any day other than a Saturday, Sunday or any other day on which DOE is not open for business.

"Capital Expenditures" means, with respect to any Person for any period, any expenditure in respect of the purchase or other acquisition of any fixed or capital asset (excluding normal replacements and maintenance which are properly charged to current operations).

"Capital Lease" means, for any Person, any lease of (or other agreement conveying the right to use) any Property of such Person that would be required, in accordance with GAAP, to be capitalized and accounted for as a capital lease on a balance sheet of such Person.

"Capital Lease Obligations" means the obligations of any Person under any Capital Lease.

"Capital Repairs" means (a) any and all work necessary, desirable or appropriate to repair, restore, refurbish or replace any equipment, structure or any other component of the Project Facilities (or any portion thereof) after Project Completion, including any such work necessitated by (i) any defect or deficiency, (ii) physical or functional obsolescence of the Project Facilities, as adjudged by Prudent Utility Practices, or (iii) modifications required by any Applicable Law or dictated by the observance of Prudent Utility Practices or (b) the substitution, replacement, enlargement or improvement of any structure, facility, equipment, Property, land or land rights constituting part of the Project Facilities.

"Capital Repairs Reserve Account" has the meaning set forth in Section 4.8(b).

"<u>Change of Control</u>" means:

(a) prior to the occurrence of a Qualified IPO in respect of the Clean Line Entities, the occurrence of any of the following events or circumstances:

(i) CLEP or the Clean Line Entities are no longer Controlled by a Permitted Holder, or

(ii) until Project Completion, any Key Person ceases Active Participation (other than as a result of sickness, death, incapacity or retirement) and within sixty (60) days either: (A) is not replaced by an individual that is acceptable to DOE, such consent not to be unreasonably withheld or delayed (it being understood and agreed that it would be unreasonable to withhold consent to the extent the replacement individual has qualifications and experience substantially similar to or better than the experience of the individual being replaced and such replacement individual is not a Prohibited Person) or (B) recommences Active Participation; or

(b) from and after the occurrence of a Qualified IPO, the occurrence of any of the following events of circumstances:

(i) the Clean Line Entities are no longer Controlled by the IPO Entity, or

(ii) any "person" or "group" (as such terms are used in Sections 13(d) and 14(d) of the Securities Exchange Act of 1934, but excluding any employee benefit plan of such person or its subsidiaries, and any person or entity acting in its capacity as trustee, agent or other fiduciary or administrator of any such plan) other than the Permitted Holders becomes the "beneficial owner" (as defined in Rules 13d-3 and 13d-5 under the Securities Exchange Act of 1934, except that a person or group shall be deemed to have "beneficial ownership" of all securities that such person or group has the right to acquire, whether such right is exercisable immediately or only after the passage of time (such right, an "option right")), directly or indirectly, of 25% or more of the equity securities of the IPO Entity entitled to vote for members of the board of directors or equivalent governing body of the IPO Entity on a fully-diluted basis (and taking into account all such securities that such "person" or "group" has the right to acquire pursuant to any option right), or

(iii) during any period of twelve (12) consecutive months, a majority of the members of the board of directors or other equivalent governing body of the IPO Entity cease to be composed of individuals (A) who were members of that board or equivalent governing body on the first day of such period, (B) whose election or nomination to that board or equivalent governing body was approved by individuals referred to in clause (A) above constituting at the time of such election or nomination at least a majority of that board or equivalent governing body or (C) whose election or nomination to that board or other equivalent governing body was approved by individuals referred to in clauses (A) and (B) above constituting at the time of such election or nomination at least a majority of that board or equivalent governing body, or

(iv) the passage of thirty (30) days from the date upon which any Person or two (2) or more Persons acting in concert shall have acquired by contract or otherwise, or shall have entered into a contract or arrangement that, upon consummation thereof, will result in its or their acquisition of the power to exercise, directly or indirectly, Control over the IPO Entity, or Control over the equity securities of the IPO Entity entitled to vote for members of the board of directors or equivalent governing body of the IPO Entity on a fully-diluted basis (and taking into account all such securities that such Person or Persons have the right to acquire pursuant to any option right) representing 25% or more of the combined voting power of such securities, or

(v) any "change of control" or any comparable term under, and as defined in, any Contractual Obligation to which the IPO Entity is a party shall have occurred; or

(c) at any time, Holdings shall cease to own, directly or indirectly, 100% of the beneficial or of record Equity Interests in each of PECL, ACL and PECL OK; or

(d) at any time, CLEP shall fail to own, directly or indirectly, 100% of the beneficial or of record Equity Interests in Holdings.

"Change of Law" means any change in any Applicable Law or the application or requirements thereof of any Governmental Authority issued after the Effective Date.

"Claiming Party" has the meaning set forth in Section 10.1.

"Clean Line Document" means, at any given time, this Agreement, any other Transaction Document in effect at such time and any Material Project Contract in effect at such time.

"Clean Line Entity" means Holdings and each of its Subsidiaries (other than PECL and any PECL Subsidiary).

"Clean Line Guarantor" means any Person that is a guarantor under any Acceptable Guarantee.

"Clean Line Material Adverse Effect" means, as of any date of determination, a material and adverse effect on (a) the Project, (b) the ability of the Clean Line Parties, taken as a whole, to perform their material obligations in a timely manner under any Transaction Document, (c) the business, Properties, operations or financial condition of the Clean Line Parties, taken as a whole, (d) the validity or enforceability of any material provision of any Transaction Document, (e) any material right or remedy of DOE under the Transaction Documents or (f) the Lien of

DOE on any of the Collateral under any Security Document (except as contemplated under this Agreement).

"Clean Line Obligor" means each of the Clean Line Parties and any Clean Line Guarantor.

"Clean Line Party" means Holdings and each of its Subsidiaries (including PECL and any PECL Subsidiary).

"CLEP" has the meaning set forth in the recitals.

"Collateral" means any Equity Interests in ACL or any other Property (whether tangible or intangible) of the Clean Line Entities whether now existing or hereinafter acquired that are subject to or are intended to be or become subject to the Lien granted to DOE pursuant to the Security Documents as required under the terms of this Agreement.

"Commencement Date" means the first date on which the conditions precedent set forth in Section 6.2 shall have been satisfied.

"Completion Conditions" means the satisfaction of each of the following conditions:

(a) the Project has commenced commercial operation and has satisfied the requirements for "substantial completion" (or term of similar import) as defined in and in accordance with all Construction Contracts and the initial Electrical Capacity (as specified in the definition thereof) of the Project has been certified by an Independent Engineer;

(b) the Project has been safely and reliably energized and energy may be delivered across the Project Facilities to SPP's, MISO's and TVA's transmission systems in accordance with the Interconnection Agreements;

(c) the Project has been constructed and become available for normal, safe and continuous operation in compliance in all material respects with the requirements and specifications of the Project Plans, the Material Project Contracts, Applicable Law, any Required Approvals and Prudent Utility Practices;

(d) all payments required to be made to each Contractor under each Material Construction Contract have been paid in full in cash, other than any payments that are subject to Contest;

(e) a final invoice has been issued by (or on behalf of) the Clean Line Entities to any applicable Contractor as to any liquidated damages payable under any Construction Contract;

(f) the Clean Line Entities have delivered to DOE executed acknowledgments of payments and releases of Liens from the Contractors under each Material Construction Contract and each Major Subcontractor thereunder for all work, services and materials, including equipment and fixtures of any kind, done, previously performed or furnished for the construction of the Project, other than to the extent payment thereof is subject to Contest;

(g) all Required Approvals that are necessary or required to have been obtained as of Project Completion under Applicable Law or any material Contractual Obligation applicable to, or binding on, any Clean Line Entity (i) have been obtained, (ii) are in full force and effect and (iii) all conditions precedent to the effectiveness of any such Required Approval have been satisfied;

(h) all Required Insurance with respect to the operational phase of the Project is in place, in good standing and in full force and effect without default and all premiums due thereon have been paid in full, and DOE has received evidence thereof;

(i) all Project Real Estate Rights, utilities and other services, means of transportation, facilities, equipment, other rights and materials or supplies necessary for the operation of the Project in accordance (in all material respects) with Prudent Utility Practices, Applicable Law, Required Approvals, the Transaction Documents and the Material Project Contracts and as otherwise contemplated by the Project Plans are available to the Clean Line Entities under the terms of the Material Project Contracts then in effect or otherwise available on commercially reasonable terms materially consistent with the then applicable Project Budget;

(j) the Capital Repairs Reserve Account has been established and funded in full; and

(k) no Default or Event of Default has occurred and is continuing.

"Construction Contract" means any design, construction, procurement, supply or other Contractual Obligation executed in connection with the construction, procurement, installation, or improvement of land, buildings, equipment, or facilities necessary or desirable for the Project.

"Construction Contractor" means any Contractor under any Construction Contract.

"Construction Costs" means any and all Project Costs anticipated to be incurred by either of DOE or any Clean Line Entity in connection with the design, development, engineering, construction, administration, management, operation, financing and ownership of the Project through the occurrence of Project Completion.

"Construction Progress Report" means a construction progress report prepared quarterly by the Clean Line Entities, which shall include: (a) a reasonably detailed assessment of the progress of construction to date in comparison with the Project Plans then in effect for such quarterly period (along with an explanation of material delays, if any) and the expected progress of construction; (b) contingencies used or reasonably expected to be used to pay Construction Costs; (c) any events that have occurred or are reasonably expected to occur that would materially affect the construction schedule; (d) a description and explanation of any Events of Loss that have occurred and (e) material disputes or Actions between any Clean Line Entity and any other Person.

"Contest" means, with respect to any matter, claim or Governmental Order involving any Person, that such Person is contesting or appealing such matter, claim or Governmental Order in good faith and by appropriate proceedings timely instituted; provided that the following conditions are satisfied: (a) such Person has established reasonably adequate reserves with respect to the contested items in accordance with GAAP and (b) such contest and any resultant failure to pay or discharge the claimed or assessed amount or to comply with the applicable Governmental Order does not, and could not reasonably (individually or in the aggregate) be expected to, result in a Clean Line Material Adverse Effect or an Adverse DOE Impact.

"Contingency Amount" means (a) as of any date occurring prior to the issuance of the Notice to Proceed, a contingency amount equal to (i) the lesser of (A) 15% and (B) such lower percentage as (1) prior to the occurrence of Project Financial Close, the Coordination Committee may agree based on input from the Independent Engineer and (2) from and after the occurrence of Project Financial Close, the Project Financing Parties determine to be acceptable for purposes of the financing the Construction Costs as part of the Project Financing *multiplied by* (ii) the amount of all Construction Costs reasonably anticipated by the Clean Line Entities as of such date of determination to be incurred from and after such date of determination in connection with achieving Project Completion (such contingency amount being the "Base Contingency Amount") and (b) on any date occurring after the issuance of the Notice to Proceed, (i) the Base Contingency Amount as of the date of the issuance of the Notice to Proceed *minus* (ii) the amount of any reduction in the Base Contingency Amount agreed by the Project Financing Parties *minus* (iii) any amounts of the Base Contingency Amount applied to the payment of Construction Costs since the issuance of the Notice to Proceed.

"Controlling Person" means, with respect to any Person, any other Person that, directly or indirectly Controls such Person.

"Contractor" means any Person with whom a Clean Line Party enters into any Project Contract or performs any part of the Work or provides any materials, equipment, hardware or supplies for any part of the Work and any Person with whom any Contractor has further subcontracted any part of the Work.

"Contractual Obligation" means, as to any Person at any given time, any contractual provision of any security issued by such Person or of any indenture, mortgage, deed of trust, contract, agreement, instrument or other undertaking to which such Person is a party at such time or by which it or any of its Property is bound at such time.

"Contributing Subsidiary Guarantors" has the meaning set forth in Section 9.2.

"Control" means (including, with its correlative meanings, "Controlled by" and "under common Control with") as used with respect to any Person, possession, directly or indirectly, of the power to direct or cause the direction of management or policies of such Person (whether through ownership of voting securities or partnership or other ownership interests, by contract or otherwise); provided, that in any event and for all purposes of the Transaction Documents, (a) with respect to any Investment Fund, such Investment Fund shall be deemed to be Controlled by its general partner and any Person that Controls such general partner and (b) in all other cases, any Person that owns directly or indirectly ten percent (10%) or more of Equity Interests having ordinary voting powers for the election of directors or other applicable governing body of another Person (but excluding limited partnership or similar types of ownership interests and tax equity investors) shall be deemed to Control such other Person.

"Converter Station Facility" has the meaning set forth in the recitals.

"Converter Station Real Estate Rights Agreements" has the meaning set forth in Section 6.2(a)(v).

"Coordination Committee" has the meaning set forth in Section 5.1(a).

"Covered Cost" has the meaning set forth in Section 11.1.

"Covered Liability" means any and all liabilities (including, without, limitation, negligence, warranty, statutory, product, strict or absolute liability, liability in tort or otherwise), obligations, losses, settlements, damages, penalties, fines (including NERC fines), sanctions, Taxes, claims, actions, demands, suits, judgments or proceedings of any kind and nature, costs, payments, expenses and disbursements (including fees and expenses of consultants, advisors, external counsel and allocable fees and expenses of internal personnel and attorneys) of whatsoever kind and nature (whether or not any of the transactions contemplated by any of the Transaction Documents are consummated), imposed on, incurred or suffered by, or asserted against any Covered Party in any way relating to or arising out of:

(a) the Project, the Project Facilities, any of the Project Real Estate Rights, or any portion or interest in any one or more of the foregoing;

(b) the Transaction Documents, the Project Contracts, the Project Financing Documents or the transactions contemplated thereby or the enforcement of any of the rights, remedies or terms of any thereof;

(c) the conduct of the business or affairs of any Clean Line Party and the Project;

(d) the sale or providing of any transmission services or any non-delivery by any Clean Line Party of any transmission services in respect of the Project;

(e) the design, condition, operation, use, non-use, ownership, lease, sublease, maintenance, repair, substitution, possession, rental, conversion, return, registration, re-registration, alteration, overhaul, modification, improvement, testing, removal, replacement, installation, storage, severance, transfer of title, decommissioning, abandonment, sale, resale or other application or disposition or use of any of the Project, the Project Facilities, or any Project Real Estate Rights or any portion of or interest in any one or more of the foregoing or any other Property in which any Clean Line Party or, solely to the extent such Property relates to the Project, any other Property in which DOE, has an interest, including any Covered Liability in any way relating to or arising out of (i) failure to comply with, or costs of compliance with any Environmental Claim or any Release of any Hazardous Substance, (ii) loss or damage to any Property or the environment or death or injury to any Person resulting therefrom, (iii) any patent, trademark or copyright infringement relating thereto and (iv) latent or other defects with respect to the Project Facilities, regardless of whether discoverable and including injury, death and Property damage to other with respect to the foregoing;

(f) the nonperformance or breach by any Clean Line Obligor or any Project Participant of any of its covenants or obligations or the falsity of any representation or warranty obligations under any Project Contract, Project Financing Document, Transaction Document or any other Contractual Obligation to which it is a party under or in respect of any Required Approval or any act, or omission to act in breach of a legal duty to act with respect to, or in connection with the Project, the Project Facilities, the Project Real Estate Rights or any portion of or interest in any one or more of the foregoing or any other Property in which any Clean Line Party has an interest;

(g) the offer, sale, delivery, refinancing, funding or syndication of the Project Financing;

(h) the imposition of any Lien on or with respect to the Project or the Project Facilities in respect of which any Covered Party has an interest (other than Permitted Liens);

(i) failure of any Clean Line Obligor or any Project Participant to comply with any Applicable Laws (including any Environmental Laws);

(j) the environmental condition and impact of or from the Project, the Project Facilities or the Project Real Estate Rights or any other Property in which any Clean Line Party has any interest, including personal injuries and injuries to the Property of third parties;

(k) any regulatory action under any Applicable Law pertaining directly or indirectly to the Project, the Project Facilities or the Project Real Estate Rights or any other Property in which any Clean Line Party has an interest;

(l) any costs incurred by DOE in connection with its performance or undertaking of any non-delegable obligations or responsibilities under the DOE Mitigation Action Plan, any Cultural Resource Agreement with NHPA, the Endangered Species Act or any other Applicable Law to the extent relating to the Project; or

(m) any of the foregoing Covered Liabilities set forth in clauses (i)-(k), to the extent in connection with, arising out of or in any way related to the design, development, construction, financing, ownership, operation, maintenance or management of the TN Facilities or the TX Facilities and any Real Estate Rights related thereto or any other business conducted by any Clean Line Party from time to time.

"Covered Party" means the United States of America and each of its agencies, departments (including the Department and SWPA), authorities and instrumentalities and each of their elected officials, board members, secretaries, officers, directors, employees, counsel, financial advisors, technical consultants, or agents of any thereof.

"Credit-Worthy Affiliate" means, as of any date of determination, any Affiliate of a Clean Line Entity that either (a) as of any date of determination, is an Acceptable Support Provider or (b) has its obligations in respect of its applicable Project Equity Commitment supported in full by an unconditional and irrevocable letter of credit issued by an Acceptable Support Provider or by an unconditional and irrevocable Guarantee issued by an Acceptable Support Provider, which letter of credit or Guarantee is in an Acceptable Form.

"Cultural Resource Agreement" means a programmatic agreement, memorandum of agreement, and/or binding commitment concerning historic properties for purposes of complying with Section 106 of the NHPA in the development, construction and operation of Project.

"Curative Party" has the meaning set forth in Schedule 1 hereto.

"Davis-Bacon Act" means Subchapter IV of Chapter 31 of Part A of Subtitle II of Title 40 of the United States Code, including, and as implemented by, the regulations set forth in Parts 1, 3 and 5 of title 29 of the Code of Federal Regulations.

"Davis-Bacon Requirements" means, to the extent that DOE (or the Department of Labor, as the case may be) has made a determination that the Davis-Bacon Act is applicable to this Agreement and/or the Project: (a) the Davis-Bacon Act and (b) as set forth in Schedule 15 hereto (as such Schedule is supplemented from time to time in accordance with Section 8.24(b)): (i) all regulations related to the Davis-Bacon Act, including those set forth in the Department of Labor regulations at 29 C.F.R. §§ 5.5(a)(1) to (10) and 5.5(b)(1) to (4) and (ii) applicable wage determinations containing locally prevailing wages as determined by the Secretary of Labor.

"DC" means direct current.

"Deadlock" has the meaning set forth in Section 5.1(f).

"Debarment Regulations" means (a) the Government-wide Debarment and Suspension (Non procurement) regulations (Common Rule), 53 Fed. Reg. 19204 (May 26, 1988), (b) Subpart 9.4 (Debarment, Suspension, and Ineligibility) of the Federal Acquisition Regulations, 48 C.F.R. §§ 9.400 – 9.409 and (c) the revised Government-wide Debarment and Suspension (Non-procurement) regulations (Common Rule), 60 Fed. Reg. 33037 (June 26, 1995).

"Debt Collection Improvement Act" means the Debt Collection Improvement Act of 1996, as amended from time to time.

"Default" means an event that, with the giving of notice or passage of time or both, would become an Event of Default.

"Default Rate" means the lesser of (a) four percent (4%) *per annum* above the Agreed Rate and (b) the maximum rate of interest permitted by Applicable Law.

"Department" has the meaning set forth in the preamble.

"Disposition" means, with respect to any Property, any direct or indirect sale, lease, license, assignment, exchange, conveyance or other transfer or disposition thereof (including the granting of any Lien or security interest in respect thereof), whether by agreement, operation of law or otherwise other than licenses of or similar arrangements for intellectual property rights (and the verb "Dispose" shall be construed accordingly).

"Documentation Package" has the meaning set forth in Schedule 1 hereto.

"DOE" has the meaning set forth in the preamble.

"DOE Acquired Real Property" means any Real Estate Rights acquired by DOE pursuant to the terms of this Agreement.

"DOE Approved Project Equity Commitment" means any Project Equity Commitment that is in an Acceptable Form.

"DOE Approved Project Financing Commitment" means any Project Financing Commitments that are in an Acceptable Form.

"DOE Delegated Real Estate Right" has the meaning set forth in Section 3.3(a).

"DOE Direct Agreement" means one or more consents to assignment or direct agreements to be entered into between DOE and the Project Financing Parties (or their applicable agent) providing for, among other terms to be agreed between DOE and the Project Financing Parties, certain step-in and lender cure rights in favor of the Project Financing Parties in respect of this Agreement and other Transaction Documents, in form and substance acceptable to DOE.

"DOE Instituted Disposition" has the meaning set forth in Section 3.3(f).

"DOE Mitigation Action Plan" has the meaning set forth in Section 4.2.

"DOE Policies" means such practices and policies as are generally applied by DOE or SWPA from time to time with respect to the ownership, operation and maintenance of its real property and transmission assets and as shall be notified by DOE to Holdings in writing from time to time, whether or not such practices or policies have the force of law.

"Dollars" or "$" means the lawful currency of the United States of America.

"Effective Date" means the date on which each of the conditions precedent set forth in Section 6.1 are satisfied.

"Electric Reliability Organization" means an organization certified by FERC to adopt and enforce mandatory standards for the reliable operation and planning of the bulk power system throughout the United States of America.

"Electrical Capacity" means the electric transmission transfer capability of the Project Facilities (or the applicable portion thereof) expressed in MW, which initially shall be 4,355 MW (gross) or 4,000 MW (net) in the aggregate.

"Emergency" means, with respect to the Project, AR Facilities or the DOE Acquired Real Property, an unplanned event that (a) is an abnormal system condition that requires immediate action to prevent or limit loss of transmission facilities that could adversely affect the reliability of the Project or the AR Facilities; (b) presents an immediate or imminent threat to the long term integrity of any part of the AR Facilities or the Project; (c) presents an immediate or imminent threat of endangerment to life, human health, safety or the environment, including damage to adjacent Property; or (d) is recognized or declared by the Federal Emergency Management Administration (FEMA), the U.S. Department of Homeland Security or other Governmental Authority with authority to declare an emergency.

"Emergency Capital Expenditures" shall mean those Capital Expenditures required to be expended consistent with Prudent Utility Practice in order to prevent or mitigate an Emergency that, in the good faith judgment of the Clean Line Entities (as subsequently confirmed by an Independent Engineer), necessitates the taking of immediate measures to prevent or mitigate such Emergency; provided that such expenditures are (a) payable under an insurance policy (in an aggregate amount not to exceed $5,000,000 in any 12-month period); (b) payable by insurance or a warranty provided under any Project Contract (in an aggregate amount not to exceed $5,000,000 in any 12-month period); (c) in an amount that does not exceed $2,000,000 in any 12-month period; or (d) otherwise reasonably necessary to prevent or mitigate an Emergency.

"Emergency Operating Expenses" shall mean those amounts required to be expended consistent with Prudent Utility Practice in order to prevent or mitigate an Emergency that, in the good faith judgment of the Clean Line Entities (as subsequently confirmed by an Independent Engineer), necessitates the taking of immediate measures to prevent or mitigate such Emergency; provided that such expenditures are (a) payable under an insurance policy (in an aggregate amount not to exceed $5,000,000 in any 12-month period); (b) payable by insurance or a warranty provided under any Project Contract (in an aggregate amount not to exceed $5,000,000 in any 12-month period); (c) in an amount that does not exceed $2,000,000 in any 12-month period; or (d) otherwise reasonably necessary to prevent or mitigate an Emergency.

"Endangered Species Act" means the Endangered Species Act of 1973, as amended from time to time, and the regulations promulgated, and any applicable rulings issued, thereunder.

"Environmental Claim" means any and all obligations, liabilities, losses, administrative, regulatory or judicial actions, suits, demands, decrees, claims, Liens, judgments, notices of noncompliance or violation, investigations (excluding routine inspections), proceedings, clean-up, removal or remedial actions or orders, or damages (foreseeable and unforeseeable, including consequential and punitive damages), penalties, fees, out-of-pocket costs, expenses, disbursements, attorneys' or consultants' fees, relating in any way to any violation of Environmental Law or any violation of any Governmental Approval issued under any such Environmental Law, including (a) any and all indemnity claims by any Governmental Authority for enforcement, cleanup, removal, response, remedial or other actions or damages pursuant to any applicable Environmental Law and (b) any and all indemnity claims by any third party seeking damages, contributions, indemnification, cost recovery, compensation or injunctive relief resulting from Release of Hazardous Substances, the violation or alleged violation of any

Environmental Law or Governmental Approval issued thereunder, or arising from alleged injury or threat of injury to health, safety or the environment.

"Environmental Laws" means any Applicable Law regulating, relating to or imposing obligations, liability or other compliance requirements concerning (a) environmental impacts resulting from the use of the Project Site or environmental conditions present on, in or under the Project Site (including, without limitation, NEPA and NHPA); (b) pollution, protection of human or animal health or safety or the environment, including flora and fauna; (c) Releases or threatened Releases of pollutants, contaminants, chemicals, radiation or Hazardous Substances; (d) otherwise relating to the generation, manufacture, processing, distribution, use, treatment, storage, recycling, disposal, transport, or handling of pollutants, contaminants, chemicals or Hazardous Substances; or (e) any noise generated by or in connection with the Project, including any regulations or guidance relating in any way to the Noise Control Act, 42 USC Section § 4901, *et seq*. or any related state laws or requirements governing noise or noise mitigation.

"Equity Collateral" has the meaning set forth in Section 11.6(a)(ii).

"Equity Interests" means, with respect to any Person, any and all shares, interests, rights to purchase, warrants, options, participations or other equivalents of or interests in (however designated) the common or preferred equity or preference share capital of a Person, including partnership interests and limited liability company interests.

"Event of Default" has the meaning set forth in Section 7.3.

"Event of Loss" means any event that causes any material portion of the Project to be damaged, destroyed or rendered unfit for normal use for any reason whatsoever, including, through a failure of title, or any loss of Property, or a condemnation.

"Existing Indebtedness" means the Indebtedness of the Clean Line Parties outstanding as of the Effective Date, as set forth in Schedule 3 hereto (as such Schedule may be updated pursuant to Section 12.3).

"Fair Share" means, with respect to a Contributing Subsidiary Guarantor as of any date of determination, an amount equal to (a) the ratio of (i) the Fair Share Contribution Amount with respect to such Contributing Subsidiary Guarantor to (ii) the aggregate of the Fair Share Contribution Amounts with respect to all Contributing Subsidiary Guarantors *multiplied* by (b) the aggregate amount paid or distributed on or before such date by all Funding Subsidiary Guarantors in respect of the Guaranteed Obligations.

"Fair Share Contribution Amount" means, with respect to a Contributing Subsidiary Guarantor as of any date of determination, the maximum aggregate amount of the obligations of such Contributing Subsidiary Guarantor under the Guarantee in Article IX that would not render its obligations hereunder or thereunder subject to avoidance as a fraudulent transfer or conveyance under Section 548 of Title 11 of the United States Code or any comparable applicable provisions of state law; provided that, solely for purposes of calculating the "Fair Share Contribution Amount" with respect to any Contributing Subsidiary Guarantor for purposes of Section 9.2, any assets or liabilities of such Contributing Subsidiary Guarantor arising by virtue of any rights to subrogation, reimbursement or indemnification or any rights to or obligations of contribution hereunder shall not be considered as assets or liabilities of such Contributing Subsidiary Guarantor.

"FERC" means the Federal Energy Regulatory Commission.

"Final Environmental Impact Statement" means the *Plains & Eastern Clean Line Transmission Line Project Final Environmental Impact Statement* and all Appendices, dated October 2015, Document No. DOE/EIS-0486.

"Financial Statements" means with respect to any Person and for any period, such Person's balance sheet as at the end of such period and the related statements of income, changes in shareholder's equity, and cash flows for such period, all in reasonable detail and prepared in accordance with GAAP, with (a) any such statements delivered in respect of any fiscal year of such Person including all notes thereto and (b) any such statements delivered in respect of any fiscal quarter of such Person being subject only to normal year end audit adjustments and the absence of footnotes.

"Financing Condition" means:

(a) as of any time of determination occurring from and after Project Financial Close, (i) the sum of the unused commitments of the Project Financing Parties under the Project Financing Documents *plus* the sum of the unused Project Equity Commitments *plus* amounts on deposit in the Advance Funding Account is equal to not less than the Remaining Project Costs, (ii) such Project Equity Commitments are in full force and effect without any materially adverse amendment, waiver, supplement or modification thereof from the form that was originally delivered for purposes of satisfying the Financing Condition, and (iii) the Project Financing Documents are in full force and effect and an Authorized Officer of Holdings shall have certified to DOE that, subject to its Knowledge, there is no existing fact or circumstance that will prevent all of the Permitted Draw Conditions from being satisfied, unless the applicable Project Financing Parties have agreed in writing to waive such condition(s); or

(b) as of any time of determination occurring prior to Project Financial Close, (i) Firm Project Equity Commitments shall be in effect (together with amounts on deposit in the Advance Funding Account) for an amount not less than 150% of the Remaining DOE Acquisition Costs as of such time of determination, (ii) the sum of DOE Approved Project Equity Commitments then in effect *plus* any Firm Project Equity Commitments then in effect *plus* amounts on deposit in the Advance Funding Account *plus* the commitments provided for under any DOE Approved Project Financing Commitment (if any) shall be not less than the Remaining Project Costs, (iii) all such DOE Approved Project Equity Commitments shall be in full force and effect without any materially adverse amendment, waiver, supplement or modification thereof from the form that was originally delivered for purposes of satisfying the Financing Condition, and (iv) if applicable, the DOE Approved Project Financing Commitments shall be in full force and effect without any materially adverse amendment, waiver, supplement or modification thereof from the form that was originally delivered for purposes of satisfying the Financing Condition and an Authorized Officer of Holdings shall have certified to DOE that, subject to its Knowledge, there is no existing fact or circumstance that will prevent all of the conditions precedent to Project Financial Close in respect of any such DOE Approved Project Financing Commitments or DOE Approved Project Equity Commitments from being achieved prior to the termination of any such DOE Approved Project Financing Commitment or DOE Approved Project Equity Commitments, as applicable, or the Clean Line Entities' needing to draw on any funds in respect of the Project Financing in order to pay any Remaining Project Costs, unless the applicable Financing Party has agreed in writing to waive such condition precedent.

"Financing Party" means any Project Financing Party or any other Person that provides a Project Equity Commitment.

"Firm Project Equity Commitment" means either (a) an irrevocable and unconditional Project Equity Commitment that is subject only to a request of funding (whether in the form of a capital call notice, flow of funds memorandum or otherwise) by Holdings and is not subject to any other condition or right of termination by the Acceptable Support Provider or Credit-Worthy Affiliate providing such Project Equity Commitments or (b) any other Project Equity Commitment that is in an Acceptable Form.

"FPA" means the Federal Power Act, as amended, and FERC's regulations thereunder.

"Force Majeure" means the occurrence of any event or act that delays or prevents a Party's performance of its obligations under the Transaction Documents or any Project Contract, but only to the extent that (a) such event is not attributable to the fault or negligence on the part of such Party, (b) such event is caused by factors beyond such Party's reasonable control and (c) despite taking all reasonable technical and commercial precautions and measures to prevent, avoid, mitigate or overcome such event and the consequences thereof, such Party has been unable to prevent, avoid, mitigate or overcome any such event or consequence, including, but not limited to, acts of God, strikes, lockouts, acts of the public enemy, wars, blockades, riots, insurrections, epidemics, landslides, lightning, earthquakes, fires, storms, floods, washouts, arrests and restraints of rulers and peoples, interruptions by government or court orders or orders of any regulatory body having proper jurisdiction, civil disturbances, explosions, breakage or accident to machinery and any other cause whether of the kind herein enumerated or otherwise. Force Majeure shall not include: (i) economic hardship of a Party or (ii) if claimed by DOE, interruptions by any Governmental Authority or Governmental Order that are directly caused by actions of DOE that specifically are targeted at any of the Clean Line Entities or the Project (and not of a more generally applicable nature) or unless arising as a result of a violation of Applicable Law by any Clean Line Entity, or the occurrence of an Event of Default.

"Fundamental Event of Default" means the occurrence of:

(a) any Event of Default of the type described in Section 7.3(f) that (i) has resulted in a Safety Event, (ii) arises as a result of a material breach by any Clean Line Entity of any material provision of the DOE Mitigation Action Plan, any Applicable

Laws or Required Approvals or (iii) has resulted in the failure of the Required Insurance to be in full force and effect; provided that to the extent any such Event of Default is capable of being cured, such Event of Default shall not constitute a "Fundamental Event of Default" until such time as DOE has given notice to Holdings of the occurrence of such Event of Default and has given the Clean Line Entities an additional sixty (60) day period to cure such Event of Default; or

(b) (i) any Event of Default of the type described in Section 7.3(e) that, except to the extent that the representation or warranty giving rise to the occurrence of such Event of Default is itself qualified by "Adverse DOE Impact" or "Clean Line Material Adverse Effect", has resulted in, or could reasonably be expected to result in, a Clean Line Material Adverse Effect or an Adverse DOE Impact, (ii) any Event of Default of the type described in Section 7.3(f) that arises as a result of any Clean Line Entity's breach of any of Section 2.3(c), Section 3.2(d), Section 4.1(i), Section 8.2, Section 8.3, Section 8.7(a), Section 8.11, Section 8.12(a), Section 8.12(c), Section 8.12(e), Section 8.13, Section 8.14, Section 8.18, Section 8.19 or Section 8.27, (iii) any Event of Default of the type described in Section 7.3(g), (iv) any Event of Default of the type described in Section 7.3(h) or (v) any Event of Default of the type described in Section 7.3(l); provided that to the extent any such Event of Default is capable of being cured, such Event of Default shall not constitute a "Fundamental Event of Default" until such time as DOE has given notice to Holdings of the occurrence of such Event of Default and has given the Clean Line Entities an additional sixty (60) day period to cure such Event of Default; or

(c) an Event of Default of the type described in Section 7.3(j); provided that to the extent such Event of Default arises as a result of an Insolvency Event of a Clean Line Guarantor, such Event of Default shall not constitute a "Fundamental Event of Default" if, within thirty (30) days of the occurrence thereof, the Clean Line Entities have provided a replacement Performance Support from an Acceptable Support Provider in accordance with Section 11.5(a); or

(d) any Event of Default of the type described in Sections 7.3(a) through 7.3(d), Section 7.3(i), Section 7.3(k) and Sections 7.3(m) through 7.3(r).

"Funding Subsidiary Guarantor" has the meaning set forth in Section 9.2.

"GAAP" means generally accepted accounting principles in the United States in effect from time to time, applied on a consistent basis.

"Governmental Approval" means any approval, consent, authorization, license, permit, order, certificate, qualification, waiver, exemption, or variance, or any other action of a similar nature, of or by a Governmental Authority, including any of the foregoing that are or may be deemed given or withheld by failure to act within a specified time period.

"Governmental Authority" means any federal, state, county, municipal, or regional authority, or any other entity of a similar nature, exercising any executive, legislative, judicial (including any court of competent jurisdiction), regulatory, or administrative function of government with statutory jurisdiction over any Clean Line Party or the Project.

"Governmental Order" means with respect to any Person, any judgment, order, decision, or decree, or any action of a similar nature, of or by a Governmental Authority having competent jurisdiction over such Person or any of its Properties; provided that the term "Governmental Order" shall not include any judgment, order, decision, or decree, or any action of a similar nature taken by DOE that is specifically targeted at the Clean Line Entities or the Project (and not of a more generally applicable nature) except such judgments, orders, decisions, decrees or actions as may arise based on a violation of Applicable Law by the Clean Line Entities or the occurrence of any Event of Default.

"Guarantee" means (a) any obligation, contingent or otherwise, of the guarantor guaranteeing or having the economic effect of guaranteeing any Indebtedness of any other Person (the "primary obligor") in any manner, whether directly or indirectly, and including any obligation of the guarantor, direct or indirect, (i) to purchase or pay (or advance or supply funds for the purchase or payment of) such Indebtedness (whether arising by virtue of partnership arrangements, by agreement to keep well, to purchase assets, goods, securities or services, to take or pay or otherwise) or to purchase (or to advance or supply funds for the purchase of) any security for the payment of such Indebtedness, (ii) to purchase or lease Property, securities or services for the purpose of assuring the owner of such Indebtedness of the payment thereof, (iii) to maintain working capital, equity capital or any other financial statement condition or liquidity of the primary obligor so as to enable the primary obligor to pay such Indebtedness, (iv) entered into for the purpose of assuring in any other manner the holders of such Indebtedness of the payment thereof or to protect such holders against loss in respect thereof (in whole or in part) or (v) as an account party in respect of any letter of credit or letter of guarantee issued to support such Indebtedness, or (b) any Lien on any assets of the guarantor securing any Indebtedness (or any existing right, contingent or otherwise, of the holder of Indebtedness to be secured by such a Lien) of any other Person, whether or not such Indebtedness is assumed by the guarantor; provided, however, that the term "Guarantee" shall not include endorsements for collection or deposit, in either case in the ordinary course of business.

"Guaranteed Obligations" has the meaning set forth in Section 9.1(a).

"Hazardous Substances" means any hazardous or toxic substances, chemicals, materials, pollutants or wastes defined, listed, classified or regulated as such in or under any Environmental Laws, including (a) any petroleum or petroleum products (including gasoline, crude oil or any fraction thereof), flammable explosives, radioactive materials, asbestos in any form that is or could become friable, urea formaldehyde foam insulation and polychlorinated biphenyls, (b) any chemicals, materials or substances defined as or included in the definition of "hazardous substances," "hazardous wastes," "extremely hazardous wastes," "restricted hazardous wastes," "toxic substances," "toxic pollutants," "contaminants" or "pollutants," or words of similar import, under any applicable Environmental Law and (c) any other chemical, material or substance, import, storage, transport, use or disposal of, or exposure to or Release of which is prohibited, limited or otherwise regulated under, or for which liability is imposed pursuant to, any Environmental Law.

"Hazardous Substances Measures" means those measures adopted by the Clean Line Entities as part of implementing the DOE Mitigation Action Plan as further described in Section 8.21, including (a) procedures, practices and activities to address and comply with Environmental Laws and Governmental Approvals with respect to any Release of Hazardous Substances in connection with the Project or any Project Real Estate Right and (b) actions to be taken in the event that a Hazardous Substance is discovered on Property on which Project Facilities are located.

"Holdings" has the meaning set forth in the preamble.

"HVDC" has the meaning set forth in the recitals.

"Immaterial Obligor" means any Clean Line Obligor (other than Holdings, ACL, PECL OK and PECL) that (a) has Property with a fair market value of less than $5,000,000, (b) does not own any rights to any of the Electrical Capacity, (c) does not own any Project Real Estate Rights, (d) is not a party to any Material Project Contract and (e) as to which the occurrence of any Insolvency Event in respect of such Clean Line Obligor could not reasonably be expected to have a Clean Line Material Adverse Effect or an Adverse DOE Effect.

"Indebtedness" of any Person shall mean, without duplication:

(a) all Indebtedness for Borrowed Money;

(b) all obligations of such Person evidenced by bonds, debentures, notes or similar instruments;

(c) all obligations of such Person under conditional sale or other title retention agreements relating to Property or assets purchased by such Person;

(d) all Guarantees by such Person of Indebtedness of others;

(e) all Capital Lease Obligations of such Person;

(f) the principal component of all obligations, contingent or otherwise, of such Person (i) as an account party in respect of letters of credit and (ii) in respect of bankers' acceptances, bank guaranties, surety or performance bonds and similar instruments; and

(g) all obligations of such Person to purchase, redeem, retire, defease any Equity Interests in such Person or any warrants, rights or options to acquire such Equity Interests, valued, in the case of redeemable preferred interests, at the greater of its voluntary or involuntary liquidation preference *plus* accrued and unpaid dividends.

"Indebtedness for Borrowed Money" means as to any Person, without duplication, (a) all indebtedness (including principal, interest, fees and charges) of such Person for borrowed money or for the deferred purchase price of property or services (other than any deferral (i) in connection with the provision of credit in the ordinary course of business by any trade creditor or utility or (ii) of any amounts payable under the Project Contracts) or (b) the aggregate amount required to be capitalized under any Capital Lease under which such Person is the lessee.

"Independent Engineer" means an independent engineer selected by (a) Holdings or (b) following satisfaction of the Financing Condition, by or on behalf of the Project Financing Parties that have executed DOE Approved Project Financing Commitments and that, in either case, is reasonably acceptable to DOE.

"Information" has the meaning set forth in Section 12.1(o).

"Insolvency Event" means, with respect to any Person, the occurrence of any of the following events, conditions or circumstances:

(a) such Person shall file a voluntary petition in bankruptcy or shall be adjudicated bankrupt or insolvent, or shall file any petition or answer or consent seeking any reorganization, arrangement, composition, readjustment, liquidation, dissolution or similar relief for itself under applicable Bankruptcy Law, or shall seek or consent to or acquiesce in the appointment of any trustee, receiver, conservator or liquidator of such Person or of all or any substantial part of its Properties (the term "acquiesce," as used in this definition, includes the failure to file in a timely manner a petition or motion to vacate or discharge any order, judgment or decree after entry of such order, judgment or decree);

(b) an involuntary case or other proceeding shall be commenced against such Person seeking any reorganization, arrangement, composition, readjustment, liquidation, dissolution or similar relief with respect to such Person or its debts under applicable Bankruptcy Law, or seeking the appointment of a trustee, receiver, liquidator, custodian or other similar official of it or any substantial part of its Property, and such involuntary case or other proceeding shall remain undismissed or unstayed for a period of ninety (90) consecutive days;

(c) a court of competent jurisdiction shall enter an order, judgment or decree approving a petition filed against such Person seeking a reorganization, arrangement, composition, readjustment, liquidation, dissolution or similar relief under the applicable Bankruptcy Law, and such Person shall acquiesce in the entry of such order, judgment or decree or such order, judgment or decree shall remain unvacated and unstayed for an aggregate of ninety (90) days (whether or not consecutive) from the date of entry thereof, or any trustee, receiver, conservator or liquidator of such Person or of all or any substantial part of its Property shall be appointed without the consent or acquiescence of such Person and such appointment shall remain unvacated and unstayed for an aggregate of ninety (90) days (whether or not consecutive);

(d) such Person shall admit in writing its inability to pay its debts as they mature or shall generally not be paying its debts as they become due;

(e) such Person shall make an assignment for the benefit of creditors or take any other similar action for the protection or benefit of creditors; or

(f) such Person shall take any corporate, limited liability company or partnership action for the purpose of effecting any of the foregoing.

"Insurance Agreement" has the meaning set forth in Section 5.1(e)(ii).

"Interconnection Agreement" means an interconnection agreement or interim interconnection agreement, filed with FERC as applicable, granting a definitive interconnection right for the Project, subject to the completion of Material Interconnection Studies and required transmission system upgrades identified within such interconnection agreement or interim interconnection agreement, which is entered into by any applicable Clean Line Party and the interconnecting transmission owner(s) and system operators for (a) interconnection of the Project with the SPP-controlled transmission system, (b) interconnection of the Project with the MISO-controlled transmission system and/or (c) interconnection of the TN Facilities with the TVA transmission system.

"Intercreditor Agreement" has the meaning set forth in Section 11.7.

"Intermediate Converter Station" has the meaning set forth in the recitals.

"Investment Fund" means any Person that is established as an investment fund and is either (a) registered with the Securities and Exchange Commission under the Investment Company Act of 1940 or (b) exempt from registration under the Investment Company Act of 1940 pursuant to Section 3(c)(1) or 3(c)(7) of such Act.

"IPO Entity" has the meaning set forth in the definition of Qualified IPO.

"Key Person" means each of Mario Hurtado and Michael Skelly.

"Knowledge" means (a) with respect to any Clean Line Party, the actual knowledge of any Principal Person of such Clean Line Party or any knowledge that should have been obtained by any such Principal Person upon reasonable investigation and inquiry and (b) with respect to DOE, the actual knowledge of any Principal Person or any knowledge that should have been obtained by any such Principal Person upon reasonable investigation and inquiry. "Knowing" and "Known" shall be construed accordingly.

"Landowner" has the meaning set forth in Schedule 1 hereto.

"Lien" means any lien (statutory or other), pledge, mortgage, charge, security interest, deed of trust, assignment, hypothecation, title retention, fiduciary transfer, deposit arrangement, easement, encumbrance or preference, priority or other security agreement or preferential arrangement of any kind or nature whatsoever in respect of an asset, whether or not filed, recorded or otherwise perfected or effective under Applicable Law, as well as the interest of a vendor or lessor under any conditional sale agreement, Capital Lease or other title retention agreement relating to such asset, (including any conditional sale or other title retention agreement, any Capital Lease having substantially the same economic effect as any of the foregoing, or any preferential arrangement having the practical effect of constituting a security interest with respect to the payment of any obligation with, or from the proceeds of, any asset or revenue of any kind).

"Local Government Contribution Payments" means all infrastructure payments, voluntary payments and other payments (which are not Taxes) to be made by any Clean Line Party to local and state governments in connection with the Project, including those set forth in Schedule 4 hereto.

"Loss Proceeds" means all proceeds (other than any proceeds of business interruption insurance and proceeds covering liability of the Clean Line Entities to third parties) resulting from an Event of Loss.

"Loss Threshold" shall have the meaning set forth in the Insurance Agreement.

"Major Subcontractor" means each subcontractor at any tier performing work under a Material Construction Contract with a subcontract having a value, individually or in the aggregate, of $5,000,000 or more.

"Material Construction Contract" means each Construction Contract with a total value of more than $5,000,000 that relates in any material respect to the development, design, engineering and construction of the AR Facilities or any Project Facilities located (or to be located) on any DOE Acquired Real Property. For the avoidance of doubt, any Construction Contract that solely relates to the Other Facilities or any Project Facilities to be located on any Project Real Estate Rights that are not DOE Acquired Real Property shall not constitute a "Material Construction Contract".

"Material Interconnection Studies" means the TVA Facilities Study, an updated Criteria 3.5 Study as described in Exhibit B to the SPP Interconnection Agreement, the TVA System Impact Study, the SPP Facilities Study, the SPP System Impact Study, the MISO Interconnection Feasibility Study, the MISO Interconnection Facilities Study and the MISO Interconnection System Impact Study (or such comparable studies (i) if renamed or modified by revisions to the interconnection procedures of TVA, SPP and MISO or (ii) as required by an Interconnection Agreement).

"Material O&M Agreement" means each O&M Agreement that relates in any material respect to the operation, management and/or maintenance of the AR Facilities or any Project Facilities located (or to be located) on any DOE Acquired Real Property. For the avoidance of doubt, any O&M Agreement that solely relates to the Other Facilities or any Project Facilities to be located on any Project Real Estate Rights that are not DOE Acquired Real Property shall not constitute a "Material O&M Agreement".

"Material Project Contract" means, at any given time, the Interconnection Agreements, the Transmission Services Agreements, the Acceptable Permitted Project Investment Commitments, the Material Construction Contracts and the Material O&M Agreements, in each case, in effect at such time.

"MISO" has the meaning set forth in the recitals.

"MISO Interconnection Facilities Study" means an "Interconnection Facilities Study," including Definitive Planning Phase studies, as applicable, as defined in the MISO OATT and applicable business practice manuals related thereto.

"MISO Interconnection Feasibility Study" means an "Interconnection Feasibility Study" as defined in the MISO OATT and applicable business practice manuals related thereto.

"MISO Interconnection System Impact Study" means an "Interconnection System Impact Study" as defined in the MISO OATT and applicable business practice manuals related thereto.

"MISO OATT" means the MISO OATT on file with FERC.

"Mitigation Rights" means any real Property and conservation credits acquired by the Clean Line Entities associated with the avoidance, minimization, or mitigation of environmental impacts of the Project pursuant to Required Approvals.

"Moody's" means Moody's Investors Service, Inc., so long as it is a rating agency.

"MW" has the meaning set forth in the recitals.

"NEPA" means the National Environmental Policy Act of 1969 of the United States, as amended from time to time, and the regulations promulgated, and any applicable rulings issued, thereunder.

"NERC" means the North American Electric Reliability Corporation.

"NERC Agreement" has the meaning set forth in Section 4.9.

"NHPA" means the National Historic Preservation Act of 1966, as amended.

"Notice to Proceed" means a written notice issued by DOE to Holdings notifying Holdings that the conditions precedent set forth under Section 6.4 have been satisfied and that the Clean Line Entities may notify the Construction Contractors to commence performance of the work under the applicable Material Construction Contracts.

"O&M Agreement" means any Contractual Obligation entered into for the operation and maintenance of the Project with an annual value of more than $1,000,000.

"OATT" means an Open Access Transmission Tariff as defined under FERC's open access transmission rules and policies.

"OCC" means the Corporation Commission of Oklahoma.

"OCC 2011 Order" has the meaning set forth in Section 12.1(t).

"OFAC" means the Office of Foreign Assets Control, an agency of the U.S. Department of the Treasury under the auspices of the Under Secretary of the Treasury for Terrorism and Financial Intelligence.

"OFAC-Listed Person" has the meaning set forth in clause (a) of the definition of Prohibited Person.

"OFAC Sanctions Program" means any economic or trade sanction that OFAC is responsible for administering and enforcing. A list of OFAC Sanctions Programs may be found at http://www.treasury.gov/resource-center/sanctions/Programs/Pages/Programs.aspx.

"OK Facilities" has the meaning set forth in the recitals.

"Oklahoma Panhandle" means the geographic area within the panhandle region of Oklahoma, including Cimarron, Texas, and Beaver Counties.

"OLA" has the meaning set forth in the preamble.

"Operating Agreement" has the meaning set forth in Section 4.6.

"Operational EOD" means an Event of Default that (a) is an Event of Default pursuant to Section 7.3(f), (b) has resulted in an Adverse DOE Impact, (c) in DOE's reasonable judgment has resulted from, or arisen out of, the Clean Line Entities' detrimental, harmful, negligent or incompetent management, monitoring, supervision or administration of the construction, operation or maintenance of the Project on a persistent basis and (d) is not otherwise a Fundamental Event of Default.

"Organizational Documents" means with respect to any Person, (a) to the extent such Person is a corporation, the certificate or articles of incorporation and the by-laws of such Person, (b) to the extent such Person is a limited liability company, the certificate of formation or articles of formation or organization and operating or limited liability company agreement of such Person and (c) to the extent such Person is a partnership, joint venture, trust or other form of business, the partnership, joint venture or other applicable agreement of formation or organization and any agreement, instrument, filing or notice with respect thereto filed in connection with its formation or organization with the applicable Governmental Authority in the jurisdiction of its formation or organization and, if applicable, any certificate or articles of formation or organization or formation of such Person.

"Other Facilities" means, collectively, the TX Facilities and the TN Facilities.

"Participation Amount" has the meaning set forth in Section 11.2.

"Parties" means the Clean Line Parties and DOE.

"Patriot Act" means the USA PATRIOT Act of 2001 and all rules and regulations adopted thereunder, as amended.

"PECL" has the meaning set forth in the preamble.

"PECL OK" has the meaning set forth in the preamble.

"PECL Subsidiary" means (a) any direct or indirect Subsidiary of Holdings that owns any of the Equity Interests in PECL and (b) any direct or indirect Subsidiary of PECL.

"Performance Support" means any Acceptable Letter of Credit or Acceptable Guarantee issued in favor of DOE from time to time pursuant to the terms of this Agreement.

"Permitted Disposition" means:

(a) with respect to any Equity Interests in any Clean Line Entity or Property comprising the OK Facilities, any Permitted Lien or Permitted Project Investment;

(b) with respect to any Electrical Capacity, any Permitted Lien or other Disposition permitted under Section 2.3(c);

(c) with respect to any Project Real Estate Rights acquired by any Clean Line Entity, any Permitted Lien or other Disposition contemplated or permitted by Section 3.2;

(d) with respect to any other Property owned by any Clean Line Entity from time to time:

(i) Dispositions of such Property in the ordinary course of business and having a fair market value not in excess of $1,000,000 for a single transaction or $5,000,000 in the aggregate for all such transfers or Dispositions; provided that such Property is not necessary to the performance of the Project or the transactions contemplated by the Transaction Documents;

(ii) Dispositions of such Property that is, (A) obsolete, (B) no longer used or useful in the operation of the Project or (C) is promptly replaced (if applicable) by new or refurbished Property of equal or greater value and utility or having the same function (including upgraded models);

(iii) Dispositions of investment property in the ordinary course or in accordance with the granting of Permitted Liens;

(iv) Dispositions in connection with Events of Loss;

(v) Dispositions of Property in connection with warranty claims or assignments of Project Contracts permitted by the Project Financing Documents;

(vi) Dispositions of Mitigation Rights; or

(vii) Dispositions otherwise approved in writing by DOE.

"Permitted Draw Conditions" means conditions requiring the satisfaction of the following:

(a) truthfulness in all material respects of representations and warranties contained in the Project Financing Documents;

(b) the non-occurrence and continuance of any "default" or "event of default" or "material adverse effect" under the Project Financing Documents;

(c) the delivery of a customary notice of borrowing; and

(d) other usual and customary drawdown conditions applicable to construction financings for transmission projects.

"Permitted Holder" means any of the following Persons:

(a) National Grid plc;

(b) solely with respect to the Control of the Clean Line Entities, CLEP (provided that CLEP is Controlled by one or more Persons specified in clause (a) or clauses (c) through (g) of this definition);

(c) the Zilkha Family;

(d) the Ziff Family;

(e) Bluescape Resources;

(f) any Qualified Owner; or

(g) any other Person (other than any Clean Line Entity) Controlled by a combination of the foregoing Persons.

"Permitted Indebtedness" means:

(a) Existing Indebtedness;

(b) obligations or liabilities under any Project Contracts, the Transaction Documents, the Project Equity Commitments, the Project Debt Commitments, the Project Financing Documents;

(c) other liabilities or obligations allowed under the Project Financing Documents, if applicable;

(d) any inter-company receivables or payables among Affiliates of Holdings for obligations not constituting Indebtedness that either Holdings or CLEP have paid on behalf of such Affiliates;

(e) Indebtedness in the nature of guaranties or letters of credit, surety bonds or performance bonds securing the performance of a Clean Line Party pursuant to a Project Contract;

(f) Indebtedness in respect of netting services, overdraft protections and otherwise in connection with deposit accounts;

(g) guarantees in the ordinary course of business of the obligations of suppliers, customers, franchisees and licensees of any Clean Line Party; and

(h) other Indebtedness in an aggregate amount not to exceed $5,000,000 at any time outstanding.

"Permitted Liens" means:

(a) any Liens provided in favor of DOE or any rights and interests of the Project Financing Parties as provided in the Project Financing Documents that could constitute a Lien;

(b) Liens for any Tax, assessment or other governmental charge not yet due, or subject to Contest;

(c) Liens in favor of materialmen, workers or repairmen, or other like Liens arising in the ordinary course of business or in connection with the construction, repair or improvement of the Project, either for amounts not yet due or for amounts subject to Contest;

(d) such other defects, matters or records affecting or encumbering title to the Project Site, which do not and will not materially impair the use, development or operation of the Project, or materially interfere with the ordinary course of the business of the Clean Line Entities, or materially detract from the value of the Project Site;

(e) zoning, entitlement, building and other land use regulations imposed by Governmental Authorities having jurisdiction over the Project Site that do not and will not materially impair the use, development or operation of the Project, or materially interfere with the ordinary course of the business of the Clean Line Entities, or materially detract from the usefulness of the Project Site for its intended purpose;

(f) deposits to secure the performance of bids, trade contracts and leases (in each case, other than Indebtedness), statutory obligations, surety bonds (other than bonds related to judgments or litigation), performance bonds and other obligations of a like nature incurred in the ordinary course of business not in excess of $5,000,000;

(g) Liens arising out of the judgment of a Governmental Authority so long as enforcement of such Lien has been stayed and an appeal or proceeding for review is being prosecuted in good faith and for the payment of which adequate reserves or other security reasonably acceptable to DOE have been provided or are fully covered by insurance;

(h) Liens to secure Capital Lease Obligations and purchase money Liens on Property purchased securing obligations not in excess of $5,000,000;

(i) Liens (not securing Indebtedness) of depository institutions and securities intermediaries (including rights of set-off or similar rights) with respect to one or more checking accounts or other banking accounts (other than Account Collateral) established by the Clean Line Entities to conduct their business;

(j) Liens securing judgments for the payment of money not constituting an Event of Default or securing appeal or other surety bonds related to such judgments;

(k) pledges or deposits or other Liens in the ordinary course of business in connection with worker's compensation, unemployment insurance, social security and other governmental rules or restrictions that have the force of law; and

(l) Liens on Property of the Clean Line Entities not essential for the operation of the Project and having a fair market value of less than $1,000,000 in the aggregate.

"Permitted Project Investments" has the meaning set forth in Section 2.3(c)(iii).

"Person" means any individual, entity, firm, corporation, company, voluntary association, partnership, limited liability company, joint venture, trust, unincorporated organization, Governmental Authority, committee, department, authority or any other body, incorporated or unincorporated, whether having distinct legal personality or not.

"Principal Person" means (a) with respect to any Clean Line Party, any officer, director, owner, key employee or other Person with primary management or supervisory responsibilities with respect to such Person or any other Person (whether or not an employee) who has critical influence on or substantive control over such Person and (b) with respect to DOE, the Person(s) holding primary management or supervisory responsibilities for DOE with respect to the Project.

"Prohibited Person" means any Person (or any Person that is an Affiliate of a Person) that is:

(a) named, identified or described on the list of "Specially Designated Nationals and Blocked Persons" as published by OFAC (an "OFAC-Listed Person");

(b) an agent, department or instrumentality of, or is otherwise beneficially owned by, Controlled by or acting on behalf of, directly or indirectly, (i) an OFAC-Listed Person or (ii) any Person, organization, foreign country or regime that is subject to any Sanctions;

(c) debarred, suspended, proposed for debarment with a final determination still pending, declared ineligible or voluntarily excluded (as such terms are defined in the Debarment Regulations) from contracting with any United States federal government department or any agency or instrumentality thereof or otherwise participating in procurement or non-procurement transactions with any United States federal government or agency pursuant to any of the Debarment Regulations;

(d) indicted, convicted or had a final and non-appealable Governmental Order rendered against it for any of the offenses listed in any of the Debarment Regulations; or

(e) otherwise blocked, subject to sanctions under or engaged in any activity in violation of other United States economic sanctions, including but not limited to, the Trading with the Enemy Act, the International Emergency Economic Powers Act, the Comprehensive Iran Sanctions, Accountability and Divestment Act or any similar law or regulation with respect to Iran or any other country, the Sudan Accountability and Divestment Act, any OFAC Sanctions Program, or any economic sanctions regulations administered and enforced by the United States or any enabling legislation or executive order relating to any of the foregoing.

"Project" has the meaning set forth in the recitals.

"Project Budget" means a reasonably detailed description and a reasonably detailed budget of anticipated Construction Costs (which shall include a Contingency Amount).

"Project Completion" means the occurrence of each of the following: (a) if the Project Financing is then in effect, (i) the Project has commenced commercial operation and has satisfied the requirements for "substantial completion" (or term of similar import) as defined in and in accordance with all Construction Contracts and the initial Electrical Capacity (as specified in the definition thereof) of the Project has been certified by an Independent Engineer, (ii) the Project has safely and reliably energized and energy may be delivered across the Project Facilities to SPP's, MISO's and TVA's transmission systems in accordance with the Interconnection Agreements and (iii) the occurrence of "final completion," "project completion" or "term conversion" (or term of similar import) for purposes of the Project Financing (including the funding of any required financial reserves as a condition precedent to the occurrence thereof) or (b) if the Project Financing is not then in effect, satisfaction of the Completion Conditions.

"Project Contracts" means each of the following:

(a) any Construction Contract, including any such agreement that may be entered into from time to time in respect of any Capital Repairs or improvements relating to the Project;

(b) each Transmission Services Agreement and each Contractual Obligation evidencing a Permitted Project Investment in effect from time to time;

(c) each Operating Agreement and Interconnection Agreement in effect from time to time;

(d) the NERC Agreement;

(e) any O&M Agreement in effect from time to time;

(f) each Real Estate Rights Agreement; and

(g) any other agreement entered into by the Clean Line Entities and/or DOE in respect of development, design, engineering, construction, ownership, operation, maintenance and management of the Project, including any management service agreements, intellectual property license agreements and any retainer agreements relating to any consultants.

"Project Costs" means all costs and expenses incurred or to be incurred by any Clean Line Entity or DOE in connection with the Project, including: (a) expenses of administering and maintaining the corporate existence of the Clean Line Entities, (b) amounts payable under any other Project Contract in effect from time to time, (c) amounts payable in respect of the Project Financing (including interest, premium, principal and fees), (d) costs to acquire title or use rights of any Project Real Estate Rights and the Project Site, (e) any network upgrade costs required to be paid pursuant to the terms of the Interconnection Agreements, (f) costs and expenses of legal, engineering, accounting, construction management and other advisors or consultants incurred in connection with the Project, (g) labor costs, (h) mobilization costs, (i) funding of any required reserves (including any debt service reserve or other similar reserve required in connection with the Project Financing), (j) maintenance and Capital Repair expenses, (k) costs associated with any Wind-Up Event, (l) costs and expenses incurred in connection with obtaining any Required Approval and Required Insurance, (m) any other Covered Cost and (n) any Covered Liability.

"Project Development Progress Report" means, as of any date, a development progress report in respect of the Project that (a) describes in detail the status of the developmental activities related to the Project completed as of such date and (b) provides a reasonably detailed schedule of the project development, design, engineering, financing and construction activities expected to be undertaken after such date in order to achieve Project Completion (the "Project Schedule").

"Project Equity Commitments" means one or more equity commitments (which may include a commitment to provide loans) provided by any Acceptable Support Provider or Credit-Worthy Affiliate to the Clean Line Entities or any of the Project Financing Parties in respect of the funding of Construction Costs.

"Project Facilities" has the meaning set forth in the recitals.

"Project Financial Close" means that the following conditions have been satisfied in full:

(a) the Clean Line Entities shall have obtained Project Financing and Project Equity Commitments in an amount equal to 100% of the total Construction Costs as set forth in the then current Project Budget (including the Contingency Amount contemplated thereby) as confirmed, at the election of DOE, by an Independent Engineer;

(b) all Project Financing Documents required in order to obtain the funding referred to in clause (a) above shall have been executed and delivered by all parties thereto and shall be in full force and effect, and DOE shall have received certified copies of all such Project Financing Documents;

(c) all conditions precedent (other than the Permitted Draw Conditions) under the Project Financing Documents referred to in clause (b) above shall have been satisfied or permanently waived;

(d) the first drawdown of loans (or issuance of debt securities, to the extent applicable) under the Project Financing shall have occurred; and

(e) DOE shall have received satisfactory evidence demonstrating that each of the foregoing conditions has been satisfied.

"Project Financing" means, subject to Section 13.5, any debt securities or syndicated commercial bank or other syndicated credit facilities (including any working capital facilities and letter of credit facilities) issued or obtained by the Clean Line Entities from Persons other than Affiliated Lenders to finance the development and construction of the Project in an amount equal to not less than forty percent (40%) of the anticipated total Construction Costs on a limited recourse basis and any refinancing that takes a similar form.

"Project Financing Commitments" means one or more debt financing commitment letters provided by lenders or financial institutions (other than Affiliated Lenders) in respect of the Project Financing.

"Project Financing Documents" means all financing (including all security documentation) and equity contribution agreements entered into in respect of the Project Financing and the Project Equity Commitments.

"Project Financing Parties" means the Persons holding any debt securities or providing loans, other credit facilities or interest rate hedging facilities as part of the Project Financing (and including any agent or trustee thereof), but excluding any Affiliated Lender. Prior to Project Financial Close, the Project Financing Parties will be deemed to include any lenders or financial institutions providing Project Financing Commitments to the Clean Line Parties.

"Project Participant" means any Contractor or any other Person (other than a Clean Line Party or DOE) that is party to a Project Contract from time to time.

"Project Plans" means the reasonably detailed execution plans for the Project (which shall include a reasonably detailed description of the Project and the Project Budget) delivered by Holdings to DOE encompassing all development, design, engineering, construction, financing, operation, maintenance, management, replacement and decommissioning activities of the Project.

"Project Real Estate Rights" means any Real Estate Rights necessary for the Project, including access roads and temporary areas to be used for construction and maintenance activities in respect of the Project.

"Project Schedule" has the meaning set forth in the definition of Project Development Progress Report.

"Project Site" means all Real Estate Rights on which any of the Project Facilities are situated or are to be constructed, including, but not limited to, the areas and encroachments covered by the Project Real Estate Rights and any other land necessary for the Project.

"Project Subsidiary" means (a) any Subsidiary of Holdings that owns any Property or other rights relating to the Project, including each of ACL, PECL OK and OLA and (b) any Subsidiary of Holdings that, directly or indirectly, owns any Equity Interests of any such Subsidiary; provided that the term "Project Subsidiary" shall not include PECL or any PECL Subsidiary.

"Project Work Agreement" means an agreement with TVA pursuant to which TVA begins the necessary work to construct system upgrades necessary for the Project prior to the execution of an Interconnection Agreement with TVA.

"Property" means any right or interest in or to any asset or property of any kind whatsoever (including Equity Interests), whether real, personal or mixed and whether tangible or intangible.

"Prudent Utility Practices" means any of the acts, practices, methods, equipment, materials, specifications and standards engaged in or approved in connection with a significant portion of the electric utility industry in North America which, as applicable, in the exercise of professional judgment in light of the facts known at the time a decision was made, would have been expected to accomplish the desired result in a manner consistent with Applicable Laws, DOE Policies, any Electric Reliability Organization requirements, reliability, safety, dependability, environmental protection and expedition.

"PUHCA" means the Public Utility Holding Company Act of 2005, and FERC's regulations thereunder.

"Qualified IPO" means the issuance by any Clean Line Entity or any Person that Controls Clean Line (the "IPO Entity") of its common Equity Interests in an underwritten primary public offering (other than a public offering pursuant to a registration statement on Form S-8) pursuant to an effective registration statement filed with the Securities Exchange Commission in accordance with the Securities Act of 1933 (whether alone or in connection with a secondary public offering) which after giving effect thereto shall result in (a) no Person or group of Persons having Control over the IPO Entity or any of the Clean Line Entities (other than the IPO Entity) and any direct or indirect Person in the ownership chain between the IPO Entity and the Clean Line Entities (other than the IPO Entity) and (b) the common voting Equity Interests of such IPO Entity being traded on a regulated United States securities exchange.

"Qualified Owner" means any Person meeting all of the following requirements at the time of its acquisition of any direct or indirect Equity Interests in the Clean Line Entities, as applicable:

(a) (i) neither such Person nor any Person that, directly or indirectly, Controls such Person or any of their respective Principal Persons is a Prohibited Person and (ii) no event has occurred and no condition exists that is likely to result in such

Person or any Person that, directly or indirectly Controls such Person or any of their respective Principal Persons becoming a Prohibited Person;

(b) such Person does not owe any delinquent Indebtedness to any Governmental Authority of the United States, including Tax liabilities, except to the extent such delinquency has been resolved (or is in the process of being resolved) with the appropriate Governmental Authority in accordance with the standards of the Debt Collection Improvement Act;

(c) (i) such Person, and each Person that, directly or indirectly, Controls such Person, and each of their respective Principal Persons, employees and agents have complied with OFAC, all other applicable Anti-Corruption Laws and all AM laws in obtaining any consents, licenses, approvals, authorizations, rights or privileges with respect to such Person's acquisition of any direct or indirect Equity Interests in the Clean Line Entities and (ii) the internal management and accounting practices and controls of such Person and each Person that, directly or indirectly, Controls such Person are adequate to ensure compliance with all applicable Anti-Corruption Laws, AM Laws and Sanctions;

(d) such Person is organized under the laws of an Organization for Economic Co-operation and Development member country;

(e) such Person has provided DOE all documentation and other information under applicable "know your customer" and anti-money laundering rules and regulations, including the Patriot Act, that would customarily be provided or delivered to a financial institution in connection with a transaction involving an extension of credit to such Person at least thirty (30) days prior to its acquisition, directly or indirectly, of any Equity Interests in the Clean Line Entities and DOE shall not have notified Holdings of its objection to such Person's acquisition of such interests within such thirty (30) day period; and

(f) all necessary Governmental Approvals arising as a result of such Person's acquisition of such Equity Interests shall have been obtained and in full force and effect, and, to the extent applicable, the Committee on Foreign Investment in the United States shall have approved such acquisition.

"Real Estate Rights" means any real property rights, including temporary property rights and access rights (whether in the form of fee simple, a leasehold, easement, sub-easement, right of way, license, permit, concession or otherwise).

"Real Estate Rights Agreement" means any agreement entered into from time to time by any Clean Line Entity and/or DOE in respect of the acquisition of any Project Real Estate Rights (including any easement or right of way).

"Release" means disposing, discharging, injecting, spilling, leaking, leaching, dumping, pumping, pouring, emitting, escaping, emptying, seeping, placing and the like, into or upon any land or water or air, or otherwise entering into the environment.

“Release Provision” has the meaning set forth in Section 11.10(a).

“Remaining DOE Acquisition Costs” means, as of any time of determination, the aggregate of all Covered Costs reasonably anticipated to be incurred in connection with the acquisition of any Project Real Estate Rights reasonably anticipated to be designated as DOE Acquired Real Property as of such time of determination, as determined from time to time by the Coordination Committee.

“Remaining Project Costs” means (a) as of the issuance of the Notice to Proceed, (i) the amount of all Construction Costs reasonably anticipated by the Clean Line Entities to be incurred after the issuance of the Notice to Proceed in connection with achieving Project Completion (based on the then applicable Project Plans and Project Schedule) as confirmed, at the election of DOE, by an Independent Engineer *plus* (ii) the Base Contingency Amount and (b) as of any time of determination after the issuance of the Notice to Proceed, the sum of (i) the amount of all Construction Costs reasonably anticipated by the Clean Line Entities as of such time of determination to be incurred from and after such time of determination in connection with achieving Project Completion (based on the then applicable Project Plans and Project Schedule) as confirmed, at the election of DOE, by an Independent Engineer *plus* (ii) the then applicable Contingency Amount.

“Representation Date” has the meaning set forth in Section 12.1.

“Required Amount” means, as of any date of determination, the amount equal, without duplication, to the sum of the Base Amount *plus* the Advanced Funding Contingency Amount.

“Required Approvals” means all material Governmental Approvals and other material consents and approvals of third parties necessary or required under Applicable Law, DOE Policies or any Contractual Obligation for the development, design, engineering, construction, financing, ownership, operation, maintenance, management, replacement and decommissioning of the Project and the sale and provision of transmission services over the Project Facilities.

“Required Insurance” means insurance coverage for the Project as required by the Insurance Agreement as in effect from time to time.

“RFP” has the meaning set forth in the recitals.

“Routing and ROW Plan” means a plan prepared by Holdings, and acceptable to the Coordination Committee, specifying the planned routing corridor for the Project Facilities, identifying all Project Real Estate Rights and including a reasonably detailed budget covering all costs, expenses and disbursements projected to be expended in connection with the acquisition of such Project Real Estate Rights.

“S&P” means Standard & Poor’s Financial Services LLC or its successor, so long as it is a rating agency.

“Safety Compliance” means with respect to the Project Facilities any and all improvements, repair, reconstruction, rehabilitation, restoration, renewal, replacement and changes in configuration or procedures respecting the Project Facilities to correct a specific

Safety Event that DOE has reasonably determined to exist by investigation or analysis, provided that DOE's determination shall be consistent with Prudent Utility Practices and Applicable Laws.

"Safety Compliance Order" means a written order from DOE to Holdings to implement Safety Compliance.

"Safety Event" means with respect to the Project Facilities (a) a material hazard, danger or other material risk to public or worker health or safety, (b) a material structural deterioration of a material portion of the Project or (c) material damage to a third party's Property or equipment.

"Sanctions" means economic or financial sanctions or trade embargoes or restrictive measures enacted, imposed, administered or enforced from time to time by (a) the United States government, including those administered by OFAC, the U.S. Department of State or the U.S. Department of Commerce, (b) the United Nations Security Council, (c) the European Union or any of its member states or (d) any other applicable Governmental Authority and including, for the avoidance of doubt, the Trading with the Enemy Act, the International Emergency Economic Powers Act, the Comprehensive Iran Sanctions, Accountability and Divestment Act and the Sudan Accountability and Divestment Act.

"Second Lien Collateral" has the meaning set forth in Section 11.6(a)(iii).

"Security Documents" means the security agreements, pledge agreements, financing statements, account control agreements or other instruments and documents that creates or purports to create or perfect a Lien on the Collateral in favor of DOE and, if applicable, the Intercreditor Agreement.

"Section 1222" has the meaning set forth in the recitals.

"Section 1222 Decision" has the meaning set forth in Section 6.1(a).

"Solvent" and "Solvency" mean, with respect to any Person on a particular date, that on such date (a) the fair value of the Property of such Person is greater than the total amount of liabilities, including contingent liabilities, of such Person, (b) the present fair salable value of the assets of such Person is not less than the amount that will be required to pay the probable liability of such Person on its debts as they become absolute and matured, (c) such Person does not intend to, and does not believe that it will, incur debts or liabilities beyond such Person's ability to pay such debts and liabilities as they mature and (d) such Person is not engaged in business or a transaction, and is not about to engage in business or a transaction, for which such Person's Property would constitute an unreasonably small capital. The amount of contingent liabilities at any time shall be computed as the amount that, in the light of all the facts and circumstances existing at such time, represents the amount that can reasonably be expected to become an actual or matured liability.

"SPP" has the meaning set forth in the recitals.

"SPP Facilities Study" means a "Facilities Study" as defined in the SPP OATT and applicable criteria and business practice documents related thereto.

"SPP OATT" means the SPP OATT on file with FERC and applicable criteria and business practice documents related thereto.

"SPP System Impact Study" means a "System Impact Study" as defined in the SPP OATT.

"Subsidiary" of any Person, means any corporation, partnership, joint venture, limited liability company, trust or estate of which (or in which) more than fifty percent (50%) of (a) the issued and outstanding capital stock having ordinary voting power to elect a majority of the board of directors of such corporation (irrespective of whether at the time capital stock of any other class or classes of such corporation shall or might have voting power upon the occurrence of any contingency), (b) the interest in the capital or profits of such partnership, joint venture or limited liability company or (c) the beneficial interest in such trust or estate, in each case, is at the time directly or indirectly owned or controlled by such Person, by such Person and one or more of its other Subsidiaries or by one or more of such Person's other Subsidiaries.

"Subsidiary Guarantor" has the meaning set forth in Section 9.1(a).

"SWPA" has the meaning set forth in the recitals.

"Taxes" means all taxes, levies, imposts, duties, deductions, charges or withholdings imposed by any Governmental Authority, including any interest, penalties or additions thereto imposed in respect thereof.

"Termination Date" means the date on which this Agreement is terminated in accordance with Sections 7.1(a) or 7.1(b).

"Texas Panhandle" means the geographic area within the panhandle region of Texas, including Sherman, Ochiltree, and Hansford Counties.

"Threatened or Endangered Species" means any species listed by the United States Fish and Wildlife Service as threatened or endangered pursuant to the Endangered Species Act, as amended, 16 U.S.C. § 1531, *et seq.*, or any species listed as threatened or endangered pursuant to a state endangered species act.

"Title Defect" has the meaning set forth in Schedule 1 hereto.

"Title Search" has the meaning set forth in Schedule 1 hereto.

"TN Facilities" means those facilities developed by the Clean Line Parties in Tennessee.

"TRA" means the Tennessee Regulatory Authority.

"TRA 2015 Order" has the meaning set forth in Section 12.1(t).

"Transaction Documents" means this Agreement, the NERC Agreement, the Insurance Agreement, the Security Documents, any Performance Support and any other Contractual

Obligation entered into between DOE and any Clean Line Obligor from time to time in respect of the Project.

"Transmission Services Agreement" means a transmission services agreement under which the Clean Line Entities have agreed to provide transmission services using the Electrical Capacity owned by the Clean Line Parties.

"TSA Precedent Agreement" means a transmission services precedent agreement pursuant to which the Clean Line Entities and the counterparty agree to negotiate and enter into a Transmission Services Agreement.

"TVA" means the Tennessee Valley Authority.

"TVA Facilities Study" means a "Facilities Study" as defined in TVA's Transmission Service Guidelines and other applicable procedure documents related thereto.

"TVA System Impact Study" means a "System Impact Study" as defined in TVA's Transmission Service Guidelines and other applicable procedure documents related thereto.

"TX Facilities" means those facilities developed by the Clean Line Parties in Texas.

"Uncontested Acquisition" means any Acquisition by Condemnation instituted as a result of a request by any Landowner or Curative Party holding the applicable Project Real Estate Rights that such Project Real Estate Rights be acquired through condemnation. Determinations as to whether any Acquisition by Condemnation meets this definition of Uncontested Acquisition are to be made by DOE in its sole discretion and the undertaking of any Uncontested Acquisition prior to the satisfaction of the conditions precedent in Section 6.3 shall be at the sole discretion of DOE. DOE's further pursuit of Uncontested Acquisitions that subsequently are contested by the Landowner or Curative Party in a court of law will become subject to the satisfaction of those conditions precedent applicable to Acquisitions by Condemnation in Section 6.3.

"Uniform Act" has the meaning set forth in Schedule 1 hereto.

"Voluntary Land Acquisition" means (a) an acquisition of Project Real Estate Rights by DOE through an arm's length third party negotiated transaction or (b) at the sole option of DOE prior to the satisfaction of the conditions precedent set forth in Section 6.3, an Uncontested Acquisition.

"Waiver Parcel" has the meaning set forth in Schedule 1 hereto.

"WAPA" means the Western Area Power Administration.

"Wind-Up Event" has the meaning set forth in Section 7.5(a).

"Wind-Up Reserve Account" has the meaning set forth in Section 7.6.

"Work" means the development, design, engineering, construction, financing, operation, maintenance (including any Capital Repairs) and management of the Project, except for any obligations expressly contemplated by this Agreement to be performed by DOE.

"Ziff Family" means, collectively, (a) Dirk Ziff, Robert D. Ziff and Daniel M, Ziff, and their children and other lineal descendants, (b) the spouses or former spouses, widows or widowers of any of the Persons referred to in clause (a), (c) any (i) estate of one or more of the Persons listed in clauses (a) and (b) above or (ii) trust having as its sole beneficiaries one or more of the Persons listed in clauses (a) and (b) above and (d) any Person (other than any Clean Line Entity) the voting power of the outstanding ownership interests of which is Controlled by one or more of the Persons referred to in clauses (a), (b) and (c) above.

"Zilkha Family" means, collectively, (a) Michael Zilkha and his children and other lineal descendants; (b) the spouses or former spouses, widows or widowers of any of the Persons referred to in clause (a); (c) any (i) estate of one or more of the Persons listed in clauses (a) and (b) above or (ii) trust having as its sole beneficiaries one or more of the Persons listed in clauses (a) and (b) above; and (d) any Person (other than any Clean Line Entity) the voting power of the outstanding ownership interests of which is Controlled by one or more of the Persons referred to in clauses (a), (b) and (c) above.

1.2 Rules of Interpretation. In this Agreement, unless otherwise indicated:

(a) any reference to this Agreement or any other Contractual Obligation means such agreement and all schedules, exhibits and attachments thereto as the same may be amended, supplemented or otherwise modified and in effect from time to time, and shall include a reference to any document that amends, modifies or supplements it, or is entered into, made or given pursuant to or in accordance with its terms;

(b) each reference to any Applicable Law or Environmental Law shall be deemed to refer to such Applicable Law or Environmental Law as the same may be amended, supplemented or otherwise modified from time to time;

(c) any reference to a Person in any capacity includes a reference to its permitted successors and assigns in such capacity and, in the case of any Governmental Authority, any Person succeeding to any of its functions and capacities;

(d) references to days shall refer to calendar days unless Business Days are specified;

(e) references to weeks, months or years shall be to calendar weeks, months or years, respectively;

(f) the table of contents and section headings and other captions therein are for the purpose of reference only and do not affect the interpretation of this Agreement;

(g) Article, Section and Schedule references within this Agreement are in reference to Articles, Sections and Schedules of this Agreement unless the context requires otherwise;

(h) in the event of any conflict or inconsistency between any provisions contained in the documents comprising this Agreement, the Articles and Sections of this Agreement, as modified by any amendments or other modifications from time to time, shall take precedence over the Schedules and any other attachments to this Agreement;

(i) defined terms in the singular shall include the plural and vice versa, and the masculine, feminine or neuter gender shall include all genders;

(j) the words “hereof”, “herein” and “hereunder”, and words of similar import, when used in this Agreement, shall refer to this Agreement as a whole and not to any particular provision of this Agreement;

(k) the words “include,” “includes” and “including” are deemed to be followed by the phrase “without limitation” unless the context specifically indicates otherwise;

(l) words not otherwise defined herein that have well-known and generally accepted technical or trade meanings are used herein in accordance with such recognized meanings;

(m) where the terms of this Agreement require that the approval, opinion, consent or other input of any Party be obtained, such requirement shall be deemed satisfied only where the requisite approval, opinion, consent or other input is given by or on behalf of the relevant Party in writing; and

(n) any reference to “recitals” shall be a reference to the paragraphs immediately following the header of “recitals.”

ARTICLE II
PROJECT OWNERSHIP STRUCTURE

2.1 <u>Scope of the Clean Line Entities’ Rights in Respect of the Project</u>.

(a) Pursuant to the terms of this Agreement (and subject in all respects to the terms and conditions hereof), the Clean Line Entities and DOE shall, at the sole cost and expense of the Clean Line Parties, undertake the Project.

(b) From and after the Commencement Date, the Clean Line Entities and their authorized representatives (including any Contractors) shall have the right (subject to the other terms and conditions of the Transaction Documents and the Real Estate Rights Agreements) to enter into and use any DOE Acquired Real Property and the AR Facilities for purposes of carrying out the Project. Prior to the Commencement Date, the Clean Line Entities shall be solely responsible for gaining any access needed to any Project Real Estate Rights. Absent agreement by the Parties as to a later date, the Clean Line Entities’ rights to enter into and use DOE Acquired Real Property or the AR Facilities shall automatically terminate on the Termination Date, and, on and after the Termination Date, all Project Facilities shall be removed at the Clean Line Entities’ expense if so requested by DOE.

(c) Subject to the foregoing and the other provisions of this Agreement, the Clean Line Parties shall not have any fee title, leasehold estate, possessory interest, permit, easement or other Real Estate Right of any kind in or to any DOE Acquired Real Property or in any of the AR Facilities. With respect to the AR Facilities and any DOE Acquired Real Property, the Clean Line Entities' interests under this Agreement shall be limited to contract rights constituting intangible personal property (and not real estate interests).

(d) The Clean Line Entities' rights under this Agreement shall be subject in all respects to (i) DOE's ownership of any DOE Acquired Real Property and of the AR Facilities and (ii) all of DOE's rights and remedies under the Transaction Documents.

(e) The Clean Line Entities' rights under this Agreement shall be subject in all respects to, and each of the Clean Line Entities shall be responsible for compliance with, the provisions of all Contractual Obligations (including any Real Estate Rights Agreement), Governmental Approvals or Governmental Orders pursuant to which DOE acquires ownership of any DOE Acquired Real Property, including paying all rents, Taxes, charges and filings fees in connection therewith on behalf of DOE; provided that to the extent that pursuant to any Applicable Law DOE has any non-delegable obligations or duties in respect of any undertakings under any Contractual Obligation (including any Real Estate Rights Agreement), Governmental Approval or Governmental Order relating to the Project, the obligations of the Clean Line Entities under this clause (e) shall be limited to (i) payment of all Covered Costs of DOE incurred in connection with such performance, (ii) providing access to DOE with respect to the Project Site and Project Facilities and (iii) otherwise using all commercially reasonable efforts to support and cooperate with DOE in order to enable DOE to perform any such non-delegable obligations and duties.

(f) Neither DOE nor any other Covered Party shall be in any way responsible or liable for any Indebtedness, losses, obligations or duties of any Clean Line Party or any other Person with respect to the Project, the TN Facilities, the TX Facilities or any other business or undertaking entered into or conducted by or on behalf of any Clean Line Party or the Project. All obligations to pay Project Costs, Taxes, assessments, insurance premiums, and all other fees, costs and expenses arising from or in connection with the Project (including the acquisition of Project Real Estate Rights) and all obligations to perform under any Contractual Obligation relating to the Project (other than DOE's obligations as expressly provided in this Agreement and in any other Transaction Document) shall be the sole responsibility of the Clean Line Parties.

2.2 Ownership of Project Facilities. Each of the Parties hereby agrees and acknowledges that:

(a) DOE shall own 100% of the AR Facilities.

(b) PECL OK shall own 100% of the OK Facilities. Except to the extent constituting a Permitted Disposition, PECL OK shall not Dispose of any of its rights or interests in the OK Facilities without DOE's prior written consent.

2.3 Rights to Electrical Capacity.

(a) Pursuant to this Agreement, Holdings and/or any Clean Line Entity designated or nominated by Holdings, collectively, own 100% of the Electrical Capacity and have the right to market, use and sell transmission services relating to such Electrical Capacity pursuant to a Transmission Services Agreement or as otherwise permitted pursuant to Section 2.3(c), subject to FERC's open access transmission rules and policies.

(b) All transmission and related services provided by any of the Clean Line Entities using any of the Project Facilities shall be provided in accordance with Applicable Laws and Prudent Utility Practices.

(c) No Clean Line Entity shall Dispose of any of its rights or interests in any of the Electrical Capacity except:

(i) marketing and sales of transmission services using Electrical Capacity pursuant to Transmission Services Agreements as contemplated in this Agreement;

(ii) pledges or assignments of the Clean Line Entities' rights and interests in the Electrical Capacity and rights under any Transmission Services Agreements to which any Clean Line Entity is a party to the Project Financing Parties as collateral security for its obligations in respect of the Project Financing or to DOE as contemplated by Section 11.6;

(iii) sales or transfers of Electrical Capacity to Persons making an equity investment in any Clean Line Entity in an aggregate amount not to exceed, unless consented to by DOE, the lesser of (A) 500 MW (net) and (B) 20% of the net Electrical Capacity ("Permitted Project Investments"); provided that such Persons: (1) agree that the use of such Electrical Capacity shall be in accordance with FERC's open access transmission rules and policies applicable to such Person, Prudent Utility Practices and Applicable Laws, (2) make the representations, warranties and covenants set forth in Schedule 13 hereto for DOE's benefit, (3) agree not to transfer such Electrical Capacity to Prohibited Persons and (4) agree to the Release Provision; provided further that after giving effect to the applicable equity investment, (x) no Change of Control shall have occurred and (y) DOE shall have a fully perfected security interest in the Equity Collateral; and

(iv) other Dispositions consented to in writing by DOE in its sole discretion.

(d) Subject to DOE's compliance with its obligations under this Agreement, in no event shall DOE or any other Covered Party under any circumstances have any liability to any Clean Line Party or any other Person in respect of any unavailability of any Electrical Capacity.

ARTICLE III
ACQUISITION OF PROJECT REAL ESTATE RIGHTS

3.1 Generally. The Project Real Estate Rights shall be those set forth in the Routing and ROW Plan as in effect from time to time and shall be acquired by the Parties in accordance with the terms of this Agreement.

3.2 Clean Line Entities' Obligation to Acquire Project Real Estate Rights.

(a) The Clean Line Entities have the primary responsibility for acquiring all Project Real Estate Rights. In connection therewith, the Clean Line Entities shall use all commercially reasonable and good faith efforts to acquire all Project Real Estate Rights in accordance with the terms and conditions set forth in Schedule 1 hereto.

(b) To the extent that any Clean Line Entity acquires any Project Real Estate Rights in Arkansas, such Clean Line Entity will grant to DOE, at no cost to DOE, a lease, sub-easement, right of way or other appropriate property interest or right of use in respect of such Project Real Estate Rights for all purposes of the development, design, engineering, construction, ownership, operation, maintenance and management of the AR Facilities. To the extent that any Clean Line Entity acquires any title insurance for Project Real Estate Rights in Arkansas or in respect of any other DOE Acquired Real Property, the Clean Line Entities shall use commercially reasonable efforts to name DOE as an additional insured in respect of such title insurance.

(c) Solely for purposes of any exercise by DOE of any of its remedies upon the occurrence of an Operational EOD, each of the Clean Line Entities hereby grants to DOE and its designated replacement operator(s), at no cost to DOE or such replacement operator(s), a right of access and use in respect of any Real Estate Rights acquired by any of the Clean Line Parties in Oklahoma and in respect of the OK Facilities. Similarly, DOE agrees, upon the occurrence of an Operational EOD and exercise of the remedy described in Section 7.4(a)(v), to grant to DOE's designated replacement operator(s) a right of access and use in respect of any DOE Acquired Real Property and the AR Facilities for purposes of carrying out the Project.

(d) Except for the grant to DOE of an interest in any Project Real Estate Rights acquired by the Clean Line Entities pursuant to the foregoing, the Clean Line Entities shall not Dispose of any of their respective rights or interests in any Project Real Estate Rights acquired by any of the Clean Line Entities (which excludes, for the avoidance of doubt, any DOE Acquired Real Property) without DOE's prior written consent; provided that no such consent shall be required for (i) any pledge or assignment to the Project Financing Parties as collateral security for Clean Line Entities' obligations under the Project Financing or to DOE (as contemplated by Section 11.6) or (ii) Project Real Estate Rights that are not necessary or are not reasonably likely to be necessary (A) for the development, construction or operation of the Project in accordance with Prudent Utility Practices, the Routing and ROW Plan, any Clean Line Document and the Project Plans as in effect from time to time or (B) for any of the Clean Line Parties to perform its obligations under any Clean Line Document to which it is a party from time to time (including any Transmission Services Agreements).

3.3 DOE's Acquisition of Project Real Estate Rights.

(a) Subject to the terms and conditions set forth in Schedule 1 hereto, Holdings shall be entitled to designate a Project Real Estate Right as a Real Estate Right to be acquired by DOE in the following circumstances (each, a "DOE Delegated Real Estate Right"):

(i) the Clean Line Entities have been unable, after using all commercially reasonable efforts and in compliance with their obligations hereunder, to locate any Landowner or Curative Party whose consent (or action) is necessary for a conveyance to the Clean Line Entities of a Project Real Estate Right in respect of any underlying Real Estate Right;

(ii) a Title Defect exists with respect to the underlying Real Estate Right and, notwithstanding the Clean Line Entities' compliance with their obligations hereunder and in Schedule 1 hereto, the Clean Line Entities have been unable to obtain any consent from or other necessary action by any Curative Party to enable the applicable Landowner to grant or convey a Project Real Estate Right to the Clean Line Entities in respect of the underlying Real Estate Right; or

(iii) the Clean Line Entities have been unable, after having otherwise complied with all of their obligations specified under Schedule 1 hereto, to acquire the applicable Project Real Estate Right.

(b) At the sole cost and expense of the Clean Line Entities (and subject to Section 11.1) and subject to the satisfaction of the conditions precedent set forth below under Sections 6.2 and 6.3, as applicable, DOE shall assume responsibility for acquiring and shall acquire any DOE Delegated Real Estate Rights through a Voluntary Land Acquisition, Acquisition by Condemnation or through any other manner available to it under Applicable Law as contemplated herein on a prompt and timely basis (taking into account the fact that DOE's ability to promptly and timely acquire any such DOE Delegated Real Estate Rights may be subject to the actions of other third party Persons or Governmental Authorities). Subject to the foregoing sentence and DOE's compliance with its other obligations under this Agreement, the Clean Line Parties bear the risk of any time and cost impacts to the Project and Other Facilities related to DOE's acquisition of the DOE Delegated Real Estate Rights.

(c) DOE shall not be required to enter into any Real Estate Rights Agreement relating to the acquisition of any DOE Delegated Real Estate Right that requires ongoing scheduled or regular payments from DOE after the payment of the initial consideration relating to the acquisition of the DOE Delegated Real Estate Right (which shall be funded using funds on deposit in, or credited to, the Advance Funding Account) or otherwise exposes DOE to any additional or ongoing payment obligations which are otherwise not fully funded in advance by a Clean Line Entity (x) under this Agreement prior to or simultaneous with DOE's agreement to undertake such payment obligation or (y) pursuant to any subsequent Transaction Document entered into between a Clean Line Entity and DOE.

(d) Notwithstanding the satisfaction (or lack of satisfaction) of the conditions precedent set forth in Sections 6.2 and 6.3, DOE agrees that promptly upon the Effective Date, and subject to receipt of adequate funding by the Clean Line Entities of the costs and expenses related thereto, it shall commence mobilization of personnel necessary to enable it to acquire DOE Delegated Real Estate Rights and set up procedures and processes for such acquisition such that, upon the satisfaction of the relevant conditions precedent, DOE shall be able to promptly pursue the acquisition of any such DOE Delegated Real Estate Rights through either Voluntary Land Acquisitions or by Acquisition by Condemnation; provided, that in no event shall DOE be obligated to commence actual acquisition or condemnation activities with respect to any DOE Delegated Real Estate Rights until the relevant conditions precedent have been satisfied.

(e) The United States of America, acting through the Secretary of the Department, shall hold title to any and all DOE Acquired Real Property and the AR Facilities.

(f) Without prejudice to DOE's rights to Dispose of any DOE Acquired Real Property or the AR Facilities in connection with an exercise of remedies following and during the occurrence of an Event of Default or after the Termination Date, DOE shall have the right to Dispose of its interest and title to all or any DOE Acquired Real Property or the AR Facilities to any other Person without the consent of any of the Clean Line Parties or any other Person (any such Disposition being a "DOE Instituted Disposition"); provided that the Clean Line Entities will not be responsible for the costs associated with any DOE Instituted Disposition; and provided further that any DOE Instituted Disposition:

(i) shall not occur prior to the earlier to occur of December 31, 2024 and Project Completion;

(ii) shall be subject to the Clean Line Entities' continued right of use in respect of such Project Real Estate Rights and the AR Facilities as provided in Section 2.1;

(iii) shall be subject to the continued right of use of the Electrical Capacity by Holdings or any other Person that holds rights to use such Electrical Capacity;

(iv) shall not be prohibited under the terms of the DOE Direct Agreement and the Intercreditor Agreement or otherwise shall have been consented to by any applicable Project Financing Parties party thereto; and

(v) shall have no materially adverse impact on any Clean Line Entities' material rights and material benefits under this Agreement or any other Transaction Document (including the Clean Line Entities' ability to secure on a commercially reasonably basis any necessary waivers, approvals or consents from DOE as required under the terms of this Agreement).

3.4 Cost Responsibility for Acquisition of Project Real Estate Rights. The acquisition of all Project Real Estate Rights shall be at the sole cost and expense of the Clean Line Entities in accordance with Sections 11.1 and 11.3.

3.5 Amendments and Modifications to Routing and ROW Plan. Holdings shall promptly notify DOE of any material proposed amendments or material modifications to the Routing and ROW Plan (including any updates to the planned routing for the AC Collection System) and provide a description of the reasons underlying such material proposed amendments or material modifications along with such other information as DOE may request in respect of such material proposed amendment or material modification. Any amendment or modification to the Routing and ROW Plan that could reasonably be expected to (a) materially and adversely affect: (i) the ability of the Clean Line Parties' to perform their respective obligations under any Clean Line Document then in effect or (ii) the construction or operation of the Project in accordance with the terms of the Project Plans, the Clean Line Documents and the Project Financing Documents, in each case, as then in effect, (b) result in an Event of Default under this Agreement or the other Transaction Documents or (c) materially increase (i) the Project Real Estate Rights reasonably anticipated to be DOE Delegated Real Estate Rights or (ii) DOE's obligations or liabilities in respect of any DOE Delegated Real Estate Rights or the AR Facilities, shall require the consent of the Coordination Committee. Each amendment or modification to the Routing and ROW Plan shall be made in material compliance with all Applicable Laws, including all Environmental Laws, Cultural Resource Agreements and all measures adopted in the DOE Mitigation Action Plan.

ARTICLE IV
DEVELOPMENT, CONSTRUCTION, OPERATION AND MAINTENANCE OF THE PROJECT

4.1 Development, Construction, Operation and Maintenance of the Project Generally.

(a) Subject to the oversight of the Coordination Committee and DOE's obligations with respect to the acquisition of Project Real Estate Rights pursuant to the terms of this Agreement, the Clean Line Entities have sole responsibility for the management of all aspects of the Project, including the day-to-day management of the Project, the administration of all Project Contracts and the performance of all of the Work.

(b) The Clean Line Entities hereby agree to perform or cause to be performed, all development, design, engineering, construction, operation, maintenance and management activities appropriate for the development of the Project in accordance with the Clean Line Documents (as in effect from time to time), the Project Plans, the Required Approvals and Prudent Utility Practices. As between DOE and the Clean Line Entities, the Clean Line Entities bear the risk of (i) any incorrect or incomplete review, examination or investigation by the Clean Line Entities of any of the Project Real Estate Rights or the Project Site and surrounding locations and (ii) any incorrect or incomplete information resulting from the development, design, engineering, construction, financing, operation, maintenance, management, replacement and decommissioning activities conducted by the Clean Line Entities or any other Person in connection with the Work, the Project and the Other Facilities.

(c) (i) DOE does not, and shall not be required to, make any warranty or representation as to any surveys, data, reports or other information provided by DOE or other Persons concerning surface conditions and subsurface conditions, including the presence of Hazardous Substances, contaminated groundwater, archeological, paleontological and cultural resources and Threatened or Endangered Species that might affect any of the Project Real Estate Rights or the Project Site; and (ii) as between DOE and the Clean Line Entities, the Clean Line Entities bear the risk of all conditions occurring on, under or at the Project Site or in connection with any of the Project Real Estate Rights, including: (A) physical conditions, (B) changes in surface topography, (C) variations in subsurface moisture content, (D) the presence or discovery of Hazardous Substances, including contaminated ground water, (E) the discovery at, near or on any of the Project Real Estate Rights of any archeological, paleontological or cultural resources and (F) the discovery at, near or on the Project Real Estate Rights of any Threatened or Endangered Species; provided that, subject to Section 2.1(e), the foregoing does not alter or excuse DOE's non-delegable obligations and responsibilities under the DOE Mitigation Action Plan, any Cultural Resource Agreement under NHPA or the Endangered Species Act or any other Applicable Law, which shall in all circumstances remain the obligation and responsibility of DOE.

(d) All Material Construction Contracts and Material O&M Agreements shall provide that DOE is a third party beneficiary thereof. Subject to agreement of the applicable Project Participant (which the Clean Line Entities shall use all commercially reasonable efforts to secure), DOE may, at its election prior to the execution of the applicable Material Construction Contract or Material O&M Agreement, become a party thereto for purposes of obtaining the benefit of any applicable warranties, indemnities and relevant protections thereunder, without any liability thereunder except as expressly assumed by DOE. Holdings shall deliver to DOE, at least ten (10) Business Days prior to the execution of any such Material Construction Contract or Material O&M Agreement, a final draft of such Material Construction Contract or Material O&M Agreement, as the case may be, so as to permit DOE to exercise the option referenced in the preceding sentence (if available following exercise of commercially reasonable efforts by the Clean Line Entities). Each Material Project Contract shall be executed by at least one of the Clean Line Parties. No waiver, approval or change to a Material Project Contract that has, or could reasonably be expected to have, an Adverse DOE Impact, shall be made without the approval of the Coordination Committee.

(e) The Clean Line Entities hereby agree to retain or cause to be retained only Contractors that are qualified, experienced and capable in the performance of the portion of the construction, operation or maintenance of the Project to be performed by such Contractor. Each of the Clean Line Entities shall contractually require that each such Contractor has, at the time of the execution of any Construction Contract or O&M Agreement, and maintains at all time during performance thereunder, all Governmental

Approvals required by Applicable Law. The retention of Contractors by any Clean Line Entity shall not relieve any such Clean Line Entity from any of its responsibilities under this Agreement or any other Transaction Document.

(f) In the performance of its obligations under this Agreement and the other Transaction Documents, each of the Clean Line Entities shall at all times comply, and contractually require that all Contractors comply, with all Applicable Laws (including with respect to the applicable contracts for construction, as defined in Department of Labor regulations at 29 C.F.R. § 5.2(j), the Davis-Bacon Requirements to the extent that DOE (or the Department of Labor, as the case may be) has determined that the Davis-Bacon Act is applicable to this Agreement and/or the Project), and all other Applicable Laws relating to labor, occupational safety and health standards, rules, regulations and federal and state orders and Environmental Laws. DOE shall make a determination or request that the Department of Labor make a determination as to the applicability of the Davis-Bacon Act to this Agreement and/or the Project no later than April 30, 2016. If DOE requests review by the Department of Labor, DOE will make any such request by April 30, 2016, and DOE shall provide Clean Line with an update by May 31, 2016 on the status of such review by the Department of Labor.

(g) Without prejudice to the Clean Line Parties' obligations in respect of the payment of Covered Costs and Covered Liabilities and subject to DOE's obligations in respect of Section 4.10, in undertaking their respective obligations as set forth in this Agreement to develop, construct, operate and maintain, as applicable, the Project, DOE and the Clean Line Entities agree to take all steps necessary to comply in all material respects with all commitments for compliance with all Applicable Laws (including Environmental Laws) and Cultural Resource Agreements, including performance of any required measures set forth in the DOE Mitigation Action Plan; provided that with respect to DOE, its undertakings under this clause (g) shall only apply to the extent of any non-delegable obligation or responsibility of DOE under the DOE Mitigation Action Plan, any Cultural Resource Agreement under NHPA or the Endangered Species Act or any other Applicable Law.

(h) Each of the Clean Line Entities shall, at its own cost and expense, comply in all material respects with all conditions imposed by and undertake all actions required by and all actions necessary to maintain in full force and effect all Required Approvals, including performance of any required measures set forth in the DOE Mitigation Action Plan.

(i) No Clean Line Party shall enter into any agreement with any Project Participant, Governmental Authority (excluding DOE), Landowner or any other third Person having regulatory jurisdiction over any aspect of the Project or having any Property interest affected by the Project that in any way purports to obligate DOE, or states or implies that DOE has an obligation, to such Person to carry out any installation, design, construction, maintenance, repair, operation, control, supervision, regulation or other activity related to the Project, unless DOE otherwise approves in writing in its sole discretion. No Clean Line Party has any power or authority to enter into a Contractual Obligation in the name of or on behalf of DOE unless expressly authorized by DOE.

DOE agrees and acknowledges that the Clean Line Parties shall enter into the Material Project Contracts from time to time for purposes of the design, development, engineering, ownership, operation, management and maintenance of the Project.

4.2 DOE Mitigation Action Plan.

(a) Following issuance of the Section 1222 Decision, DOE shall prepare a plan pursuant to 10 C.F.R. § 1021.331 (the "DOE Mitigation Action Plan") that explains how the mitigation measures in the Section 1222 Decision will be planned and implemented and addresses the following:

(i) mitigation commitments concerning Environmental Laws and Cultural Resource Agreements identified in the Section 1222 Decision;

(ii) any environmental protection measures, species-specific protection measures and best management practices identified in the Final Environmental Impact Statement;

(iii) reasonable and prudent measures or implementing terms and conditions set forth in the Biological Opinion; and

(iv) any conditions and procedures included in any Cultural Resource Agreement.

(b) The DOE Mitigation Action Plan shall be prepared before DOE takes any action directed by the Section 1222 Decision that is the subject of a mitigation commitment.

(c) The DOE Mitigation Action Plan shall be as complete as possible and commensurate with the information available regarding the course of action directed by the Section 1222 Decision. DOE may revise the DOE Mitigation Action Plan as more specific and detailed information becomes available, including to address any modified terms and conditions issued in connection with any Environmental Laws and the Cultural Resource Agreement.

(d) The DOE Mitigation Action Plan will be available on the DOE NEPA Website (http://www.energy.gove/nepa/) and on the Plains and Eastern EIS website (www.plainsandeasterneis.com). Pursuant to 10 C.F.R. § 1021.331, DOE shall make copies of the DOE Mitigation Action Plan available for inspection in the appropriate DOE public reading room(s). Copies of the DOE Mitigation Action Plans shall also be available upon written request.

(e) Holdings shall promptly inform DOE when more specific and detailed information becomes available that should be incorporated into the DOE Mitigation Action Plan, including enforceable commitments included in any Government Approvals for construction, operation and maintenance of the Project.

4.3 Amendments and Modifications to the Project Plans. Holdings shall promptly notify DOE of any proposed material amendments or material modifications to the Project Plans and provide a description of the reasons underlying such proposed material amendments or material modifications along with such other information as DOE may request in respect of such proposed material amendment or material modification. Any amendment or modification to the Project Plans that results in the anticipated Electrical Capacity being reduced by more than 1,500 MW (gross) or 1,000 MW (net) in the aggregate shall require the prior approval of the Coordination Committee. Further, the Clean Line Parties shall take all actions required under the Interconnection Agreements prior to making material modifications to the Project, for which prior notice, consultation, review or approval may be required by the applicable Interconnection Agreement.

4.4 Construction Contracts and Project Contracts.

(a) Unless otherwise determined by Holdings in its reasonable judgment to be beneficial to the Project (as notified by Holdings to DOE in writing prior to the signing of any of the Material Construction Contracts), the Material Construction Contracts for the Project Facilities shall (i) be lump sum, fixed price contracts, (ii) be in the nature of "turnkey" contracts concerning the works covered thereunder, (iii) contain provisions relating to guaranteed performance levels, guaranteed completion dates and liquidated damages that are consistent with current market practice for the construction of transmission facilities in the United States and (iv) require each Construction Contractor to provide credit support for its obligations under the applicable Material Construction Contract in the form of a creditworthy parent guarantee, bond, retainage or letter of credit or some combination of the forgoing. Each Material Construction Contract with respect to the AR Facilities shall provide that title to all Works covered thereunder will be transferred to DOE as completed, and upon payment by the Clean Line Entities of all amounts due and payable under such Material Construction Contract, all such Contractors shall waive any claims thereto or Liens thereon (to the maximum extent permitted by Applicable Law) and the Clean Line Entities shall advance funds to DOE for all Taxes DOE must pay as a result thereof.

(b) The Clean Line Entities bear sole responsibility to pay all fees, expenses, Taxes, assessments, insurance premiums, indemnification claims and other amounts under the Construction Contracts and other Project Contracts, and DOE shall not be in any way responsible or liable for any payments, losses, obligations or duties under or in respect of the Construction Contracts or any other Project Contracts.

(c) Each Construction Contractor shall be required to maintain and pay for customary insurance policies for such Construction Contract, including (if not obtained by the Clean Line Entities) builder's all-risk, delayed start-up, general and automobile liability, employer's liability, workers' compensation and excess liability coverages, as applicable, and that are otherwise consistent with the Insurance Agreement unless otherwise approved by the Coordination Committee.

4.5 Interconnection Agreements. The Project Facilities shall be interconnected to the electric transmission systems operated by SPP and MISO and the TN Facilities will be interconnected to the electrical transmission system operated by TVA, in each case pursuant to Interconnection Agreements that, among other things, provide for interconnection sufficient to allow the Clean Line Parties to safely and reliably deliver energy across the Project Facilities up to the Electrical Capacity and also satisfy their obligations under the Transmission Services Agreements.

4.6 Operational Coordination with SPP, MISO and TVA. At such time as required by Applicable Law, but in any event no later than Project Completion, the Clean Line Parties shall enter into one or more agreements with SPP, MISO and TVA, as applicable, regarding the coordinated operation of the Project with SPP, MISO and TVA, which shall include identification of the entity responsible for exercising operational control of the Project as well as any agreements with respect to any inter-balancing area interchange of energy or ancillary services between the Project and the neighboring control areas (each, an "Operating Agreement"). Holdings shall consult with and report to DOE on the development of such Operating Agreements. Holdings shall provide DOE with a final draft of any such Operating Agreement at least ten (10) Business Days prior to the execution thereof by the Clean Line Parties; provided that such draft may redact or exclude such data or other information the disclosure of which is prohibited by Applicable Law; provided that the Clean Line Entities shall use all commercially reasonable efforts to apply for any consent or exemption that may be available under Applicable Law or from any Person or Governmental Authority for purposes of providing any such data or other information to DOE and shall, promptly upon receipt of such consent or exemption, provide DOE with an unredacted copy of such Operating Agreement. The Clean Line Parties have sole responsibility in respect of the execution, delivery and performance of each Operating Agreement, which may include delegating performance responsibilities to qualified third parties consistent with Prudent Utility Practices.

4.7 Maintenance of the Project Facilities. The Clean Line Entities have sole responsibility for engaging experienced and responsible Contractors to operate, maintain and repair the Project Facilities to a standard not less than Prudent Utility Practices and in accordance with Applicable Law and Required Approvals, and if such standard is not met then DOE may, subject to the terms of the DOE Direct Agreement and the Intercreditor Agreement to the extent applicable, direct the Clean Line Entities to terminate any applicable O&M Agreement(s) of each applicable Contractor in accordance with its terms. Except with the consent of the Coordination Committee, each Material O&M Agreement shall not (a) require a payment of a bonus or a fee materially in excess of expected bonus or fee levels for comparable contracts payable on a third party arms' length basis or (b) cap the liability of such Contractor at less than all fees (excluding cost reimbursement) received by it under such Material O&M Agreement.

4.8 Capital Repairs and Reserve Account.

(a) The Clean Line Entities shall perform, or engage Contractors to perform, all Capital Repairs necessary or advisable in accordance with Prudent Utility Practices in connection with the Project. The Clean Line Entities shall be solely responsible for the costs and expenses of any such Capital Repairs.

(b) On and after Project Completion, Holdings shall establish and maintain at all times a capital repairs and maintenance reserve account (the "Capital Repairs Reserve

Account"), which Capital Repairs Reserve Account shall be funded at all times with an amount sufficient to cover all estimated Capital Repairs in respect of the Project, *plus* a reasonable contingency amount as determined by the Independent Engineer appointed by the Project Financing Parties (or if there is no Project Financing, the Coordination Committee in consultation with the Independent Engineer), which are required by Prudent Utility Practice or reasonably anticipated to be incurred in the upcoming twelve (12) months. If at any time the Clean Line Entities fail to utilize such funds in the Capital Repair Reserve Account to make Capital Repairs when required, then subject to prior notice to Holdings and a grace period of thirty (30) days, DOE may, at its option (but with no obligation to) draw (i) on the Performance Support or (ii) if agreed to by the Project Financing Parties, from the Capital Repairs Reserve Account, and, in each case, apply the proceeds thereof to the making of any such Capital Repairs.

4.9 NERC Standards. Prior to the issuance of the Notice to Proceed, the Clean Line Entities and DOE shall enter into an agreement (the "NERC Agreement") pursuant to which (a) the Clean Line Entities shall assume sole responsibility for compliance with all applicable or desirable reliability standards (including NERC reliability standards) related to the Project, including any related documentation obligations, audits, violations and mitigation obligations, (b) the Clean Line Parties shall be solely responsible for all liabilities or claims that arise in connection with the operation of the Project (or any portion thereof) as a result of the noncompliance of the Project (or any portion thereof) with NERC's reliability standards and (c) the Clean Line Parties shall indemnify DOE and each Covered Party for all Covered Liabilities in connection with the operation of the Project (or any portion thereof) as a result of the Project's non-compliance with all applicable reliability standards or regulations.

4.10 DOE Cooperation. To the extent reasonably requested by Holdings, DOE shall coordinate and cooperate in good faith with the Clean Line Entities on the Project, including providing information and assistance in the preparation of any application for any Required Approval; provided that such cooperation and coordination shall be at the Clean Line Entities sole cost and expense and shall not impose an unreasonable burden on DOE.

ARTICLE V
COORDINATION COMMITTEE

5.1 Coordination Committee.

(a) Holdings and DOE will establish a coordination committee promptly after the date of this Agreement (the "Coordination Committee"), which shall be composed of two (2) representatives from Holdings and two (2) representatives from DOE. Each of Holdings and DOE may replace its respective representatives at any time by providing written notice to the other Person. The Coordination Committee shall coordinate and manage the efforts of the Clean Line Entities and DOE relating to the Project and provide a forum for updates, discussion and attempted resolution of any relevant issues with respect to the Transaction Documents and the Project.

(b) Prior to the occurrence of Project Completion, the Coordination Committee shall meet not less than once a month, and from and after the occurrence of

Project Completion, the Coordination Committee shall meet not less than once a fiscal quarter, in each case at mutually convenient times, locations or means as the Coordination Committee shall determine. The Coordination Committee will have the authority to create sub-committees to consider specific issues whenever it deems appropriate. Each of Holdings and DOE shall have the right to call a special meeting of the Coordination Committee upon not less than five (5) Business Days' prior written notice to the other Person. One (1) of Holdings' representatives will be designated as the Chair of the Coordination Committee. Holdings and DOE may submit any item for inclusion on any agenda of any Coordination Committee meeting.

(c) Subject to Section 7.4(a), meetings of the Coordination Committee shall require a quorum consisting of one representative of each of Holdings and DOE. If a quorum is not present at the commencement of any meeting, the Chair will reschedule the meeting to take place within the following ten (10) Business Days and will give notice of such scheduled meeting to the representatives on the Coordination Committee.

(d) Other employees and/or agents of the Parties shall be entitled to attend meetings of the Coordination Committee. Meetings may be conducted in person, by telephone or video conference call or by such other means as which permits the Parties' representatives to be verified and to hear and be heard by the other Parties' representatives. Attendees who are not representatives of any Party shall be identified at the commencement of any meeting and shall have no power to vote on any matters but may participate in discussions in accordance with the Coordination Committee's rules of order, which may limit the amount of time that such other attendees may participate.

(e) Notwithstanding the delegation of authority granted to the Parties pursuant to this Agreement, and subject to Section 7.4(a), the following actions shall require the affirmative approval of one (1) representative of each of Holdings and DOE on the Coordination Committee:

(i) the approval of any public announcements relating to DOE's involvement in the Project;

(ii) the adoption, implementation and/or material modification of an insurance agreement (the "Insurance Agreement") for the Project and the making of any material claim in respect of any insurance relating to the Project;

(iii) the estimation of costs required to be funded into the Wind-Up Reserve Account, any matters relating to the funding of the Wind-Up Events, the decision to commence the Wind-Up Events and the entry into of any Contractual Obligations or undertakings relating to the Wind-Up Events;

(iv) if no Project Financing is then currently in effect, the issuance of any completion or similar certificate or the acceptance of any performance tests under any Material Construction Contract;

(v) the determination from time to time of the amount of any Remaining DOE Acquisition Costs and to the extent applicable, the Contingency Amount; and

(vi) any express consents or approvals delegated to the Coordination Committee under this Agreement, including pursuant to Sections 3.5, 4.1(d), 4.3, 4.4(c), 4.7, 4.8(b), 7.3(m), 7.6 and 7.7.

(f) If the representatives of Holdings and DOE participating in a meeting of the Coordination Committee are unable to reach an agreement on a matter before the Coordination Committee (a "Deadlock"), Holdings and DOE shall attempt to resolve such Deadlock through negotiations of the representatives. If such Deadlock is not resolved within seven (7) days, the Deadlock shall be referred to a panel consisting of a senior level executive of each of Holdings and DOE with the authority to resolve the matter causing such Deadlock, who shall attempt to resolve such Deadlock within seven (7) days. For construction-related, operational-related or other technical issues or for financial or accounting issues, Holdings and DOE shall have the right to appoint an independent technical or financial consultant to assist in resolving such Deadlock.

(g) DOE shall have the right to retain one or more technical (including engineering, market, legal or financial) consultants with respect to its participation on the Coordination Committee at the sole cost and expense of the Clean Line Entities.

(h) All costs and expenses incurred by the representatives of DOE in the Coordination Committee shall be borne by the Clean Line Entities.

ARTICLE VI
CONDITIONS PRECEDENT

6.1 Conditions Precedent to Effective Date. DOE's obligations hereunder shall become effective upon the satisfaction of the following conditions:

(a) the Secretary of the Department shall have issued a Record of Decision (the "Section 1222 Decision") authorizing the participation by DOE in the Project pursuant to the statutory authority granted under Section 1222 and addressing all required determinations necessary for purposes of the participation decision under NEPA, the Endangered Species Act, the NHPA, and any other Applicable Law;

(b) each of the Parties shall have duly executed and delivered this Agreement;

(c) Holdings shall have delivered to DOE (i) certified Organizational Documents of each of the Clean Line Parties, (ii) secretary's certificates, officer's certificates, resolutions and good standing certificates for each of the Clean Line Parties (including certificates certifying to such matters as DOE shall reasonably require) and (iii) legal opinions from counsel to the Clean Line Parties;

(d) at least thirty (30) days shall have passed since the Environmental Protection Agency shall have published a notice of availability for the Final Environmental Impact Statement in respect of the Project;

(e) Holdings shall have delivered to DOE certified copies of duly executed term sheets for TSA Precedent Agreements in respect of not less than 3,500 MW of the Electrical Capacity in the aggregate, each of which shall be in full force and effect;

(f) the Clean Line Entities shall be in compliance with all funding obligations required under the AFDA;

(g) **[**Reserved**]**

(h) Holdings shall have delivered to DOE (i) an updated Project Budget and a reasonably detailed project budget for the development, design, engineering and construction of the Other Facilities and (ii) an updated base case model of projections of operating costs and results (including projections in respect of revenues, expenses, cash flow, debt service and sources and uses of revenues) for the Project and for the Other Facilities (the "Base Case Projections");

(i) Holdings shall have delivered to DOE a copy of audited consolidated financial statements of CLEP for the calendar year ending December 31, 2014 and unaudited consolidated financial statements of CLEP for each of the four (4) fiscal quarters of the calendar year ending December 31, 2015;

(j) Holdings shall have delivered to DOE a Project Development Progress Report as of the Effective Date;

(k) Holdings shall have paid all costs and expenses (including costs and expenses of all consultants, advisors and counsel to DOE) accrued and invoiced;

(l) all representations and warranties made by any of the Clean Line Obligors in this Agreement shall be true and correct as of the Effective Date;

(m) no Default or Event of Default shall have occurred and be continuing;

(n) (i) no Governmental Order shall be in effect nor shall any Change of Law have occurred that, in either case, as applicable, sets aside, enjoins or legally prohibits (A) DOE's performance under this Agreement or (B) DOE's participation in the Project and (ii) no other final and non-appealable Governmental Order shall be in effect nor shall any Change of Law have occurred that, in either case, as applicable, sets aside, enjoins or legally prohibits (A) the execution or delivery of this Agreement or (B) any Clean Line Entity's performance under this Agreement; and

(o) (i) ACL shall have been duly formed and organized, (ii) all Property or physical facilities held by or in the name of any of Holdings or any of its Subsidiaries to the AR Facilities or any Project Real Estate Rights located in Arkansas shall have been transferred to ACL and documentary evidence thereof shall have been delivered by

Holdings to DOE and (iii) neither PECL nor any PECL Subsidiary (to the extent then in existence) shall thereafter own directly or control real Property of the Project or any physical facilities of the Project Facilities (excluding rights under any Project Contracts where multiple Clean Line Parties are parties).

6.2 Conditions Precedent to Voluntary Land Acquisitions.

(a) DOE's initial obligation to assist with the acquisition of Project Real Estate Rights by way of Voluntary Land Acquisitions shall commence upon the satisfaction of the following conditions precedent:

(i) the Effective Date shall have occurred;

(ii) the Clean Line Entities shall have complied with all of the requirements and procedures set forth in Schedule 1 hereto with respect to the DOE Delegated Real Estate Right to be acquired;

(iii) Holdings shall have delivered to DOE (A) the Routing and ROW Plan, (B) the Project Plans and (C) an updated Project Development Progress Report as of the Commencement Date and an updated Project Budget, which shall include a summary and explanation of any deviations from the Project Budget and the Project Schedule delivered as a condition to the occurrence of the Effective Date;

(iv) Holdings shall have delivered to DOE certified copies of duly executed and enforceable TSA Precedent Agreements, Acceptable Transmission Services Agreements or Acceptable Permitted Project Investment Commitments in respect of not less than 3,500 MW of the Electrical Capacity in the aggregate, each of which shall be in full force and effect; provided that no less than 1,500 MW of such Electrical Capacity in the aggregate (calculated as the sum of (A) with respect to Acceptable Permitted Project Investments, the sum of each portion of the Electrical Capacity transferred (and for which the Clean Line Entities have received payment or will receive payment within three (3) years after the date of such Permitted Project Investment) pursuant to each Acceptable Permitted Project Investment Commitment and (B) with respect to the Acceptable Transmission Services Agreements, the sum of the average Electrical Capacity committed in the initial five (5) years of the term for each such Acceptable Transmission Services Agreement) shall be committed pursuant to Acceptable Transmission Services Agreements and Acceptable Permitted Project Investment Commitments;

(v) Holdings shall have delivered to DOE copies of duly executed purchase options or comparable site control agreements (collectively, the "Converter Station Real Estate Rights Agreements") that permit the Clean Line Entities to obtain all Real Estate Rights necessary for the construction of the Converter Station Facility and the Intermediate Converter Station, and such purchase options, if any, shall have exercise periods consistent with the Project Schedule, each of which shall be in full force and effect;

(vi) the Clean Line Parties shall be diligently proceeding with obtaining all necessary interconnection rights for the Project, including completion of the following conditions:

(A) SPP – the SPP Facilities Study and the SPP System Impact Study shall have been completed and the Clean Line Parties shall have executed an Interconnection Agreement for interconnection of the Project with the SPP-controlled transmission system;

(B) MISO – the MISO Interconnection Feasibility Study, the MISO Interconnection Facilities Study and the MISO Interconnection System Impact Study shall have been completed and the Clean Line Parties shall have executed an Interconnection Agreement for interconnection of the Project with the MISO-controlled transmission system; and

(C) TVA – the TVA Facilities Study and the TVA System Impact Study shall have been completed and the Clean Line Parties shall have executed a Project Work Agreement or Interconnection Agreement for interconnection of the TN Facilities with the TVA transmission system;

(vii) Holdings shall have delivered to DOE certified copies of (x) Firm Project Equity Commitments that are then in full force and effect and that provide for commitments (together with amounts on deposit in the Advance Funding Account) in an amount equal to not less than 150% of the Remaining DOE Acquisition Costs, as of the Commencement Date and (y) Project Equity Commitments or letters of interest and/or Project Financing Commitments or letters of interest in respect of the Project Financing (together with amounts on deposit in the Advance Funding Account) in an aggregate amount sufficient to cover all other Remaining Project Costs;

(viii) Holdings shall have delivered to DOE the required Performance Support in an amount not less than the Applicable Amount;

(ix) Holdings shall have completed the following design, engineering and project management activities and delivered evidence thereof to DOE:

(A) obtained design criteria, structure geometrics, structure loading schedules and estimated weights from vendors;

(B) selected the insulator and hardware vendor and completed electrical testing specifications;

(C) completed LiDAR survey, structure spotting, preliminary access road layout and vegetation clearing assessment;

(D) completed the conductor, metallic return conductor and optical ground wire/shield wire design;

(E) completed preliminary foundation design; and

(F) prepared a reasonably detailed project execution and construction schedule.

(x) DOE and Holdings shall have entered into the Insurance Agreement and Holdings shall have delivered to DOE evidence that all Required Insurance is in full force and effect (including written binding verification of such coverage);

(xi) (A) no Governmental Order shall be in effect nor shall any Change of Law have occurred that, in either case, as applicable, sets aside, enjoins or legally prohibits (1) DOE's performance under this Agreement or any other Transaction Document then in effect or (2) DOE's participation in the Project and (B) no other final and non-appealable Governmental Order shall be in effect nor shall any Change of Law have occurred that, in either case, as applicable, (1) sets aside, enjoins or legally prohibits any Clean Line Entity's performance under this Agreement or any other Transaction Document then in effect or any Clean Line Entity's performance in any material respect under any Material Project Contract to which it is a party or (2) affects in any material respect the legality, validity or enforceability of any of the Transaction Documents, any Project Equity Commitment or any of the Material Project Contracts then in effect;

(xii) (A) all representations and warranties made by any Clean Line Obligor in any of the Transaction Documents shall be true and correct in all material respects (except to the extent any such representation and warranty itself is qualified by "materiality", "material adverse effect", "Adverse DOE Impact", "Clean Line Material Adverse Effect" or a similar qualifier, in which case it shall be true and correct in all respects) and (B) no Default, Event of Default or Event of Loss shall have occurred and be continuing, in each case, as of the Commencement Date;

(xiii) the Clean Line Entities shall have granted to DOE a first priority perfected security interest in the Equity Collateral as required at such time pursuant to Section 11.6, together with such legal opinions, certificates and other documents in respect thereof as DOE may reasonably request; and

(xiv) Holdings shall have delivered to DOE a certificate of an Authorized Officer as to the satisfaction of the foregoing conditions precedent.

(b) After the occurrence of the Commencement Date, DOE's obligations to acquire or continue to acquire DOE Delegated Real Estate Rights through Voluntary Land Acquisitions or any other means shall only be subject to the following conditions being satisfied:

(i) the Clean Line Entities shall have complied with all of the requirements and procedures set forth in Schedule 1 hereto with respect to the DOE Delegated Real Estate Rights to be acquired;

(ii) Acceptable Transmission Services Agreements and Acceptable Permitted Project Investment Commitments in respect of not less than 1,500 MW of the Electrical Capacity in the aggregate (calculated as the sum of (A) with respect to Acceptable Permitted Project Investments, the sum of each portion of the Electrical Capacity transferred (and for which the Clean Line Entities have received payment or will receive payment within three (3) years after the date of such Permitted Project Investment) pursuant to each Acceptable Permitted Project Investment Commitment and (B) with respect to the Acceptable Transmission Services Agreements, the sum of the average Electrical Capacity committed in the initial five (5) years of the term for each such Acceptable Transmission Services Agreement) shall be in full force and effect and no event shall have occurred and be continuing (whether as a result of a default or the failure of a condition precedent or otherwise) that gives the Project Participant party thereto the right to terminate such Acceptable Transmission Services Agreement or such Acceptable Permitted Project Investment Commitment;

(iii) the Converter Station Real Estate Rights Agreements shall be in full force and effect or the Clean Line Entities shall own in fee free and clear of all Liens other than Permitted Liens all Real Estate Rights necessary for the construction of the Converter Station Facility and the Intermediate Converter Station;

(iv) the executed Interconnection Agreements for interconnection of the Project with the SPP-controlled transmission system and the MISO-controlled transmission system and the executed Project Work Agreement or Interconnection Agreement for interconnection of the TN Facilities with the TVA transmission system shall be in full force and effect and no event shall have occurred and be continuing (whether as a result of a default or the failure of a condition precedent or otherwise) that gives the Project Participant party thereto the right to terminate such Interconnection Agreements or Project Work Agreement (except to the extent the Project Work Agreement has been replaced by an Interconnection Agreement with TVA);

(v) either (A) the Project Equity Commitments (including Firm Project Equity Commitments that are then in full force and effect and that provide for commitments (together with amounts on deposit in the Advance Funding Account) in an amount equal to not less than 150% of the Remaining DOE Acquisition Costs as of any date on which any Clean Line Entity designates any Project Real Estate Right as a DOE Delegated Real Estate Right), Project Financing Commitments and any letters of intent delivered as a condition to the occurrence of the Commencement Date shall continue to be in full force and effect or (B) the Financing Condition shall be satisfied;

(vi) (A) no Governmental Order shall be in effect nor shall any Change of Law have occurred that, in either case, as applicable, sets aside, enjoins or legally prohibits (1) DOE's performance under this Agreement or any other Transaction Document then in effect or (2) DOE's participation in the Project and (B) no other final and non-appealable Governmental Order shall be in effect nor shall any Change of Law have occurred that, in either case, as applicable, (1) sets aside, enjoins or legally prohibits any Clean Line Entity's performance under this Agreement or any other Transaction Document then in effect or any Clean Line Entity's performance in any material respect under any Material Project Contract to which it is a party or (2) affects in any material respect the legality, validity or enforceability of any of the Transaction Documents, any Project Equity Commitment or any of the Material Project Contracts then in effect; and

(vii) no Event of Default shall have occurred and be continuing.

(c) Following the Commencement Date, at any time Holdings delivers a written notice of designation of any Project Real Estate Rights as a DOE Delegated Real Estate Right, Holdings shall concurrently deliver a certificate of an Authorized Officer certifying as to the satisfaction of all conditions specified in Section 6.2(b) (a form of which is attached as Schedule 6 hereto).

6.3 Conditions Precedent to Acquisitions by Condemnation.

(a) DOE's initial obligation to assist with the acquisition of Project Real Estate Rights by way of Acquisitions by Condemnation shall commence upon the satisfaction of the following conditions precedent:

(i) the Commencement Date shall have occurred;

(ii) the Clean Line Entities shall have complied with all of the requirements and procedures set forth in Schedule 1 hereto with respect to the DOE Delegated Real Estate Right to be condemned;

(iii) the Financing Condition shall be satisfied and Holdings shall have delivered to DOE certified copies of all applicable executed DOE Approved Project Financing Commitments, DOE Approved Project Equity Commitments, Project Equity Commitments and/or Project Financing Documents;

(iv) (A) all Performance Support in an amount not less than the Applicable Amount shall be in full force and effect, (B) to the extent that Project Financial Close has occurred, the Clean Line Entities shall have granted a perfected security interest in the Second Lien Collateral in accordance with Section 11.6 in favor of DOE (but only to the extent that the first priority security interest in favor of the Project Financing Parties has been granted and/or perfected) and shall have delivered to DOE such legal opinions, certificates and other documents in respect thereof as DOE shall have requested and (C) to the extent that Project Financial Close has occurred, the Intercreditor Agreement shall be in full force and effect;

(v) (A) Acceptable Transmission Services Agreements and Acceptable Permitted Project Investment Commitments in respect of not less than 2,000 MW of the Electrical Capacity in the aggregate (calculated as the sum of (A) with respect to Acceptable Permitted Project Investments, the sum of each portion of the Electrical Capacity transferred (and for which the Clean Line Entities have received payment or will receive payment within three (3) years after the date of such Permitted Project Investment) pursuant to each Acceptable Permitted Project Investment Commitment and (B) with respect to the Acceptable Transmission Services Agreements, the sum of the average Electrical Capacity committed in the initial five (5) years of the term for each such Acceptable Transmission Services Agreement) shall be in full force and effect and no event shall have occurred and be continuing (whether as a result of a default or the failure of a condition precedent or otherwise) that gives the Project Participant party thereto the right to terminate such Acceptable Transmission Services Agreement or such Acceptable Permitted Project Investment Commitment and (B) the Converter Station Real Estate Rights Agreements shall be in full force and effect or the Clean Line Entities shall own in fee free and clear of all Liens other than Permitted Liens all Real Estate Rights necessary for the construction of the Converter Station Facility and the Intermediate Converter Station;

(vi) (A) the Clean Line Parties shall have delivered to DOE certified copies of the Interconnection Agreements necessary for the operation of the Project, each of which shall have been duly executed and delivered and shall be in full force and effect, (B) each of the Material Interconnection Studies shall have been completed and (C) the Clean Line Parties are in compliance with the Interconnection Agreements;

(vii) the Clean Line Parties shall have initiated joint discussions among officials and representatives of SPP, MISO and TVA to address any necessary inter-balancing area coordination and operational issues for the drafting of the applicable Operating Agreement;

(viii) Holdings shall have delivered to DOE evidence that all Required Insurance is in full force and effect (including written binding verification of such coverage);

(ix) (A) no Governmental Order shall be in effect nor shall any Change of Law have occurred that, in either case, as applicable, sets aside, enjoins or legally prohibits (1) DOE's performance under this Agreement or any other Transaction Document then in effect or (2) DOE's participation in the Project and (B) no other final and non-appealable Governmental Order shall be in effect nor shall any Change of Law have occurred that, in either case, as applicable, (1) sets aside, enjoins or legally prohibits any Clean Line Entity's performance under this Agreement or any other Transaction Document then in effect or any Clean Line Entity's performance in any material respect under any Material Project Contract to which it is a party or (2) affects in any material respect the legality, validity or enforceability of any of the Transaction Documents, any Project Equity Commitment or any of the Material Project Contracts then in effect;

(x) (A) all representations and warranties made by any Clean Line Obligor in any of the Transaction Documents shall be true and correct in all material respects (except to the extent any such representation and warranty itself is qualified by "materiality", "material adverse effect", "Adverse DOE Impact", "Clean Line Material Adverse Effect" or a similar qualifier, in which case it shall be true and correct in all respects) and (B) no Default, Event of Default or Event of Loss shall have occurred and be continuing, in each case, as of the applicable date;

(xi) Holdings shall have delivered to DOE an updated Project Development Progress Report and an updated Project Budget, which shall include a summary and explanation of any deviations from the Project Budget and the Project Schedule delivered as a condition to the occurrence of the Commencement Date and which shall include any Project Costs associated with the Interconnection Agreements or any Operating Agreement then in effect; and

(xii) Holdings shall have delivered to DOE a certificate of an Authorized Officer as to the satisfaction of the foregoing conditions precedent.

(b) After the satisfaction of the foregoing conditions precedent to DOE's obligation to assist with the acquisition of Project Real Estate Rights by way of Acquisitions by Condemnation, DOE's obligations to acquire or continue to acquire any DOE Delegated Real Estate Rights by way of Acquisitions by Condemnation shall only be subject to the following conditions being satisfied at all times:

(i) the Clean Line Entities shall have complied with all of the requirements and procedures set forth in Schedule 1 hereto with respect to the DOE Delegated Real Estate Rights to be acquired;

(ii) Acceptable Transmission Services Agreements and Acceptable Permitted Project Investment Commitments in respect of not less than 2,000 MW of the Electrical Capacity in the aggregate (calculated as the sum of (A) with respect to Acceptable Permitted Project Investments, the sum of each portion of the Electrical Capacity transferred (and for which the Clean Line Entities have received payment or will receive payment within three (3) years after the date of such Permitted Project Investment) pursuant to each Acceptable Permitted Project Investment Commitment and (B) with respect to the Acceptable Transmission Services Agreements, the sum of the average Electrical Capacity committed in the initial five (5) years of the term for each such Acceptable Transmission Services Agreement) shall be in full force and effect and no event shall have occurred and be continuing (whether as a result of a default or the failure of a condition precedent or otherwise) that gives the Project Participant party thereto the right to terminate such Acceptable Transmission Services Agreement or such Acceptable Permitted Project Investment Commitment;

(iii) the Converter Station Real Estate Rights Agreements delivered pursuant to the foregoing conditions precedent shall continue to be in full force and effect and neither any Clean Line Entity nor any other Person party thereto shall be in default thereunder (or the Clean Line Entities shall then own in fee free and clear of Liens other than Permitted Liens all Real Estate Rights necessary for the construction of the Converter Station Facility and the Intermediate Converter Station);

(iv) the Interconnection Agreements delivered pursuant to the foregoing conditions precedent shall continue to be in full force and effect and neither any Clean Line Entity nor any other Person party thereto shall be in default thereunder;

(v) the Financing Condition shall be satisfied;

(vi) (A) no Governmental Order shall be in effect nor shall any Change of Law have occurred that, in either case, as applicable, sets aside, enjoins or legally prohibits (1) DOE's performance under this Agreement or any other Transaction Document then in effect or (2) DOE's participation in the Project and (B) no other final and non-appealable Governmental Order shall be in effect nor shall any Change of Law have occurred that, in either case, as applicable, (1) sets aside, enjoins or legally prohibits any Clean Line Entity's performance under this Agreement or any other Transaction Document then in effect or any Clean Line Entity's performance in any material respect under any Material Project Contract to which it is a party or (2) affects in any material respect the legality, validity or enforceability of any of the Transaction Documents, any Project Equity Commitment or any of the Material Project Contracts then in effect; and

(vii) no Event of Default shall have occurred and be continuing.

(c) After the conditions precedent to DOE's initial obligation to assist with the acquisition of Project Real Estate Rights by way of Acquisitions by Condemnation have been satisfied, at any time Holdings delivers a written notice of designation of any Project Real Estate Rights as a DOE Delegated Real Estate Right, Holdings shall concurrently deliver a certificate of an Authorized Officer certifying as to the satisfaction of all conditions specified in Section 6.3(b) (a form of which is provided as Schedule 7 hereto).

(d) Notwithstanding the foregoing, from and after the Commencement Date, DOE may, at its sole option, elect to pursue an Uncontested Acquisition prior to the satisfaction in full of the conditions precedent set forth above, so long as the conditions precedent required to be satisfied for DOE's acquisition of DOE Delegated Real Estate Rights through a Voluntary Land Acquisition are satisfied.

6.4 Conditions Precedent to Notice to Proceed.

(a) Prior to the issuance by any Clean Line Entity of any notice to proceed under any Material Construction Contract that involves any physical construction activity on any Project Real Estate Right, Holdings shall first have received a Notice to Proceed from DOE. DOE shall issue a Notice to Proceed to Holdings promptly upon satisfaction of the following conditions precedent:

(i) the applicable Material Construction Contract shall have been duly executed and delivered and shall be in full force and effect;

(ii) the Financing Condition is satisfied and Acceptable Transmission Services Agreements and Acceptable Permitted Project Investment Commitments in respect of not less than 2,000 MW of the Electrical Capacity in the aggregate (calculated as the sum of (A) with respect to Acceptable Permitted Project Investments, the sum of each portion of the Electrical Capacity transferred (and for which the Clean Line Entities have received payment or will receive payment within three (3) years after the date of such Permitted Project Investment) pursuant to each Acceptable Permitted Project Investment Commitment and (B) with respect to the Acceptable Transmission Services Agreements, the sum of the average Electrical Capacity committed in the initial five (5) years of the term for each such Acceptable Transmission Services Agreement) shall be in full force and effect and no event shall have occurred and be continuing (whether as a result of a default or the failure of a condition precedent or otherwise) that gives the Project Participant party thereto the right to terminate such Acceptable Transmission Services Agreement or such Acceptable Permitted Project Investment Commitment;

(iii) the Performance Support in an amount not less than the Applicable Amount shall be in full force and effect;

(iv) Holdings shall have delivered to DOE evidence that all Required Insurance is in full force and effect (including written binding verification of such coverage);

(v) the Converter Station Real Estate Rights Agreements shall be in full force and effect or the Clean Line Entities shall then own in fee free and clear of Liens other than Permitted Liens all Real Estate Rights necessary for construction of the Converter Station Facility and the Intermediate Converter Station;

(vi) (A) no Governmental Order shall be in effect nor shall any Change of Law have occurred that, in either case, as applicable, sets aside, enjoins or legally prohibits (1) DOE's performance under this Agreement or any other Transaction Document then in effect or (2) DOE's participation in the Project and (B) no other final and non-appealable Governmental Order shall be in effect nor shall any Change of Law have occurred that, in either case, as applicable, (1) sets aside, enjoins or legally prohibits any Clean Line Entity's performance under this Agreement or any other Transaction Document then in effect or any Clean Line Entity's performance in any material respect under any Material Project Contract to which it is a party or (2) affects in any material respect the legality, validity or enforceability of any of the Transaction Documents, any Project Equity Commitment or any of the Material Project Contracts then in effect;

(vii) the Clean Line Entities and DOE shall have executed the NERC Agreement;

(viii) all Interconnection Agreements and Material O&M Agreements shall have been duly executed and be in full force and effect; provided that to the extent that the Project Financing is in effect, the Material O&M Agreements shall be limited to those that are required to be in effect at such time as required under the terms of the Project Financing Documents;

(ix) to the extent that DOE (or the Department of Labor, as the case may be) shall have made a determination that the Davis-Bacon Act applies to this Agreement and/or the Project, Holdings shall have delivered a certificate of an Authorized Officer to DOE dated not less than fifteen (15) days prior to the delivery of the Notice to Proceed stating either that the Clean Line Parties are in compliance with all applicable Davis-Bacon Requirements and, to the extent the Davis-Bacon Act is applicable, have included the provisions and wage determinations set forth in Schedule 15 hereto (as such Schedule is supplemented from time to time in accordance with Section 8.24(b)) in each applicable contract for construction, as defined in Department of Labor regulations at 29 C.F.R. § 5.2(j);

(x) (A) all representations and warranties made by any Clean Line Obligor in any of the Transaction Documents shall be true and correct in all material respects (except to the extent any such representation and warranty itself is qualified by "materiality", "material adverse effect", "Adverse DOE Impact", "Clean Line Material Adverse Effect" or a similar qualifier, in which case it shall be true and correct in all respects) and (B) no Default, Event of Default or Event of Loss shall have occurred and be continuing, in each case, as of the applicable date; and

(xi) Holdings shall have delivered to DOE a certificate of an Authorized Officer as to the satisfaction of the foregoing conditions precedent.

(b) Notwithstanding anything herein to the contrary, the Clean Line Entities shall not be obligated to satisfy the conditions specified in this Section 6.4 in order to issue any purchase orders, work authorizations or limited notices to proceed (however titled) under any Material Construction Contract that concern (i) design, engineering, procurement or other non-site activities; (ii) civil, environmental and/or geotechnical surveys; (iii) pre-construction activities on Real Estate Rights held by the Clean Line Entities on which the Converter Station Facility and the Intermediate Converter Station will be constructed or installed such as installation of roads for access and clearing, grading and installation of appropriate base material (*e.g.*, rock); (iv) clearing of rights-way on Real Estate Rights that are not DOE Acquired Real Property and/or (v) construction activities on Real Estate Rights in Oklahoma held by the Clean Line

Entities on which the Converter Station Facility will be constructed or installed; provided further that to the extent that the Performance Support then in effect is equal to the Applicable Amount that applies from and after the issuance of the Notice to Proceed (regardless of whether the Notice to Proceed has been issued or the other conditions to the issuance thereof have been satisfied), the Clean Line Entities shall not be obligated to satisfy the other conditions specified in this Section 6.4 in order to issue any purchase orders, work authorizations or limited notices to proceed (however titled) under any Construction Contract solely to commence clearing of rights of-way on any Project Real Estate Rights on DOE Acquired Real Property.

(c) Notwithstanding Section 6.4(b), to the extent that DOE (or the Department of Labor, as the case may be), determines that the Davis-Bacon Act is applicable to this Agreement and/or the Project, all construction, as defined in Department of Labor regulations at 29 C.F.R. § 5.2(j), shall be performed in compliance with the Davis-Bacon Requirements and the provisions and wage determinations set forth in Schedule 15 hereto (as such Schedule is supplemented from time to time in accordance with Section 8.24(b)) shall be incorporated into all such applicable contracts for construction.

ARTICLE VII
TERM, TERMINATION, EVENTS OF DEFAULT AND REMEDIES

7.1 Term and Termination.

(a) Except to the extent terminated as contemplated below, the term of this Agreement shall commence on the Effective Date and continue until retirement from service of the Project Facilities and the completion of the Wind-Up Events, including the payment of all costs and expenses associated with the Wind-Up Events, at which point this Agreement shall terminate (save for any obligations that expressly survive such termination).

(b) DOE may, at its option, terminate this Agreement upon the occurrence of the following events:

(i) (A) if at any time there is a final and non-appealable Governmental Order from a court of competent jurisdiction (not initiated or issued by DOE) finding that DOE is legally prohibited from participating in the Project or performing its obligations under the Transaction Documents or (B) any Change of Law shall have occurred that sets aside or legally prohibits DOE's participation in the Project;

(ii) if (A) the Financing Condition is not satisfied by December 31, 2021 or (B) the Commencement Date has not occurred by December 31, 2018; or

(iii) if any Event of Default occurs and is continuing; provided that from and after issuance of the Notice to Proceed, (A) DOE shall not terminate this Agreement unless such Event of Default is a Fundamental Event of Default and (B) DOE's right to terminate this Agreement shall be subject to the terms and conditions of the DOE Direct Agreement and the Intercreditor Agreement, if any;

provided, further that, after Project Completion, DOE shall not terminate this Agreement for an Operational EOD if the remedy described in Section 7.4(a)(v) is available to DOE.

(c) DOE's obligations under any other Transaction Document shall, at its election, terminate without any other action or agreement on the Termination Date, except to the extent that DOE shall otherwise agree that any such obligation survives in such other Transaction Document.

7.2 Acquisition Option.

(a) After the Effective Date, Holdings and DOE shall discuss and determine whether, under Applicable Law, DOE may grant to Holdings (or its nominee, assignee or designee) an option to acquire from DOE the DOE Acquired Real Property and AR Facilities after the Termination Date (the "Acquisition Option"). To the extent DOE determines that such an Acquisition Option may be granted under Applicable Law, DOE and Holdings shall cooperate in good faith to enter into an agreement to set forth all of the terms, conditions and procedures under which such an Acquisition Option may be exercised by Holdings (or its nominee, assignee or designee).

(b) Following the Termination Date, subject to the Acquisition Option (if applicable) and the terms and conditions of the DOE Direct Agreement and the Intercreditor Agreement, if any, DOE shall have the right to Dispose of any of its rights or interests in any DOE Acquired Real Property or any of the AR Facilities, including through a dismantling of any of the AR Facilities and a Disposition of any DOE Acquired Real Property to any Person without any consent by any Clean Line Party or any other Person.

7.3 Events of Default. The following events or circumstances shall constitute events of default under this Agreement (collectively, "Events of Default"):

(a) the Clean Line Parties fail to fund the Advance Funding Account in accordance with the terms set forth in this Agreement and such failure continues for a period of thirty (30) days following written notice to Holdings from DOE;

(b) (i) any Performance Support required to be maintained by the Clean Line Parties shall cease to be in full force and effect; provided that no Event of Default shall have occurred under this clause (b)(i) to the extent that either (A) such Performance Support has been drawn on in full by DOE and the proceeds thereof placed in a DOE or U.S. Treasury account or a collateral account pledged solely to DOE as a result of either the applicable provider of such Performance Support no longer constituting an Acceptable Support Provider or the pending expiration of such Performance Support or (B) Holdings shall have reinstated such Performance Support in an amount equal to the then Applicable Amount within thirty (30) days following written notice to Holdings from DOE, or (ii) following a draw on the Performance Support by DOE to satisfy any payment obligation of a Clean Line Party hereunder, the Clean Line Entities fail to replenish or reinstate such Performance Support to the then Applicable Amount in accordance with Section 11.5(a) within fifteen (15) Business Days following written notice to Holdings from DOE;

(c) (i) any Clean Line Obligor, any of their respective Controlling Persons or any Principal Person of any Clean Line Obligor or any of their respective Controlling Persons becomes (whether through a transfer or otherwise) a Prohibited Person, (ii) any Clean Line Obligor enters into a transaction with a Person who is a Prohibited Person (other than as required by Applicable Law) and such transaction is not voided or unwound (to the extent permissible under Applicable Law) within thirty (30) days following written notice to Holdings from DOE or (iii) any Clean Line Obligor, any of their respective Controlling Persons or any Principal Person, employee or agent of any Clean Line Obligor or any of their respective Controlling Persons fails to comply with any AM Laws, Anti-Corruption Laws or Sanctions;

(d) any Clean Line Obligor fails to pay, in accordance with the terms of this Agreement or any other Transaction Document, any amounts required to be paid by such Clean Line Obligor pursuant thereto, and such failure to pay shall continue unremedied for a period of thirty (30) days after written notice from DOE that such amount was due;

(e) any representation or warranty made or deemed made by any Clean Line Obligor in any Transaction Document or in any certificate or other document provided by or on behalf of any Clean Line Obligor to DOE are found to have been incorrect, false or misleading in any material respect (except to the extent any such representation and warranty itself is qualified by "materiality", "material adverse effect", "Adverse DOE Impact", "Clean Line Material Adverse Effect" or a similar qualifier, in which case it shall be true and correct in all respects) when made or deemed to have been made;

(f) DOE or any Clean Line Obligor fails to perform or observe any of its material obligations under any other term, covenant or agreement set forth in this Agreement or any other Transaction Document where such failure has not been remedied within thirty (30) days (if such default is remediable) after such Party receives notice of such failure from the non-defaulting Party; provided, that if such Party or Clean Line Obligor, as applicable, commences and diligently pursues efforts to cure such default within such thirty (30) day period, and such default (i) in the case of a default by any Clean Line Obligor, could not reasonably be expected to have an Adverse DOE Impact and (ii) is capable of being cured, such Party or Clean Line Obligor, as applicable, may continue to effect such cure and such default will not be deemed to be an Event of Default for an additional one-hundred twenty (120) days so long as such Party or Clean Line Obligor, as applicable, is diligently pursuing such cure;

(g) following the grant of a security interest in any Collateral, (i) any of the Security Documents shall fail in any material respect to provide the Liens, security interests, rights, titles, interests, remedies, powers or privileges intended to be created thereby (including the priority intended to be created thereby), or any Lien or security interest on the Collateral fails to have the priority contemplated therefor in such Security Document, or (ii) any such Security Document, Lien or security interest ceases to be in full force and effect, or the validity thereof or the applicability thereof to any obligation of any Clean Line Obligor under the Transaction Documents are disaffirmed by or on behalf of any Clean Line Obligor;

(h) any Transaction Document or any material provision thereof, at any time, for any reason, (i) is or becomes invalid, illegal, void or unenforceable or any Clean Line Obligor has repudiated or disavowed or taken any action to challenge the validity or enforceability of any Transaction Document or (ii) ceases to be in full force and effect, except in connection with its expiration or termination in accordance with its terms in the ordinary course;

(i) one or more final and non-appealable Governmental Orders (not initiated or issued by DOE) are entered against any Clean Line Obligor that has an Adverse DOE Impact and such Governmental Order(s) are not vacated, discharged or stayed or bonded pending appeal for any period of thirty (30) days;

(j) any Insolvency Event occurs with respect to any Clean Line Obligor (other than any Immaterial Obligor);

(k) any Change of Control occurs that is not otherwise consented to by DOE;

(l) any of the Clean Line Entities fails to obtain, renew, maintain or comply in all material respects with any Required Approval, or having been obtained, any such Required Approval is, pursuant to a final and non-appealable order of the applicable Governmental Authority (not initiated or issued by DOE), (i) rescinded, terminated, suspended, modified, withdrawn or withheld, (ii) is determined to be invalid, (iii) ceases to be in full force and effect or (iv) is amended or modified so as to result in a Clean Line Material Adverse Effect or causes an Adverse DOE Impact, and such failure or other event described above has not been remedied within sixty (60) days (if such default is remediable) after any Clean Line Entity obtains Knowledge of such failure or other event;

(m) all or substantially all of the Project Facilities are destroyed or become permanently inoperative as a result of an Event of Loss that is not covered by insurance or not repaired or restored with Loss Proceeds in accordance with the terms of this Agreement, unless within sixty (60) days of such Event of Loss, Holdings presents to the Coordination Committee a remedial and financing plan to restore or rebuild such Project Facilities, and such plan has been approved by the Coordination Committee within thirty (30) days thereafter;

(n) an Abandonment occurs;

(o) any Clean Line Obligor is debarred or suspended from contracting with the United States government or any agency or instrumentality thereof;

(p) at any time that the Project Financing is in effect, (i) any of the Project Financing Parties has declared any Indebtedness owed to the Project Financing Parties under any of the Project Financing Documents to be due and payable or required to be prepaid or redeemed (other than by a regularly scheduled required prepayment or redemption), purchased or defeased or an offer to prepay, redeem, purchase or defease such Indebtedness is required to be made, in each case, prior to the stated maturity thereof or (ii) the Project Financing Parties have instituted foreclosure action in respect of any of the Collateral;

(q) from and after the Commencement Date but prior to the occurrence of Project Completion, any of the Project Equity Commitments required to be in effect as a condition to DOE's obligation to acquire any DOE Delegated Real Estate Rights ceases to be in full force and effect, and such Project Equity Commitments are not replaced within a period of thirty (30) days after written notice from DOE or the Person providing such Project Equity Commitments that such Project Equity Commitments are no longer in full force and effect; or

(r) the occurrence of any other event specified to be an "Event of Default" or similar event in any Performance Support.

7.4 Remedies Upon Event of Default.

(a) Upon the occurrence of and during the continuance of any Event of Default, subject to the terms of the DOE Direct Agreement and the Intercreditor Agreement, DOE shall be entitled to exercise any and all of the following remedies (following any applicable notice and cure periods):

(i) DOE shall be entitled to seek temporary or permanent injunction, specific performance or other equitable relief specifically to enforce the obligations of the Clean Line Obligors under this Agreement or any other Transaction Document (and each of the Clean Line Parties hereby acknowledges and agrees that its failure to perform its obligations under this Agreement and the other Transaction Documents will cause irreparable harm to DOE and that the remedy at law for any violation or threatened violation thereof would be inadequate);

(ii) DOE may elect that Holdings' representatives on the Coordination Committee shall not have any right to decide, approve, authorize or vote on any matters before the Coordination Committee specifically relating to remedies to be taken against the Clean Line Parties upon such Event of Default;

(iii) DOE shall be entitled to suspend (without any consequence to DOE hereunder) performance of any of its condemnation or acquisition obligations under this Agreement or any other Transaction Document;

(iv) DOE shall be entitled to exercise all of its rights as a secured creditor of the Clean Line Entities in respect of the Collateral;

(v) if an Operational EOD occurs and is continuing, DOE may, after notice and the expiration of any applicable cure period, exercise replacement rights with respect to the Clean Line Entities by appointing another qualified and experienced Person to step in and assume management and operational control of the Project (at the sole cost and expense of the Clean Line Parties) and in such circumstances, DOE may elect that (A) Holdings' representatives on the Coordination Committee shall cease to have any right to decide, approve, authorize or vote on any matters that would otherwise be decided by the Coordination Committee and (B) the Clean Line Parties shall cease to have any rights to enter into or use any DOE Acquired Real Property or the AR Facilities (except for the rights with respect to Electrical Capacity provided pursuant to Section 2.3);

(vi) DOE shall be entitled to draw on the Performance Support to the extent necessary to satisfy any payment obligations of (A) DOE in respect of any Covered Cost, Covered Liability or any other payment paid or payable by DOE in connection with the Project or (B) any Clean Line Obligor due and owing to DOE or any Covered Party;

(vii) DOE shall be entitled to default interest at the Default Rate on any overdue and unpaid amounts owing to DOE by any Clean Line Obligor; and

(viii) DOE shall be entitled to exercise any and all other remedies available to it at law or in equity.

(b) Prior to any exercise of remedies by DOE, DOE shall provide Holdings notice of the occurrence of the applicable Event of Default. Any costs and expenses incurred by DOE in connection with its exercise of any of its remedial rights shall be for the sole account of the Clean Line Parties. Except as otherwise set forth herein, each right and remedy of DOE hereunder shall be cumulative and shall be in addition to every other right or remedy provided herein or now or hereafter existing at law or in equity or by statute or otherwise, and the exercise or the beginning of the exercise by DOE of any one or more of any such rights or remedies shall not preclude the simultaneous or later exercise by DOE of any or all other such rights or remedies.

(c) Upon the occurrence of and during the continuance of any Event of Default by DOE, the Clean Line Entities shall be entitled to exercise any and all other remedies available to it at law or in equity (following any applicable notice and cure periods); provided that, for the avoidance of doubt, no Event of Default by DOE shall have occurred to the extent that such Event of Default arises as a result of any Governmental Order or Change of Law that sets aside, enjoins or legally prohibits DOE's performance under this Agreement or any other Transaction Document or DOE's participation in the Project so long as such Governmental Order or Change of Law is not directly caused by actions of DOE that are specifically targeted at any of the Clean Line Entities or the Project (and not of a more generally applicable nature) or is a result of a violation of Applicable Law by any of the Clean Line Entities or the occurrence of an Event of Default. Except as otherwise set forth herein, each right and remedy of any Clean Line Party shall be cumulative and shall be in addition to every other right or remedy provided herein or now or hereafter existing at law or in equity or by statute or otherwise, and the exercise or the beginning of the exercise by a Clean Line Party of any one or more of any such rights or remedies shall not preclude the simultaneous or later exercise by such Clean Line Party of any or all other such rights or remedies.

7.5 Winding-Up of the Project.

(a) Upon retirement of the Project and the Project Facilities from service or to the extent required by DOE in connection with its exercise of its rights under Section 7.1, but subject to the Acquisition Option, the DOE Direct Agreement and the Intercreditor Agreement, the Clean Line Entities shall promptly wind-up the activities of the Project, which shall include, if requested by DOE, the following actions (the "Wind-Up Events"):

(i) dismantling, demolishing and removing all equipment, facilities and structures;

(ii) terminating applicable agreements in accordance with the terms thereof;

(iii) securing, maintaining and disposing of debris with respect to the Project Facilities and any Project Real Estate Rights; and

(iv) performing any activities necessary to comply with Applicable Law and Prudent Utility Practices and that are otherwise prudent to retire the Project Facilities, restore the Project Real Estate Rights to the original condition and protect the Parties from liability.

(b) All costs and expenses related to the Wind-Up Events shall be borne by the Clean Line Parties.

7.6 Wind-Up Reserve Account. Commencing no earlier than the twentieth (20^{th}) anniversary of Project Completion, Holdings shall establish and maintain a depositary account on terms reasonably acceptable to DOE (the "Wind-Up Reserve Account"), which Wind-Up Reserve Account shall be pledged on a first priority basis to DOE and shall not be pledged to any other Person; provided that if on the twentieth (20^{th}) anniversary of the date of Project Completion, the remaining useful life of the Project and the Project Facilities is reasonably estimated to be in excess of ten (10) years, Holdings may delay the establishment of the Wind-Up Reserve Account until a date that is reasonably estimated by an Independent Engineer to be ten (10) years prior to the expiration of the useful life of the Project. Simultaneously with the establishment of the Wind-Up Reserve Account, and each subsequent year thereafter, Holdings shall deposit an amount into the Wind-Up Reserve Account equal to (a)(i) the current estimated costs to implement all of the Wind-Up Events, as determined by the Coordination Committee *plus* a reasonable contingency amount thereon as determined by an Independent Engineer (on an annual basis) *less* (ii) the amount on deposit in the Wind-Up Reserve Account; *divided* by (b) the estimated number of years, as determined by the Coordination Committee (on an annual basis), until commencement of the Wind-Up Events. Notwithstanding anything to the contrary set forth above, Holdings shall have the option of funding the then-required amount of the Wind-Up Reserve Account with an Acceptable Letter of Credit or cash, or any combination thereof.

7.7 Event of Loss. To the extent that the Loss Proceeds associated with any Event of Loss (or the time contemplated for repair or replacement of any affected Property) are reasonably anticipated to be less than the Loss Threshold, the Clean Line Entities shall be entitled to elect to repair and restore any Property affected by such Event of Loss and shall be entitled to all Loss Proceeds payable in connection with such Event of Loss. To the extent that the Loss Proceeds associated with any Event of Loss (or the time contemplated for repair or replacement of any affected Property) are reasonably anticipated to exceed the Loss Threshold, then the Parties shall initiate the Wind-Up Events unless the Parties and, if applicable, the Project Financing Parties, mutually agree to repair or replace the affected Property or the Clean Line Entities present a remedial and financing plan approved by the Coordination Committee within one hundred twenty (120) days after such Event of Loss to repair, replace or restore such affected Property. Any Loss Proceeds payable in respect of any Event of Loss shall be applied as follows: *first*, to the extent that the Clean Line Entities are entitled to repair or restore any affected Property and have so elected to repair and restore such affected Property, such Loss Proceeds shall be paid to the Clean Line Entities to enable the repair and restoration of such affected Property; *second*, to the extent of any excess Loss Proceeds remaining after any such repair or restoration is completed, an amount determined by DOE as necessary to be reserved (taking into consideration the amount of the Performance Support and any amounts available in the Wind-Up Reserve Account) to cover any potential additional claims for damages to DOE relating to such Event of Loss shall be set aside in a reserve account pledged to the benefit of DOE and maintained for a period of two (2) years or such shorter time period as agreed to by the Coordination Committee (and to the extent necessary shall be applied to the payment of any such damages); and *third*, any remaining excess Loss Proceeds shall be released to the Clean Line Entities, subject to the terms of the Project Financing Agreements.

7.8 Survival of Obligations. The rights and obligations of the Clean Line Parties under Sections 2.3, 7.2, 11.1, 11.3, 11.4, 11.8, 11.9, 13.17, 13.18 and 13.20, and Article IX shall survive the Termination Date; provided that Section 7.2(a) shall terminate within six (6) months after the Termination Date (unless otherwise extended as agreed to by DOE); provided further that the survival of any rights of the Clean Line Entities, other than the Acquisition Option (if applicable), shall not in any way limit DOE's right to dispose, transfer, sell, dismantle or take any other actions with respect to any of the AR Facilities or DOE Acquired Real Property after the Termination Date.

ARTICLE VIII
COVENANTS

8.1 Recordkeeping. Holdings shall and shall cause all of its Subsidiaries to keep proper records and books of account in which full, true and correct entries in accordance with GAAP and FERC standards and all Applicable Laws are made in respect of all dealings and transactions relating to the Project and the conduct of their business.

8.2 DOE's Access Rights, Etc. Upon reasonable advance notice and during normal business hours, DOE (through its officers, agents and designated representatives) shall have:

(a) the right to visit and inspect the Project, subject to reasonable safety and security requirements of which DOE receives prior written notice;

(b) access to books, documents, papers and records of the Clean Line Parties for the purposes of audit, examination, inspection and monitoring;

(c) the right to discuss the affairs, finances and accounts of the Clean Line Parties with representatives of the Clean Line Parties (including any auditors or accountants of the Clean Line Entities); and

(d) the independent right to (i) monitor the development, design, engineering, construction, financing, ownership, operation, maintenance and management of the Project (including participating in any acceptance testing) and (ii) review and comment on draft copies of all Material Project Contracts, and applications for Governmental Approvals for the Project.

The Clean Line Entities shall coordinate and cooperate, and require their Contractors to coordinate and cooperate, with DOE to facilitate DOE's access rights set forth above.

8.3 Reporting Requirements. During the term of this Agreement, Holdings shall furnish to DOE the following items:

(a) after the Commencement Date and prior to the issuance of the Notice to Proceed, within twenty (20) Business Days after the end of each calendar quarter, a Project Development Progress Report based upon Holdings' good faith reasonable estimates of the information contained therein;

(b) after issuance of the Notice to Proceed through Project Completion, within twenty (20) Business Days after the end of each calendar quarter, a Construction Progress Report based upon Holdings' good faith reasonable estimates of the information contained therein;

(c) from and after Project Completion, within thirty (30) days after the end of each calendar quarter, quarterly operating reports in a form to be mutually agreed between Holdings and DOE and which shall include (i) an update on all material issues with respect to the Project (including any material Events of Loss or Actions that have arisen or exist with respect to the Project or any material noncompliance with any Required Approval then in effect), (ii) a summary of the operating status of the Project (including with respect to Electrical Capacity, availability, forced outages, safety statistics and outage status for planned outages) and (iii) such other information as DOE may reasonably request to be included from time to time;

(d) as soon as available, but in any event within sixty (60) days after the end of each of the first three (3) fiscal quarters of each fiscal year of Holdings, unaudited Financial Statements for Holdings and (on a consolidated basis) its Subsidiaries for such fiscal quarter and the then elapsed portion for the relevant fiscal year and comparative figures for the same periods in the immediately preceding fiscal year;

(e) as soon as available, but in any event within one hundred twenty (120) days after the end of each fiscal year of Holdings (starting with the fiscal year ending December 31, 2016), (i) audited Financial Statements of Holdings and (on a consolidated basis) its Subsidiaries for such fiscal year, accompanied by a report and opinion of an independent auditor to the effect that such financial statements present fairly in all material respects the financial condition, results of operations, shareholders' equity and cash flows of Holdings and its Subsidiaries for such fiscal year, which report and opinion is prepared in accordance with GAAP and (ii) a certificate of an Authorized Officer of Holdings, which certificate shall state that such Financial Statements fairly represent the financial condition and results of operations of Holdings and its Subsidiaries for such fiscal year;

(f) concurrently with the delivery of any Financial Statements pursuant to clauses (c) and (d) above, a certificate of an Authorized Officer of Holdings certifying that, to the Knowledge of the Clean Line Parties, no Default or Event of Default exists, or, if such certification cannot be made, the nature and period of existence of such Default or Event of Default and what corrective action Holdings and its Subsidiaries have taken or propose to take with respect thereto;

(g) within sixty (60) days after the end of each calendar year commencing with the calendar year in which Project Completion occurs, a report prepared by Holdings detailing the proposed maintenance and outage program for the Project for such calendar year;

(h) promptly, but in any event within ten (10) Business Days (or, in the case of clause (xii), notice of the occurrence of any Safety Event or any other accident related to the Project that involves a loss of life within twenty-four (24) hours) after any of the Clean Line Parties obtains Knowledge thereof or information pertaining thereto, notice of:

(i) following Project Financial Close but prior to Project Completion, the occurrence of any event or circumstance that has resulted in, or could reasonably be expected to result in, a failure to satisfy the Permitted Draw Conditions;

(ii) the occurrence of any event that constitutes a Default or Event of Default, specifying the nature thereof, together with a certificate of an Authorized Officer of Holdings indicating any steps that the Clean Line Parties have taken or propose to take to remedy the same;

(iii) the occurrence of (A) any Action, pending or threatened, that relates to the legality, validity or enforceability of any of the Transaction Documents, (B) any material Action, pending or threatened, that relates to the Project or to which a Clean Line Party is a party or (C) any material hearing or proceeding initiated against any Clean Line Party by any Governmental Authority that specifically affects the Project;

(iv) any actual or proposed termination, rescission, discharge (otherwise than by performance), amendment, supplement, modification, waiver or indulgence or breach in any material respect of any Material Project Contract or Required Approval together with a copy of any notice or correspondence received in respect thereof and copies of any proposed amendment, supplement, modification or waiver in respect of such Material Project Contract or Required Approval;

(v) other than Permitted Liens, any Lien being granted or established or becoming enforceable over any of the Properties of the Clean Line Entities or the Equity Interests in any of the Clean Line Entities, together with a description thereof;

(vi) any proposed material change in the nature or scope of the Project or the business or operations of the Clean Line Parties, together with a description thereof;

(vii) the occurrence of any Event of Loss that is reasonably likely to result in Loss Proceeds in excess of $5,000,000, together with a description thereof;

(viii) any non-compliance of any Performance Support with the criteria established with respect thereto and any event, condition or circumstance that represents or could reasonably be expected to lead to non-compliance by any issuer with the required criteria with respect thereto or the renewal thereof;

(ix) the occurrence of any event of Force Majeure affecting, or that any Clean Line Party claims would affect, the performance by such Person of any obligation under any Transaction Document or is otherwise reasonably likely to have a Clean Line Material Adverse Effect;

(x) any material dispute between any Clean Line Entity and any Project Participant party to any Material Project Contract (where DOE is not also a party to such dispute), together with a copy of any material notice or material correspondence received in respect thereof;

(xi) any proposed cancellation or material change in any Required Insurance maintained by any Clean Line Entity or by any other Person for the benefit of any Clean Line Entity or DOE, together with a report describing such event and the potential insurance-related impact thereof;

(xii) the occurrence of any Safety Event or any other accident related to the Project that involves a loss of life together with a reasonably detailed report describing such Safety Event or accident, the impact of such Safety Event or accident and the remedial efforts required and (as and when taken) implemented with respect thereto;

(xiii) any actual or alleged violations in any material respect by any of the Clean Line Parties of any Environmental Laws or any applicable NERC reliability standards in connection with the Project, together with a reasonably detailed summary of such violations, copies of any material notices or material correspondence received in connection therewith and a description of the remedial efforts that the Clean Line Parties propose to take in connection therewith;

(xiv) any material dispute between a Clean Line Entity and a Governmental Authority with respect to the Project's compliance with a term or condition of a Governmental Approval or Governmental Order, together with a copy of any notice or correspondence in respect thereof; and

(xv) any material Environmental Claims related to the Project, together with a copy of any material correspondence relating thereto and a description of any steps that the Clean Line Parties are taking or propose to take with respect thereto;

(i) promptly, but in any event no later than ten (10) Business Days after receipt, filing, delivery or sending thereof, copies of:

(i) Reserved;

(ii) any notice of a delinquent payment owed by any Clean Line Party to any Project Participant pursuant to the terms of any Project Contract if such payment is more than thirty (30) days delinquent and is in excess of $5,000,000, together with a copy of all correspondence received or sent by any Clean Line Party in respect of such delinquent payment;

(iii) any notices or material correspondence from any Project Participant relating to (A) any material delay in the completion of the Project or (B) the occurrence of any event that could reasonably be expected to interrupt operation of the Project for more than thirty (30) Business Days;

(iv) any material reports filed by any Clean Line Party with any Governmental Authority relating to the Project or any other financial information, statutory audits, proxy materials or other material information delivered or provided by any Clean Line Entity to any Governmental Authority;

(v) any material notices, certificates or reports delivered by any Clean Line Party to the Project Financing Parties or any material notices or other material written correspondence received by any of the Clean Line Parties from or on behalf of the Project Financing Parties (including any notices of the occurrence of a default or event of default in respect thereof); and

(vi) any Required Approval issued to or on behalf of the Clean Line Entities in respect of the Project.

(j) as soon as available but in any event no later than ten (10) Business Days following execution thereof, copies of any executed Project Financing Documents and any amendments, modifications, supplements or waivers in respect thereof;

(k) (i) no later than five (5) Business Days prior to the commencement of any commissioning testing in respect of the Project, written notice thereof; (ii) written notice of the occurrence of Project Completion (which shall include a certificate by an Authorized Officer of Holdings as to the satisfaction of the conditions to the occurrence of Project Completion) and (iii) promptly upon receipt of delivery thereof, a copy of any notice of the occurrence of the commencement of commercial operations to any party to any Transmission Services Agreement;

(l) on an annual basis after the Commencement Date and within thirty (30) days of each anniversary thereof, a certificate from an Authorized Officer of Holdings that the Clean Line Entities are in compliance with Section 8.5 and that all Required Insurance is in full force and effect, accompanied by a certification from Holding's insurance broker confirming the foregoing; and

(m) promptly upon request, such other information or documents as DOE may reasonably request from time to time.

8.4 Authorizations and Approvals.

(a) The Clean Line Entities shall obtain, and in the case of Required Approvals of Contractors, shall cause its Contractors to obtain, all Required Approvals, at their sole cost and expense. No later than ninety (90) days after the Commencement Date, Holdings shall provide a schedule of all Known Required Approvals to DOE and a plan for the acquisition of such Required Approvals. Concurrently with the delivery of any Financial Statements pursuant to Section 8.3(c) or 8.3(d) above, Holdings shall report, on a quarterly basis, the status of all applications for Required Approvals. In the event that a Required Approval is denied or includes terms and conditions that may materially affect Project operations, Holdings shall immediately notify DOE of such event and consult with DOE on measures taken to remedy such adverse event.

(b) For any Required Approval that is issued in any Clean Line Entity's name or otherwise is applicable to any Clean Line Entity, the applicable Clean Line Entity shall, at its own cost and expense, comply with all conditions imposed by and undertake all actions required by and all actions necessary to maintain in full force and effect all Required Approvals. To the extent that a Required Approval is issued solely in DOE's name or jointly to both DOE and any Clean Line Entity, the Clean Line Entities shall be responsible for any costs or expenses that DOE incurs in taking all actions necessary to maintain in full force and effect such Required Approval.

(c) Prior to Project Completion, the Clean Line Entities shall have obtained from FERC any exemptions or waivers from regulation under PUHCA for which it may be eligible under FERC's regulations.

(d) In the event that any Required Approval must be issued in DOE's name, Holdings shall undertake necessary efforts to obtain such Required Approval, subject to DOE's reasonable cooperation with Holdings at Holdings' sole expense, as such cooperation by DOE is limited by Section 4.10. In the event that DOE must act as the lead agency and directly coordinate with any Governmental Authority in connection with obtaining any Governmental Approval, the Clean Line Entities shall promptly provide all necessary support consistent with Applicable Law to facilitate the approval, mitigation or compliance process for such Governmental Approval.

(e) Each Clean Line Entity shall, at its own cost and expense, (i) obtain all Governmental Approvals or any other approvals, consents, exemptions, authorizations or other actions by, or notices to, or filings with, any other Person that may be necessary or required from time to time in connection with the performance by such Clean Line Entity of its obligations and undertakings under this Agreement or any other Transaction Document (in light of the current stage of construction, management and/or operation of the Project as of any date of determination) and (ii) comply with the terms and conditions of any such Governmental Approval or other approval, consent, exemption, authorization, notice or filing (if applicable) to the extent in effect from time to time, in each case, except where the failure to so obtain or comply with any such Governmental Approval or other approval, consent, exemption, authorization, notice or filing could not reasonably be expected to result, individually or in the aggregate, in a Clean Line Material Adverse Effect or an Adverse DOE Impact.

8.5 Insurance.

(a) The Clean Line Entities shall obtain, maintain or cause to be maintained insurance of the types, in the amounts and with the deductibles specified in the Insurance Agreement, as in effect from time to time, and in all cases in accordance with Prudent Utility Practices.

(b) The Clean Line Entities shall cause DOE to be named as an "additional insured" and as "loss payee" under each of its insurance policies to the extent required under the terms of the Insurance Agreement. The Parties will also determine appropriate insurance protections to be set forth and agreed in the Insurance Agreement for DOE and the other Covered Parties through insurance policies procured by the Construction Contractors and other major Contractors, including additional insured and loss payee endorsements.

(c) Each of the Clean Line Entities shall use all commercially reasonable efforts to enforce any Contractual Obligations by any Construction Contractor under a Material Construction Contract to obtain and maintain any of the Required Insurance.

(d) In the event that any Clean Line Entity fails to procure or maintain (or cause to be procured or maintained) any Required Insurance, DOE may (but shall not be obligated to) take out the Required Insurance and pay the premiums on the same. All amounts so advanced for such purpose by DOE shall be a Covered Liability owed by the Clean Line Parties to DOE and the Clean Line Parties shall forthwith pay any such amounts to DOE.

8.6 Payment of Taxes and Other Amounts. Each of the Clean Line Parties shall pay or arrange for the payment of (before they become overdue) all present and future (a) Taxes (including stamp taxes), duties, fees, expenses, or other charges payable on or in connection with the Project or the execution, issue, delivery, registration, or notarization of, or for the legality, validity, or enforceability of, this Agreement, the Security Documents and the other Transaction Documents, (b) claims, levies, or liabilities (including claims for labor, services, materials and supplies) for sums that have become due and payable and that have resulted in or, if unpaid, might result in the imposition of a Lien upon the Property of any Clean Line Entity with respect to the Project Real Estate Rights on the AR Facilities (or any part thereof), (c) Taxes, payments, fees and expenses relating to the acquisition of the Project Real Estate Rights and (d) Local Government Contribution Payments.

8.7 Maintenance of Existence and Property.

(a) Each Clean Line Party shall preserve and maintain (i) its legal existence as a limited liability company and (ii) all of its licenses, rights, privileges and franchises material to the conduct of its business and the Project.

(b) Each Clean Line Party shall engage only in the business consistent with the Transaction Documents and the Project Financing Documents to which it is a party and any business reasonably incidental or related thereto (including with respect to the Other Facilities).

(c) Each Clean Line Entity shall (i) keep (or cause to be kept) all its Properties (including with respect to the Project) in good working order and condition to the extent necessary to ensure that its business can be conducted properly at all times and (ii) develop, construct, operate, maintain and repair the Project or cause the Project to be developed, constructed, operated, maintained and repaired in all material respects in accordance with (A) the standards set forth in the Clean Line Documents as in effect from time to time, (B) in all material respects in accordance with manufacturer's recommendations (to the extent required to maintain material warranties in effect), (C) Required Approvals and (D) Prudent Utility Practices.

8.8 Compliance with Applicable Laws. Each of the Clean Line Entities shall, and with respect to the construction, operation and maintenance of the Project shall use commercially reasonable efforts to enforce and diligently pursue all contractual remedies available to it to cause each Project Participant to, comply with and conduct its business and operations in compliance with all Required Approvals and Applicable Laws, including Environmental Laws and Cultural Resource Agreements, except where the failure to comply could not reasonably be expected to result, individually or in the aggregate, in a Clean Line Material Adverse Effect or an Adverse DOE Impact.

8.9 Diligent Construction of the Project. Each of the Clean Line Entities shall use diligent efforts to construct and complete, or cause to be constructed and completed, the Project in all material respects in accordance with the Project Contracts, Required Approvals, Prudent Utility Practices, the Project Schedule, the Project Budget and the terms and conditions of the applicable Transaction Documents.

8.10 Performance of Obligations. Each of the Clean Line Entities shall (a) perform and observe all of its material covenants and obligations contained in any Material Project Contract or Required Approval, (b) take all reasonable and necessary action to prevent the termination, suspension or cancellation of any Material Project Contract or Required Approval (except for the expiration of any Material Project Contract or Required Approval in accordance with its terms and not as a result of a breach or default thereunder by any Clean Line Entity) and (c) enforce against the relevant Project Participant each material covenant or obligation under each Material Project Contract to which such Person is a party in accordance with its terms, in each case except where failure to do so could not reasonably be expected to have a Clean Line Material Adverse Effect or an Adverse DOE Impact.

8.11 Permitted Liens. Each Clean Line Entity shall not, and shall not agree to, create, assume or otherwise permit to exist (a) any Lien upon any of the Collateral or any of its other material Property, whether now owned or hereafter acquired, or in any proceeds or income therefrom, other than Permitted Liens or (b) any Lien upon its Equity Interests other than Permitted Liens.

8.12 Merger; Bankruptcy; Dissolution; Transfer of Assets. Each Clean Line Entity shall not, and shall not agree to:

(a) enter into any transaction of merger, combination or consolidation;

(b) liquidate, wind-up or dissolve itself or otherwise commence any Insolvency Event in respect of itself or file any petition or pass a resolution seeking the same;

(c) Dispose of all or any part of its Property, including its interest in the Project, whether now owned or hereafter acquired, except for Permitted Dispositions;

(d) acquire by purchase or otherwise the business, Property or assets of, or Equity Interests or other evidence of beneficial ownership interests in, any Person, other than purchases or other acquisitions of inventory or materials or spare parts or Capital Expenditures, each in the ordinary course of business or any Emergency Capital Expenditures or Emergency Operating Expenses; or

(e) transfer or release (other than as permitted by clause (c) above) the Collateral or any portion thereof.

8.13 New Subsidiaries; Partnerships. Without the prior written consent of DOE, no Clean Line Entity shall: (a) form or have any Subsidiaries other than (i) those in existence as of the Effective Date or (ii) new Project Subsidiaries that become a party to this Agreement pursuant to Section 8.18, (b) enter into any partnership, joint venture or similar arrangement, (c) acquire any Equity Interests in or make any capital contribution to any other Person (other than to another Clean Line Entity or, in the case of Holdings only, acquire any Equity Interests in or make any capital contribution to PECL and any PECL Subsidiary) or (d) enter into any management contract or similar arrangement whereby its business or operations are managed by any other Person.

8.14 Subsidiaries of Holdings. No Project Subsidiary shall own (a) any real Property rights other than those relating to the Project or (b) any Equity Interests other than Equity Interests in any Subsidiary of Holdings or any other Person that is also a Project Subsidiary. None of the Project Subsidiaries shall be a party to any Contractual Obligation relating to the ownership, development, construction, procurement, operation, management or maintenance of any Properties other than those relating to the Project and the Other Facilities.

8.15 Other Transactions. Except for the Transaction Documents, the Project Equity Commitments, the Project Financing Commitments and the Project Financing Documents, no Clean Line Entity shall, directly or indirectly, enter into any transaction or series of related transactions with any Affiliate other than in the ordinary course of business on fair and reasonable terms no less favorable to the Clean Line Entities than those that would be included in an arm's-length transaction with a non-Affiliate.

8.16 Testing. The applicable Clean Line Entities shall (a) provide, or cause to be provided, reasonable prior notice to DOE regarding the startup testing of the Project pursuant to the Material Construction Contracts, (b) provide DOE (or its representatives, agents or consultants) with the opportunity to observe the startup testing of the Project and (c) provide DOE with any material data or material reports received by any Clean Line Entity in connection with the startup testing of the Project pursuant to the Material Construction Contracts.

8.17 Creation and Perfection of Security Interests; Additional Documents; Filings and Recordings.

(a) Each of the Clean Line Entities shall execute and deliver, from time to time as reasonably requested by DOE at the expense of the Clean Line Entities, such other documents as shall be necessary or advisable or that DOE may reasonably request in connection with the rights and remedies of DOE granted or provided for by the Transaction Documents and to consummate the transactions contemplated therein.

(b) Each of the Clean Line Entities shall, at its own expense, take all actions that have been or shall be reasonably requested of such Clean Line Entity or that any Clean Line Entity knows is necessary to establish, maintain, protect, perfect and continue the perfection of the security interests of DOE created by the Security Documents with the priority provided for under the Security Documents (subject to Permitted Liens and, with respect to the Second Lien Collateral, only to the extent that the first priority security interest in favor of the applicable Financing Parties has been established and/or perfected) and shall furnish timely notice of the necessity of any such action, together with such instruments, in execution form, and such other information as may be required or reasonably requested to enable DOE to effect any such action. Without limiting the generality of the foregoing, each of the Clean Line Entities shall, at its own expense, (i) execute or cause to be executed and shall file or cause to be filed or register or cause to be registered such financing statements, continuation statements, fixture filings and mortgages or deeds of trust in all places necessary or advisable (in the reasonable opinion of counsel for DOE) to establish, maintain and perfect such security interests and in all other places that DOE shall reasonably request (provided, however, that, with respect to the Second Lien Collateral, the Clean Line Entities shall not be obligated to execute, file or register any such statements, filings, mortgages or deeds of trust or other documents that are not required to be executed, filed or registered in respect of the first priority security interest granted in favor of the applicable Financing Parties), (ii) discharge all other Liens (other than Permitted Liens) adversely affecting the rights of any Clean Line Entity in the Collateral and (iii) deliver or publish all notices to third parties that may be reasonably required to establish or maintain the validity, perfection or priority of any Lien created pursuant to the Security Documents (provided, however, that, with respect to the Second Lien Collateral, the Clean Line Entities shall not be obligated to deliver or publish any notices that are not required to be delivered or published in respect of the first priority security interest granted in favor of the applicable Financing Parties).

8.18 Additional Project Subsidiaries and Subsidiary Guarantors.

(a) Within twenty (20) Business Days following the formation or acquisition, directly or indirectly (including through any merger or consolidation), by any Clean Line Entity of any Project Subsidiary, Holdings shall, at the sole cost and expense of the Clean Line Entities, cause such Project Subsidiary to become a Party hereto by executing and delivering to DOE a joinder agreement to this Agreement in form and substance reasonably satisfactory to DOE along with the documents set forth in clause (c) below.

(b) Within twenty (20) Business Days following the formation or acquisition, directly or indirectly (including through any merger or consolidation), by any Clean Line Party of any PECL Subsidiary, Holdings shall, at the sole cost and expense of the Clean Line Parties, cause such PECL Subsidiary to become a Subsidiary Guarantor and be obligated for all Guaranteed Obligations by executing and delivering to DOE a joinder agreement to this Agreement in form and substance reasonably satisfactory to DOE along with the documents set forth in clause (c) below.

(c) Together with the delivery of any joinder agreement referenced in either clause (a) or (b) above, the applicable Clean Line Party shall deliver to DOE (i) certified Organizational Documents of such Clean Line Party, (ii) secretary's certificates, officer's certificates, resolutions and good standing certificates for such Clean Line Party (including certificates certifying to such matters as DOE shall reasonably require) and (iii) if requested by DOE, legal opinions from counsel to such Clean Line Party.

8.19 Lobbying Disclosure Requirement. Each of the Clean Line Parties shall complete and submit Standard Form-LLL, "Disclosure Form to Report Lobbying," in accordance with its instructions.

8.20 Improper Use. Unless required under Applicable Law or as otherwise provided for under this Agreement, no Clean Line Entity shall use, operate or occupy, or allow (directly or indirectly) the use, maintenance, operation or occupancy of, any portion of the Project Site or the Project in any manner or for any purpose: (a) that could reasonably be expected to have a Clean Line Material Adverse Effect or an Adverse DOE Impact, (b) that may make void, voidable or cancelable any insurance or material warranty then in force with respect to the Project Facilities or (c) other than for the intended purpose thereof in the construction, operation and maintenance of the Project Facilities.

8.21 Hazardous Substance Management.

(a) In the event of a Release or discovery of Hazardous Substances on Property on which the Project Facilities are located, the responsible Clean Line Entity shall, or shall cause another Person to take all reasonable actions, consistent with Prudent Utility Practice, Applicable Law and all applicable provisions of the Transaction Documents and the Project Documents, to report, investigate, oversee, manage, treat, handle, store, remediate, remove, transport (where applicable), deliver or dispose of such Hazardous Substances; provided that where consistent with Applicable Law and Prudent Utility Practice, the Hazardous Substances may be left *in situ*.

(b) If any Clean Line Entity or any Construction Contractor Releases or causes to Release Hazardous Substances in connection with the Project or any Project Real Estate Rights in an amount, type, quality or location that would require reporting or notification to any Governmental Authority or other Person or taking any preventive or remedial action, in each case under Applicable Law, Governmental Approvals or any applicable provision of the Transaction Documents and Project Contracts, the responsible Clean Line Entity shall (i) promptly notify DOE in writing and advise DOE of any obligation to notify any state or federal Governmental Authorities under Applicable Law and (ii) notify any such state or federal Governmental Authorities.

(c) The responsible Clean Line Entity shall, or shall cause another Person to take reasonable steps, including design and/or construction technique modifications, to avoid and/or minimize disturbance of known *in situ* Hazardous Substances. Where the disturbance of Hazardous Substances, including excavation or dewatering, is unavoidable or is required by Applicable Law, the Clean Line Entities shall utilize appropriately trained Contractors.

8.22 Safety Compliance.

(a) DOE shall use good faith efforts to inform Holdings at the earliest practicable time of any circumstance or information relating to the Project which, in DOE's reasonable judgment, is likely to result in a Safety Compliance Order. Except in the case of an Emergency, DOE shall consult with Holdings prior to issuing a Safety Compliance Order concerning the risk to public or worker safety, alternative compliance measures, cost impacts, and the availability of Clean Line Entity resources to fund the Safety Compliance work.

(b) Subject to conducting such prior consultation as required (unless in the case of an Emergency), DOE may issue Safety Compliance Orders to the Clean Line Entities at any time.

(c) The Clean Line Entities shall implement all Safety Compliance work as expeditiously as reasonably possible following issuance of the Safety Compliance Order. The Clean Line Entities shall diligently prosecute the work necessary to achieve such Safety Compliance until completion. The Clean Line Entities shall perform all work required to achieve Safety Compliance at the sole cost and expense of the Clean Line Entities.

(d) The Clean Line Entities shall adopt and comply with those applicable safety and Emergency response measures for the Project adopted in accordance with the DOE Mitigation Action Plan and all other safety-related or emergency response measures required under Applicable Law.

8.23 Prohibited Persons.

(a) Each Clean Line Party shall provide immediate written notice (including a brief description relating thereto) to DOE if, at any time, it learns that the representations made with respect to Prohibited Persons (including in respect of the Debarment Regulations) were erroneous when made or have become erroneous by reason of changed circumstances.

(b) If any Project Participant or any Person that controls a Project Participant or any of their respective Principal Persons becomes a Prohibited Person, the Clean Line Parties shall, within sixty (60) days of Knowing that such Person has become a Prohibited Person, engage and continue to engage in constructive discussions with DOE regarding the removal or replacement of such Person or, if such removal or replacement is not reasonably feasible, the implementation of other mitigation matters.

8.24 Davis-Bacon Act.

(a) To the extent that DOE (or the Department of Labor, as the case may be) has determined that the Davis-Bacon Act is applicable to this Agreement and/or the Project, the Clean Line Entities shall (i) in respect of this Agreement, comply with all Davis-Bacon Requirements (including the provisions and wage determinations set forth in Schedule 15 hereto (as such Schedule is supplemented from time to time in accordance with Section 8.24(b)) and the provisions and applicable wage determinations set forth in such Schedule 15 shall be deemed incorporated into this Agreement as if set out in their entirety in this Section 8.24 and (ii) in respect of any applicable Project Contract (A) be responsible for the compliance by any applicable Contractor performing construction, as defined in Department of Labor regulations at 29 C.F.R. § 5.2(j), with the Davis-Bacon Requirements and (B) cause each applicable Contractor performing construction, as defined in Department of Labor regulations at 29 C.F.R. § 5.2(j), to include in such contract to which it is a party the provisions and applicable wage determinations set forth in Schedule 15 hereto (as such Schedule is supplemented from time to time in accordance with Section 8.24(b)).

(b) To the extent DOE (or the Department of Labor, as the case may be) has determined that the Davis-Bacon Act is applicable to this Agreement and/or the Project, from time to time after such determination is made and in any event prior to Clean Line entering into any applicable Project Contract subject to the Davis-Bacon Act, DOE may supplement Schedule 15 hereto to incorporate the wage determinations containing locally prevailing wages as determined by the Secretary of Labor applicable to this Agreement or such Project Contract, as the case may be.

8.25 AM Laws, Anti-Corruption Laws Etc. Each Clean Line Party shall and shall cause its Principal Persons, employees and agents to (a) comply with all applicable AM Laws and Anti-Corruption Laws in obtaining any Required Approvals, Project Real Estate Rights or any other consents, rights or privileges with respect to the Project, (b) conduct the business of the Project in compliance with all applicable AM Laws and Anti-Corruption Laws and (c) maintain internal management and accounting practices and controls that are adequate to ensure the Clean Line Parties' compliance with all applicable AM Laws and Anti-Corruption Laws.

8.26 ACL Indebtedness. ACL shall not incur any Indebtedness owed to any other Clean Line Entity or any Affiliate thereof unless such Clean Line Entity or Affiliate has granted a Lien on its rights of payment in respect of such Indebtedness pursuant to Security Documents that are in form and substance acceptable to DOE as contemplated by Section 11.6.

8.27 Renewable Energy Transmission. At any time during which any Transmission Services Agreements are in effect, the Clean Line Entities shall use all commercially reasonable efforts to ensure that at least 75% of the total Electrical Capacity covered by all Transmission Services Agreement that are then in effect to be covered by Transmission Services Agreements used for the transmission of renewable energy resources; provided that, to the extent the transmission of energy from non-renewable resources is required by Applicable Law (including pursuant to any open access tariff rules), such events would not render the underlying Transmission Services Agreement from being disqualified toward the 75% threshold.

ARTICLE IX
GUARANTEE

9.1 Guarantee of the Obligations.

(a) Subject to the provisions of Section 9.2, PECL and each PECL Subsidiary (each, a "Subsidiary Guarantor" and, collectively, the "Subsidiary Guarantors") jointly and severally hereby absolutely, irrevocably and unconditionally guarantee to DOE, for the benefit of DOE and each other Covered Party, the due and punctual payment in full of all obligations of Holdings and the Project Subsidiaries under this Agreement, whether direct or indirect, absolute or contingent, when the same shall become due (including amounts that would become due but for the operation of the automatic stay under Section 362(a) of the Bankruptcy Code, 11 U.S.C. § 362(a)) (collectively, the "Guaranteed Obligations") and agrees to pay any and all expenses incurred by DOE in enforcing its rights under this Article IX.

(b) Each Subsidiary Guarantor and DOE hereby confirms that it is the intention of all such Persons that the guarantee set forth in this Article IX and the Guaranteed Obligations of each Subsidiary Guarantor hereunder not constitute a fraudulent transfer or conveyance for purposes of Bankruptcy Law, the Uniform Fraudulent Conveyance Act and the Uniform Fraudulent Transfer Act. To effectuate the foregoing intention, DOE and the Subsidiary Guarantors hereby irrevocably agree that the obligations of each Subsidiary Guarantor under this Article IX at any time shall be limited to the maximum amount as will result in the obligations of such Subsidiary Guarantor under this Article IX not constituting a fraudulent transfer or conveyance.

9.2 Contribution by Subsidiary Guarantors. All Subsidiary Guarantors desire to allocate among themselves (collectively, the "Contributing Subsidiary Guarantors"), in a fair and equitable manner, their obligations arising under this Guarantee. Accordingly, in the event of any payment or distribution is made on any date by a Contributing Subsidiary Guarantor (a "Funding Subsidiary Guarantor") under this Guarantee such that its Aggregate Payments exceeds its Fair Share as of such date, such Funding Subsidiary Guarantor shall be entitled to a contribution from each of the other Contributing Subsidiary Guarantors in an amount sufficient to cause each Contributing Subsidiary Guarantor's Aggregate Payments to equal its Fair Share as of such date. The amounts payable as contributions hereunder shall be determined as of the date on which the related payment or distribution is made by the applicable Funding Subsidiary Guarantor. The allocation among Contributing Subsidiary Guarantors of their obligations as set forth in this Section 9.2 shall not be construed in any way to limit the liability of any Contributing Subsidiary Guarantor hereunder. Each Guarantor is a third party beneficiary to the contribution agreement set forth in this Section 9.2.

9.3 Payment by Subsidiary Guarantors. Subject to Section 9.2, the Subsidiary Guarantors hereby jointly and severally agree, in furtherance of the foregoing and not in limitation of any other right which Holdings or the Project Subsidiaries may have at law or in equity against any Subsidiary Guarantor by virtue hereof, that upon the failure of Holdings or the Project Subsidiaries to pay any of the Guaranteed Obligations when and as the same shall become due (including amounts that would become due but for the operation of the automatic stay under Section 362(a) of the Bankruptcy Code, 11 U.S.C. § 362(a)), Subsidiary Guarantors will upon demand pay, or cause to be paid, in cash, to DOE, an amount equal to the sum of the unpaid amount of all Guaranteed Obligations then due *plus* accrued and unpaid interest on such Guaranteed Obligations at the Default Rate (including interest which, but for Holdings or the Project Subsidiaries becoming the subject of a case under the Bankruptcy Code, would have accrued on such Guaranteed Obligations, whether or not a claim is allowed against Holdings or the Project Subsidiaries for such interest in the related bankruptcy case) and all other Guaranteed Obligations then owed to Holdings or the Project Subsidiaries as aforesaid.

9.4 Guarantee Absolute. Each Subsidiary Guarantor guarantees that the Guaranteed Obligations will be paid strictly in accordance with the terms of this Agreement, regardless of any law, regulation or order now or hereafter in effect in any jurisdiction affecting any of such terms or the rights of any Covered Party with respect thereto. The obligations of each Guarantor under this Article IX are independent of the Guaranteed Obligations or any other obligations of any Clean Line Entity under or in respect of this Agreement and the other Transaction Documents, and a separate action or actions may be brought and prosecuted against each Subsidiary Guarantor to enforce this guarantee under this Article IX, irrespective of whether any action is brought against any Clean Line Entity or whether any Clean Line Entity is joined in any such action or actions.

9.5 Liability of Guarantors Absolute; Waivers. Each Subsidiary Guarantor agrees that its obligations hereunder are irrevocable, absolute, independent and unconditional and shall not be affected by any circumstance which constitutes a legal or equitable discharge of a guarantor or surety other than payment in full of the Guaranteed Obligations (other than contingent or indemnification obligations for which no claim has been made) or valid release of a Subsidiary Guarantor with DOE's consent. Each Subsidiary Guarantor hereby waives, for the benefit of DOE and each Covered Party: (a) any right to require DOE, as a condition of payment or performance by such Subsidiary Guarantor, to (i) proceed against Holdings or any Project Subsidiary, any other guarantor (including any other Subsidiary Guarantor) of the Guaranteed Obligations or any other Person, (ii) proceed against or exhaust any Collateral or other security held by DOE or (iii) pursue any other remedy in the power of DOE whatsoever, (b) any defense arising by reason of the incapacity, lack of authority or any disability or other defense of Holdings or any Project Subsidiary or any other Subsidiary Guarantor including any defense based on or arising out of the lack of validity or the unenforceability of the Guaranteed Obligations or any agreement or instrument relating thereto or by reason of the cessation of the liability of Holdings or any Project Subsidiary or any other Subsidiary Guarantor from any cause other than payment in full of the Guaranteed Obligations, (c) any defense based upon any statute or rule of law which provides that the obligation of a surety must be neither larger in amount nor in other respects more burdensome than that of the principal, (d) any defense based upon DOE's errors or omissions in the administration of the Guaranteed Obligations, except for errors or omissions determined in the final, non-appealable judgment of a court of competent jurisdiction to have resulted directly and primarily from DOE's or any Covered Party's gross negligence or willful misconduct, (e) (i) any principles or provisions of law, statutory or otherwise, which are or might be in conflict with the terms hereof and any legal or equitable discharge of such Subsidiary Guarantor's obligations hereunder, (ii) the benefit of any statute of limitations affecting such Subsidiary Guarantor's liability hereunder or the enforcement hereof, (iii) any rights to set-offs, recoupments and counterclaims, and (iv) promptness, diligence and any requirement that DOE protect, secure, perfect or insure any security interest or Lien or any Property subject thereto, (f) notices, demands, presentments, protests, notices of protest, notices of dishonor and notices of any action or inaction, including acceptance hereof, notices of default hereunder or any agreement or instrument related thereto, notices of any renewal, extension or modification of the Guaranteed Obligations or any agreement related thereto, notices of any extension of credit to Holdings or any Project Subsidiary, (g) any duty on the part of DOE to disclose to such Subsidiary Guarantor any matter, fact or thing relating to the business, condition (financial or otherwise), operations, performance, Properties or prospects of Holdings or any Project Subsidiary now or hereafter Known by DOE, (h) any defenses or benefits that may be derived from or afforded by law which limit the liability of or exonerate guarantors or sureties, or which may conflict with the terms hereof, (i) any defenses related to any change in the time, manner or place of payment of, or in any other term of, all or any of the Guaranteed Obligations or any other amendment or waiver of or any consent to departure from the Transaction Documents, including any increase in the Guaranteed Obligations, (j) any defense related to the taking, exchange, release or non-perfection of any Collateral or any manner of application of the Collateral or the proceeds thereof to all or any of the Guaranteed Obligations, or any manner of sale or other disposition of any Collateral for all or any of the Guaranteed Obligations, (k) any defense related to any change, restructuring or termination of the corporate structure or existence of Holdings or any Project Subsidiary, (l) any defense related to the failure of any other Person to execute or deliver the guarantee under this Article IX or the release or reduction of liability of any Subsidiary Guarantor or other guarantor or surety with respect to the Guaranteed Obligations and (m) defenses related to any other circumstance or any existence of or reliance on any representation by DOE that might otherwise constitute a defense available to, or a discharge of, Holdings, any Project Subsidiary or any other guarantor or surety.

9.6 Continuing Guarantee; Assignments. The guarantee in this Article IX is a continuing guarantee and shall (a) remain in full force and effect until the latest of (i) the payment in full in cash of the Guaranteed Obligations and all other amounts payable under this Article IX and (ii) the Termination Date, (b) be binding upon each Subsidiary Guarantor, its successors and assigns and (c) inure to the benefit of and be enforceable by the Covered Parties and their successors, transferees and assigns.

9.7 Obligations and Rights of Subsidiary Guarantors. Except to the extent set forth in this Article IX and rights that inure to all Parties under this Agreement, no Subsidiary Guarantor shall have any rights under this Agreement.

ARTICLE X
FORCE MAJEURE

10.1 Force Majeure. To the extent a Party is delayed or prevented by Force Majeure from performing, in whole or in part, its obligations under this Agreement, and such Party (a "Claiming Party") gives written notice and details of such Force Majeure to the other Party as soon as reasonably practicable after such Party becomes aware of the occurrence of such Force Majeure, then the Claiming Party shall be excused from the performance of its obligations under this Agreement (other than any obligation of the Clean Line Parties to make payments to DOE under the Transaction Documents, including under Sections 11.1, 11.3 and 11.4 and Article IX) during such Force Majeure, but for no longer period and only to the extent performance of such obligations are prevented or delayed by such Force Majeure. The Claiming Party shall exercise due diligence to remedy such Force Majeure within a reasonable period, at the Clean Line Entities' cost in all cases. The occurrence of a Force Majeure shall not entitle any Party to terminate this Agreement.

ARTICLE XI
COST AND EXPENSE FUNDING, ADVANCE FUNDING, INDEMNITY AND COLLATERAL

11.1 Cost and Expense Funding. Each of the Clean Line Entities, jointly and severally, agree to pay for (a) all out-of-pocket costs, expenses and disbursements incurred by DOE (including the costs, expense and disbursements of all internal personnel, consultants, advisors, agents and counsel engaged by DOE) in connection with the development, preparation, negotiation and execution of, and any amendment, supplement or modification to, this Agreement, the other Transaction Documents, the Real Estate Rights Agreements and any other documents prepared in connection therewith and in connection with the Project, (b) all costs, expenses, fees, Taxes, disbursements and payments made by DOE (including the costs, expenses and disbursements of surveyors, appraisers, agents, consultants, advisors and counsel (including Shearman & Sterling LLP) engaged by DOE, and all Local Government Contribution Payments) in connection with the acquisition by DOE of any Project Real Estate Rights, (c) all costs (including the costs, expense and disbursements of all internal personnel, consultants, advisors, agents and counsel engaged by DOE) incurred by DOE in connection with the administration, inspection, enforcement, defense or preservation of any rights or claims under this Agreement, the other Transaction Documents and the Real Estate Rights Agreements, (d) any costs incurred by DOE in connection with its performance or undertaking of any non-delegable obligations or responsibilities under the DOE Mitigation Action Plan, any Cultural Resource Agreement with NHPA, the Endangered Species Act or any other Applicable Law, and (e) any other costs, expenses and disbursements incurred by DOE in connection with its participation in the Project, including, any costs and expenses associated with any of the Wind-Up Events or otherwise arising as a result of DOE's exercise of any rights or remedies under this Agreement, any other Transaction Document, any Real Estate Rights Agreement or any expenditures which DOE deems necessary to protect its and the public's interest in respect of the Project (collectively, the "Covered Costs"). Without limiting the above, Covered Costs shall include all costs and expenses that would not have been incurred by DOE but for its participation in the Project.

11.2 Participation Amount. Commencing on and after the Project Completion, Holdings shall pay to DOE at the end of each fiscal quarter an amount equal to 2% of the gross revenues received by the Clean Line Parties from the Project during such fiscal quarter resulting from the sale of transmission service in connection with the Project (as such gross revenue amount is reflected in Holdings' Financial Statements for such fiscal quarter, including, with respect to the first such fiscal quarter, sales of transmission service which occurred at any time prior to Project Completion) (the "Participation Amount"). The Clean Line Parties shall only be required to pay the Participation Amount after (a) the payment of operating costs and expenses in respect of the Project then due and debt service in respect of the Project Financing then due, (b) the funding of a customary debt service reserve account in favor of the Project Financing Parties under the Project Financing and (c) the funding of the Capital Repairs Reserve Account then required, for such quarterly period; provided that such amounts shall not be deducted from gross revenues for purposes of calculating the Participation Amount due and payable pursuant to this Section 11.2. The Participation Amounts shall be made available to DOE to offset costs associated with federal hydropower infrastructure or for any other authorized purpose.

11.3 Advance Cost Funding.

(a) Within ten (10) Business Days following the Effective Date, Holdings shall deposit, or cause to be deposited, an amount equal to the Required Amount, as notified by DOE to Holdings on or before the Effective Date, into the account specified by DOE in such notice (the "Advance Funding Account").

(b) No later than fifteen (15) Business Days prior to the end of each fiscal quarter of Holdings, DOE shall deliver to Holdings a request for funding of the Advance Funding Account in an amount equal to the then applicable Required Amount (which request shall include a calculation of the Required Amount and shall take into consideration amounts already on deposit in the Advance Funding Account). In addition, if at any time, DOE shall determine that the amount on deposit in the Advance Funding Account is less than the Base Amount applicable as of such time, DOE shall have the right to deliver to Holdings an additional request for funding of the Advance Funding Account in an amount equal to the then applicable Base Amount (including a calculation of such Base Amount). Within fifteen (15) Business Days of Holdings' receipt of any request for funding of the Advance Funding Account from DOE, Holdings shall cause the applicable Required Amount or Base Amount to be deposited into the Advance Funding Account.

(c) DOE will provide Holdings quarterly statements of the Covered Costs expended by DOE and reasonable supporting documentation of such expenditures within thirty (30) days of the close of each quarter.

(d) Subject to limits established under Applicable Law, Holdings shall have the right to conduct, at its own expense, reasonable audits of the books, records, and documents of DOE relating to the items on any particular accounting statement provided by DOE.

(e) DOE agrees to account for its costs incurred pursuant to this Agreement under an accounting procedure in customary usage for accounting of Federal project expenses. Holdings shall have the right to audit DOE's cost records and accounts to verify statements of costs submitted by DOE. DOE agrees to refund any amounts paid if they are found in such audit to exceed the total amount due DOE for its actual costs incurred pursuant to this Agreement without any penalty or interest. The Clean Line Entities agree that such audit of DOE's records and accounts is for the sole purpose of verifying that an accounting statement sets forth the actual costs as reflected by the records, and that accounts are maintained in accordance with the established accounting procedures.

(f) DOE may withdraw at any time from the Advance Funding Account amounts necessary to pay for Covered Costs incurred by DOE.

(g) DOE agrees not to enter into any Contractual Obligations in connection with the Project that contain amounts payable from time to time by DOE over a period in excess of five (5) future years except to the extent that (i) Holdings has approved any such Contractual Obligation, (ii) such Contractual Obligation is for an initial five (5) year term but has an extension option that can be exercised by, or consented to by, DOE in its sole discretion to extend the length of such Contractual Obligation prior to the termination thereof for additional rolling periods of up to five (5) years or (iii) DOE's obligations to make payments for any period that is later than five (5) years after any date of determination are subject to the availability of funding to DOE with which to make payments in respect thereof.

11.4 Indemnification.

(a) Each Clean Line Entity shall, jointly and severally, indemnify and defend each Covered Party against, and hold each of them harmless from, any and all Covered Liabilities, including, any Covered Liabilities incurred by any Covered Party as a result of any investigation, Action or inquiry (whether or not such Covered Party is a party thereto) related to DOE's entry into and performance under each Transaction Document and its participation in the Project or otherwise arising as a result of the Clean Line Parties operations and business; provided, however, that a Covered Party will not be indemnified for any Covered Liability to the extent (i) determined in the final, non-appealable judgment of a court of competent jurisdiction to have resulted directly and primarily from such Covered Party's gross negligence or willful misconduct or (ii) resulting from a claim brought by or on behalf of any Clean Line Entity against such Covered Party for breach in bad faith of such Covered Party's obligations hereunder or under any other Transaction Document, if such Clean Line Party has obtained a final and non-appealable judgment in its favor in respect of such claim as determined by a court of competent jurisdiction.

(b) In the case of any Covered Liability indemnified by the Clean Line Entities that is covered by a policy of insurance maintained by the Clean Line Entities or by third parties pursuant to the Project Contracts, DOE agrees to cooperate, at the Clean Line Entities' expense, with the insurers in the exercise of their rights to investigate, defend or compromise such Covered Liability as may be required to retain the benefits of such insurance with respect to such Covered Liability.

(c) DOE shall, promptly after it has any actual knowledge thereof, notify Holdings of any Covered Liability as to which indemnification is sought; provided, however, that the failure to deliver such prompt notice shall not release any Clean Line Entity from any of its obligations to indemnify any Covered Party. Any Covered Liability payable to any Covered Party shall be paid on or prior to the date which is the later of (i) the date ten (10) days after receipt by Holdings of a written demand therefor from DOE accompanied by a written statement describing in reasonable detail each Covered Liability that is the subject of, and the basis for, such indemnity and the computation of the amount so payable and (ii) the date two (2) Business Days prior to the date on which any Covered Liability is payable. Subject to the rights of insurers under policies of insurance maintained by the Clean Line Entities, the Clean Line Entities may, unless an Event of Default shall have occurred and be continuing, with respect to any Covered Liability for which indemnification is sought and for which they shall have acknowledged liability to the DOE in writing, and (if requested by DOE in writing after any such acknowledgment of liability has been given by the Clean Line Entities) at the sole cost and expense of the Clean Line Entities, investigate and, if permitted by Applicable Law, defend any Covered Liability for which indemnification is sought with counsel reasonably acceptable to DOE, and DOE shall cooperate, at the Clean Line Entities' expense, with all reasonable requests of the Clean Line Entities in connection therewith; provided that in the event that in the course of the investigation or defense of any such Covered Liability, the Clean Line Entities shall in good faith reasonably determine that they are not liable for indemnification with respect thereto notwithstanding such acknowledgment of liability, Holdings may give notice to the DOE of such fact and, in such case, any acknowledgment theretofore made by the Clean Line Entities of their liability with respect to such Covered Liability shall be deemed revoked, and the Clean Line Entities may thereupon cease to defend such Covered Liability; provided that (A) Holdings shall have given DOE reasonable prior written notice of the Clean Line Entities' intention to renounce such acknowledgment, (B) the Clean Line Entities' conduct regarding the defense of such Covered Liability or any decision to withdraw from such defense shall not materially prejudice or have materially prejudiced DOE's ability to contest such Covered Liability (taking into account, among other things, the timing of the Clean Line Entities' withdrawal and the theory or theories upon which the Clean Line Entities shall have based their defense) and (C) the Clean Line Entities shall have given DOE all materials, documents and records relating to their defense of such Covered Liability as DOE shall have requested in connection with the assumption by DOE of the defense of such Covered Liability at the cost and expense of the Clean Line Entities. If the Clean Line Entities shall cease to defend any Covered Liability pursuant to the preceding sentence, the Clean Line Entities shall indemnify the Covered Parties to the extent that the actions of the Clean Line Entities in defending such Covered Liability or the manner or the time of the Clean Line Entities' election to withdraw from the defense of such Covered Liability shall have caused any Covered Party to incur any cost, loss, liability or expense which such Covered Party would not have incurred had the Clean Line Entities not assumed and thereafter ceased the defense of such Covered Liability in such manner or at such time.

(d) Notwithstanding the foregoing provisions, the Clean Line Entities shall not be entitled to assume and control the defense of any such Covered Liability if an Event of Default has occurred and is continuing or if such Covered Liability involves or could reasonably be expected to result in, in the sole judgment of DOE, (i) an Action involving a possible imposition of any criminal liability or penalty or civil penalty on any Covered Party, (ii) the granting of injunctive relief against any Covered Party affecting Property or activity not related to the transactions contemplated by the Transaction Documents, or (iii) a conflict of interest between any of the Covered Parties and the Clean Line Entities or a risk of the sale, forfeiture or loss of any of the Project Facilities or Project Real Estate Rights or any material portion thereof or interest therein, and, in either case, DOE informs Holdings that such Covered Party desires to be represented by separate counsel, in which case the fees and expenses of such separate counsel shall be borne by the Clean Line Entities. The Clean Line Entities shall provide to any Covered Party as to which any Covered Liability has been or may be asserted, such documents and other information relating thereto as such Covered Party may reasonably request from time to time. The Clean Line Entities shall also assist and testify in all proceedings at the request of DOE even if no Clean Line Entity is involved in such proceedings, all at the Clean Line Entities' cost. The Clean Line Entities shall not enter into any compromise or settlement of Covered Liability if such settlement would have any unindemnified adverse effect on the Project, the Project Facilities, the Project Real Estate Rights or the ability of the Clean Line Entities to perform their obligations under any of the Transaction Documents or Real Estate Rights Agreements or would require any Covered Party to admit any wrongdoing on its part, without the prior written consent of DOE and each applicable Covered Party. No Covered Party shall be entitled to indemnification hereunder with respect to any Covered Liability with respect to which it shall have entered into any settlement or other compromise, unless it shall theretofore have given notice to Holdings of such Covered Liability and the material facts relating thereto, and the Clean Line Entities shall have had a period which shall end on the earlier of (A) the thirtieth (30th) day after the date of delivery to Holdings of such notice and (B) the later of the date on which the relevant offer of settlement or compromise shall have expired and the tenth (10th) day after the date of delivery to Holdings of such notice, in which to acknowledge liability pursuant to the preceding section. No such consent shall be required if (x) an Event of Default shall have occurred and be continuing or (y) such Covered Party waives its right to be indemnified with respect to such Covered Liability.

11.5 Performance Support.

(a) Commencing on the Commencement Date and throughout the term of this Agreement, Holdings shall provide DOE Performance Support, and maintain in full force and effect such Performance Support, in an amount equal to the then Applicable Amount. DOE shall be entitled to make a drawing or demand payment under any such Performance Support in respect of any of the following: (i) to pay any Project Costs (including any costs or expenses associated with any Wind-Up Event) or other payment obligations in respect of the Project to the extent any Clean Line Party has failed to do so, (ii) to pay any Covered Costs to the extent that there are insufficient funds available to DOE in the Advance Funding Account with which to make payment of any such Covered Costs, (iii) as payment of any Covered Liability which any Clean Line Party has otherwise failed to make in accordance with the terms of this Agreement, including the terms set forth under Section 11.4, (iv) to pay any Capital Repairs to the extent that there are insufficient funds available to the Clean Line Entities in the Capital Repairs Reserve Account or to the extent the Clean Line Entities fail to make such Capital Repairs, following the notice and cure period specified in Section 4.8(b), (v) in all other cases in which any Clean Line Party is obligated to make a payment to DOE or any Covered Party pursuant to the terms of this Agreement and has failed to make any such payment within fifteen (15) Business Days of a request for such payment, in the amount of any such payment and (vi) under any other circumstances expressly contemplated by such Performance Support (including as a result of the provider thereof no longer constituting an Acceptable Support Provider, in which case DOE shall hold such funds in trust and apply such funds in the same manner as permitted in respect of the Performance Support). Following a draw made under the Performance Support which reduces the amount available for drawing thereunder (or in the case where the full amount of the Performance Support has been drawn and the proceeds thereof are placed in a DOE or U.S. Treasury account or a collateral account pledged solely to DOE as a result of either the applicable provider of such Performance Support no longer constituting an Acceptable Support Provider or the pending expiration of such Performance Support, following any application of funds in such account), Holdings shall replenish or reinstate such Performance Support to the then Applicable Amount within fifteen (15) Business Days following notice from DOE.

(b) Subject to draw or demand provisions relating to the termination or expiration of the applicable Performance Support as provided in such Performance Support or the failure of the provider of such Performance Support to be an Acceptable Support Provider (in which case DOE shall be entitled to draw on, or demand payment under, such Performance Support subject to the grace periods provided in such Performance Support), DOE shall not make a drawing or demand under the Performance Support if funds in the Advance Funding Account or Wind-Up Reserve Account (other than funds which have been allocated for a specific purpose) are available to satisfy any payment obligation of the Clean Line Entities. Prior to making any drawing or demand on the Performance Support, DOE shall provide to Holdings ten (10) days advance written notice; provided that no such notice shall be required in connection with any drawing or demand arising as a result of the pending termination or expiration of the applicable Performance Support or the failure of the provider of such Performance Support to be an Acceptable Support Provider.

11.6 Collateral.

(a) To secure their obligations under this Agreement, the Clean Line Entities shall grant for the benefit of DOE:

(i) (A) on or prior to Project Completion, a first priority perfected security interest in the Wind-Up Reserve Account and all funds on deposit in, or credited in each such account from time to time and (B) on or prior to Project Completion, a perfected security interest (which, prior to Project Financial Close, shall be a first priority Lien and, from and after Project Financial Close, to the extent the Clean Line Entities have granted any security interest to any Financing Party, shall be a second priority Lien) on the Capital Repairs Reserve Account (collectively, the "Account Collateral");

(ii) on or before the Commencement Date, a perfected security interest (which, prior to Project Financial Close, shall be a first priority Lien and, from and after Project Financial Close, to the extent the Clean Line Entities has granted any security interest to any Financing Party, shall be a second priority Lien) on 100% of the Equity Interests in ACL and any Indebtedness owed by ACL to Holdings, PECL or any other Subsidiary or Affiliate of Holdings (including any Person making any equity investment in ACL as part of a Permitted Project Investment) from time to time (collectively, the "Equity Collateral"); and

(iii) concurrently with the grant by the Clean Line Entities of any security interest to any Financing Party, a second priority Lien on all of the Clean Line Entities' Properties and assets (including the Capital Repairs Reserve Account but excluding other Account Collateral and the Other Facilities) in which the Clean Line Entities have granted a security interest for the benefit of such Financing Parties (the "Second Lien Collateral").

(b) The Collateral shall be free and clear of any other security interest or Lien, except for Permitted Liens.

11.7 Intercreditor Agreement. In connection with the closing of the Project Financing, DOE shall agree to enter into an intercreditor agreement (the "Intercreditor Agreement") with the Financing Parties pursuant to which it shall agree to subordinate its security interest in the Capital Repairs Reserve Account, the Equity Collateral and Second Lien Collateral under the Security Documents to the security interest in the Capital Repairs Reserve Account, the Equity Collateral and Second Lien Collateral created for the benefit of the Financing Parties. The Intercreditor Agreement will be on usual and customary terms for transactions with a first priority Lien and junior Lien, including (a) a provision whereby DOE shall agree (i) to a 365-day standstill period (which shall be extended for so long as the Project Financing Parties are exercising remedies) with respect to taking any action in respect of any shared Collateral and (ii) to not object to the use of cash collateral and (b) provisions for debtor in possession financings and adequate protection payments for the senior lien holders.

11.8 Limitation of Liability to DOE.

(a) None of the Covered Parties shall have any liability whatsoever for payment of any obligations incurred by any Clean Line Obligor or any of its Affiliates or any other Person in connection with the Project, the Other Facilities, the Project Contracts, the Project Financing Documents or any of the transactions contemplated thereby. Each Clean Line Party hereby waives on behalf of itself and its Affiliates all rights to assert any claims against DOE or any of the Covered Parties in connection with the Project and the Other Facilities on the basis of breach of contract, misrepresentation, tort, detrimental reliance, promissory estoppel or any other legal principle in the event that (i) a final and non-appealable Governmental Order finds that DOE is legally prohibited from participating in the Project or performing its obligations under the Transaction Documents, (ii) if there is a Change in Law that sets aside or legally prohibits DOE's participation in the Project or (iii) the Project is delayed in any respect as a result of any Action or Governmental Order that affects DOE's ability to comply with its undertakings hereunder; provided that DOE itself shall agree to not take the position that it lacks the statutory authority to participate in the Project.

(b) DOE's review of any of the Project Contracts or the Project Financing Documents shall not be considered to be a guaranty or endorsement of any of the terms thereof or of any of the obligations of the Clean Line Obligors or any other Person thereunder or any information provided by the Clean Line Obligors or any other Person in connection with the negotiation, execution and delivery or performance of the Project Contracts or the Project Financing Documents (including any projections or other financial information provided in connection therewith) and is not a representation, warranty or other assurance as to the ability of the Clean Line Entities or any other Person party to the Project Contracts or the Project Financing Documents to perform their obligations thereunder.

11.9 Consequential Damages.

(a) No claim shall be made by any Clean Line Obligor or any of its Affiliates or representatives against DOE or any other Covered Party for any special, indirect, consequential or punitive damages (whether or not the claim therefor is based on contract, tort or duty imposed by law) in connection with, arising out of or in any way related to the transactions contemplated by this Agreement, the other Transaction Documents, the Project, the Other Facilities or any act or omission or event occurring in connection therewith, and each Clean Line Obligor and each of its Affiliates hereby waives and releases any such claim for any such damages, whether or not accrued and whether or not Known or suspected to exist in its favor.

(b) No claim shall be made by DOE or any other Covered Party against any Clean Line Obligor or any of its Affiliates for any special, indirect, consequential or punitive damages (whether or not the claim therefor is based on contract, tort or duty imposed by law) in connection with, arising out of or in any way related to the actions contemplated by this Agreement, the other Transaction Documents or any act or omission or event occurring in connection therewith, and DOE and/or any other applicable Covered Party shall waive and release any such claim for any such damages, whether or not accrued and whether or not Known or suspected to exist in its favor; provided that nothing in this paragraph shall limit each Clean Line Entity's indemnity obligations as set forth in Section 11.4 to the extent that such special, indirect, consequential or punitive damages are included in any claim by a third party unaffiliated with any Clean Line Obligor with respect to which DOE or any other Covered Party is entitled to indemnification.

11.10 Release Provision.

(a) The Clean Line Entities shall use commercially reasonable efforts to include in the Project Financing Documents and in each Material Project Contract (other than any Interconnection Agreement) that the Clean Line Entities or DOE enters into in respect of the Project a provision pursuant to which the Project Financing Parties or such Project Participant, as applicable, shall agree that such Person has no recourse to any Covered Party under such Project Financing Document (other than in respect of DOE's express obligations or undertakings pursuant to the Transaction Documents, the Intercreditor Agreement and/or the DOE Direct Agreement) or applicable Material Project Contract (other than any Interconnection Agreement) and shall expressly release any Covered Party from any claim, liability or other obligation under such Project Financing Document or the applicable Material Project Contract (other than any Interconnection Agreement) (the "Release Provision"). The Release Provision included in the Project Financing Documents or any applicable Material Project Contract (other than any Interconnection Agreement) shall be in form and substance acceptable to DOE; provided that a provision substantially similar to the following shall be deemed to be in form and substance acceptable to DOE:

> *"Each of the parties hereby, in consideration of $1000, receipt of which is hereby acknowledged, releases and waives any and all claims, remedies or rights against the* **[***Covered Parties***]** *with respect to any and all liabilities (including, without, limitation, any liabilities arising as a result of negligence, warranty, statutory, product, strict or absolute liability, liability in tort or otherwise), obligations, losses, settlements, damages, penalties, fines, sanctions, taxes, claims, actions, demands, suits, judgments or proceedings of any kind and nature, costs, payments, expenses and disbursements (including fees and expenses of consultants, advisors, external counsel and allocable fees and expenses of internal personnel and attorneys) of whatsoever kind and nature (whether or not any of the transactions contemplated by* **[***this Agreement***]** *are consummated), imposed on, incurred or suffered by, or asserted against such party in any way relating to or arising out of* **[***this Agreement, the Project***]** *or the transactions contemplated hereby; for all purposes of this*

provision, the ***[****Covered Parties****]*** *shall be deemed to be third party beneficiaries in all respects."*

(b) The bracketed language in the foregoing provision may be conformed as necessary to reflect the terms and provisions of the relevant Project Financing Document or Material Project Contract; provided that any such changes shall not narrow the scope of the Release Provision, except that (i) the Clean Line Entities shall be permitted to add an appropriate exception to the Release Provision in the Project Financing Documents for any direct and express obligations or undertakings made by DOE in the Transaction Documents, the Intercreditor Agreement and/or the DOE Direct Agreement in favor of such Project Financing Party and (ii) the Clean Line Entities shall be permitted to add an appropriate exception to the Release Provision in any Material Project Contract for any direct and express obligations or undertakings by DOE in favor of the applicable Project Participant under such Material Project Contract (and/or under any related agreement entered into between DOE and the applicable Project Participant).

(c) None of the Clean Line Parties shall enter into any Project Financing or into any Material Project Contract (other than an Interconnection Agreement) unless the applicable Project Financing Documents or Material Project Contract (other than an Interconnection Agreement) includes a Release Provision and none of the Clean Line Parties shall agree to amend, modify or otherwise waive any Release Provision included in the Project Financing Documents or Material Project Contract without the consent of DOE. If Clean Line Entities are unable to obtain a Release Provision for a Material Project Contract, then no Clean Line Entity shall enter into such Material Project Contract without (i) delivering to DOE a substantially final draft of such Material Project Contract and (ii) receiving from DOE its written consent for the Clean Line Entities to enter into such Material Project Contract (not to be unreasonably withheld or delayed); provided, however, that DOE shall consent to such Material Project Contract if it is satisfied that such Material Project Contract does not include any terms or conditions that could reasonably be expected to expose DOE or any other Covered Party to any material obligation or liability.

ARTICLE XII
REPRESENTATIONS AND WARRANTIES

12.1 Representations and Warranties of the Clean Line Parties. Each Clean Line Party makes the following representations and warranties, as applicable, to and in favor of DOE as of the Effective Date, on each of the dates required to be made pursuant to Article VI and on any other date on which any such representation and warranty is required to be made (or deemed to be made) by the express terms of any other Transaction Document or any notice or other document or instrument required to be delivered to DOE pursuant to the terms hereof or the terms of any other Transaction Document (any of the foregoing dates, a "Representation Date"):

(a) Organization.

(i) Holdings is a limited liability company organized, validly existing and in good standing under the laws of the State of Delaware. PECL is a limited liability company organized, validly existing and in good standing under the laws of the State of Arkansas. ACL is a limited liability company organized, validly existing and in good standing under the laws of the State of Delaware. PECL OK is a limited liability company organized, validly existing and in good standing under the laws of the State of Oklahoma. OLA is a limited liability company organized, validly existing and in good standing under the laws of the State of Delaware. Each other Subsidiary of Holdings that is a party hereto from time to time after the Effective Date is a limited liability company, corporation or limited liability partnership duly constituted, validly organized or formed, as applicable, and existing and in good standing under the laws of the jurisdiction of its organization or formation, as applicable.

(ii) Each Clean Line Party (A) is duly qualified and in good standing under the laws of each jurisdiction where its business requires such qualification, except where the failure to be so qualified could not reasonably be expected to result in a Clean Line Material Adverse Effect and (B) has all requisite power and authority to (1) conduct its business, (2) to own or hold under lease its Properties, (3) to execute, deliver, and perform its obligations under this Agreement and any other Clean Line Document to which it is a party as of the applicable Representation Date, and (4) to grant the Liens contemplated by any of the Security Documents to which it is a party as of the applicable Representation Date.

(b) Authorization. Each of the Clean Line Parties has duly authorized, executed and delivered this Agreement and any other Clean Line Document to which it is a party that has been executed and delivered by it as of as of the applicable Representation Date. No Governmental Approval or any approval, consent, exemption, authorization, or other action by, or notice to, or filing with, any other Person is necessary or required in connection with (i) the execution and delivery by any applicable Clean Line Party of this Agreement, (ii) to the extent applicable as of the applicable Representation Date, the grant by such Clean Line Entity of the Liens granted by it pursuant to the Security Documents or (iii) to the extent applicable, the perfection or maintenance of the Liens created under the Security Documents (including the first or second priority nature thereof, as applicable, and in respect of the Second Lien Collateral, only to the extent that the first priority security interests in favor of the Project have been established and/or perfected), except in each case for such Governmental Approvals or other authorizations, approvals, actions, notices and filings as which have been duly obtained, taken, given or made and are in full force and effect. Except as set forth on Schedule 11 (as such Schedule may be updated in accordance with Section 12.3), as of the applicable Representation Date, the Clean Line Entities have obtained, taken, given or made, as applicable, all Governmental Approvals or any approval, consent, exemption, authorization, or other action by, or notice to, or filing with, any other Person that is necessary or required in connection with the performance by any applicable Clean Line Party of this Agreement and the other Transaction Documents in light of the current stage of construction, management and/or operation of the Project as of such Representation Date, except where the failure to obtain, take, give or make could not reasonably be expected to result, individually or in the aggregate, in a Clean Line Material Adverse Effect or an Adverse DOE Impact.

(c) No Conflict. Neither the execution and delivery of this Agreement nor any other Clean Line Document to which the applicable Clean Line Party is a party as of the applicable Representation Date, nor the performance by such Clean Line Party of any of its obligations thereunder does or will: (i) contravene, conflict with or violate any provision in any Organizational Document or any other agreement relating to the management or affairs of such Clean Line Party, (ii) except as could not reasonably be expected to result in a Clean Line Material Adverse Effect, contravene, conflict with, violate or fail to comply with any final and non-appealable Governmental Order or Governmental Approval applicable to such Clean Line Party or any Applicable Law, (iii) except as could not reasonably be expected to result in a Clean Line Material Adverse Effect, contravene or result in any breach or default under any Contractual Obligation to which the applicable Clean Line Party is a party or by which it or any of its Properties may be bound, or (iv) result in, or require the creation or imposition of any Lien (other than Permitted Liens) upon or with respect to any Properties of the applicable Clean Line Party now owned or hereafter acquired.

(d) Binding Obligation. Each Clean Line Document that has been executed and delivered as of the applicable Representation Date is a valid and binding obligation of the applicable Clean Line Party enforceable against it in accordance with its terms, except as enforceability may be limited by applicable bankruptcy, insolvency, reorganization, moratorium or similar laws in effect from time to time that affect creditors' rights generally and by legal and equitable limitations on the availability of specific remedies.

(e) Capitalization. All of the Equity Interests of PECL, ACL, PECL OK and OLA have been duly authorized, validly issued, are fully paid and non-assessable and are owned directly or indirectly by Holdings, and all of the Equity Interests of Holdings have been duly authorized, validly issued, and are fully paid and non-assessable, in each case free and clear of all Liens (other than any Permitted Liens). As of the date of this Agreement, all of the Equity Interests of Holdings are owned directly by CLEP. Except as set forth in Schedule 5 (as such Schedule may be updated in accordance with Section 12.3) hereto there are no outstanding options, warrants or rights for conversion into or acquisition, purchase or transfer of Equity Interests of any Clean Line Party or any agreements or arrangements for the issuance by any Clean Line Party of additional Equity Interests. Except as set forth in Schedule 5 (as such Schedule may be updated in accordance with Section 12.3) hereto, each Clean Line Party does not have outstanding (i) any securities convertible into or exchangeable for its Equity Interests or (ii) any rights to subscribe for or to purchase, or any option for the purchase of, or any agreement, arrangement or understanding providing for the issuance (contingent or otherwise) of, or any call, loan commitment or claims of any character relating to, its Equity Interests.

(f) Litigation. With respect to any pending or threatened Actions to which DOE is not otherwise a party:

(i) Except as set forth in Schedule 9 (as such Schedule may be updated in accordance with Section 12.3) hereto, there is no pending or, to any Clean Line Party's Knowledge, threatened Action (A) that relates to the legality, validity or enforceability of this Agreement or any of the other Transaction Documents, (B) that relates to the Project or (C) that relates to any Clean Line Document to which any Clean Line Party is a party as of the applicable Representation Date which, in the case of clauses (B) or (C), either singly or in the aggregate has had a continuing, or could reasonably be expected to have a Clean Line Material Adverse Effect or otherwise materially and adversely affect the interests of DOE, including in its capacity as an agency of the United States government.

(ii) No Clean Line Party has failed to observe, in any material respect, any final and non-appealable Governmental Order that has, or could reasonably be expected to have, a Clean Line Material Adverse Effect. There is no injunction, writ, or preliminary restraining order of any nature issued by a Governmental Authority directing that any transactions contemplated by any of the Transaction Documents not be consummated as herein or therein provided.

(iii) No final and non-appealable Governmental Order has been entered against any Clean Line Party that has, or could reasonably be expected to have, a Clean Line Material Adverse Effect or an Adverse DOE Impact.

(g) Taxes.

(i) Each Clean Line Party (A) has timely filed or caused to be filed all material federal, state and local Tax returns required by Applicable Law to be filed by it, and each such Tax return was complete and accurate in all material respects, and (B) has timely paid or caused to be paid (1) all material Taxes payable by it that have become due pursuant to such Tax returns and (2) all other material Taxes and assessments payable by it that have become due, in each case, other than those Taxes subject to Contest.

(ii) The Clean Line Parties do not owe any delinquent Indebtedness to any Governmental Authority of the United States, including in respect of any Tax liability, except to the extent such delinquency is the subject of a Contest or has been resolved, or is in the process of being resolved, with the appropriate Governmental Authority in accordance with the standards of the Debt Collection Improvement Act.

(h) Fees. No Clean Line Party has any obligation to pay any Person in respect of any finder's, broker's, or other similar fees in connection with this Agreement or any other Transaction Document.

(i) Financial Statements. Each of the Financial Statements delivered to DOE pursuant to the terms of this Agreement has been prepared in accordance with GAAP consistently applied and presents fairly, in all material respects, the financial condition of such Person as of the respective dates of the balance sheets included therein and the results of operations of such Person for the respective periods covered by the statements of income included therein, subject to the absence of notes and normal year-end audit adjustments with respect to the quarterly unaudited financial statements. Except as reflected in such Financial Statements, as of the date of such Financial Statements, there are no material liabilities or obligations of such Person of any nature whatsoever as of the balance sheet date contained in such financial statements that are required to be disclosed in accordance with GAAP, subject to the absence of notes for the quarterly unaudited financial statements.

(j) Project Plans, Base Case Projections and Sufficiency of Funds.

(i) The Project Schedule, the Project Plans and the Base Case Projections, as amended or supplemented from time to time in accordance with the terms of this Agreement, when prepared or made (A) were complete and based on assumptions that the Clean Line Entities believed to be reasonable, (B) are consistent with the provisions of any Clean Line Documents and Project Financing Documents then in effect, (C) have been prepared in good faith and with due care and (D) fairly represented the Clean Line Entities' expectation as to the matters covered thereby.

(ii) The Project Schedule, as amended or supplemented from time to time in accordance with the terms of this Agreement, accurately specifies in summary form the work necessary to reach Project Completion on a specified timeline.

(iii) The Project Budget as amended or supplemented from time to time in accordance with the terms of this Agreement represents the Clean Line Entities' good faith, best estimate of total Project Costs anticipated to be incurred to construct the Project in the manner contemplated by the Project Plans.

(k) Immunity. None of the Clean Line Parties and none of their respective Properties enjoys any right of immunity from set off, suit or execution with respect to any Property or obligations under any Transaction Document.

(l) Compliance with Applicable Laws; Environmental Matters. Except as set forth in Schedule 10 (as such Schedule may be updated in accordance with Section 12.3) hereto:

(i) Each Clean Line Party is in compliance with, and has conducted (or caused to be conducted) its business and operations and the business and operations of the Project in compliance with, all Applicable Laws, including Environmental Laws, in each case applicable to such Clean Line Party or the Project, except where the failure to comply could not reasonably be expected to result, individually or in the aggregate, in a Clean Line Material Adverse Effect or an Adverse DOE Impact.

(ii) As of the applicable Representation Date, there are no Environmental Claims pending or, to the Knowledge of any Clean Line Party, threatened against such Clean Line Party, any Property of such Clean Line Party or the Project, except as could not reasonably be expected to result, individually or in the aggregate, in a Clean Line Material Adverse Effect or an Adverse DOE Impact.

(iii) As of the applicable Representation Date, to the Knowledge of each Clean Line Party, there are no present or past actions, activities, circumstances, conditions, events or incidents, including the Release of any Hazardous Substances that could reasonably be expected to form the basis of an Environmental Claim against any Clean Line Party or DOE or in respect of the Project Site, except as could not reasonably be expected to result, individually or in the aggregate, in a Clean Line Material Adverse Effect or an Adverse DOE Impact.

(iv) As of the applicable Representation Date, none of the Clean Line Parties nor, to the Knowledge of each Clean Line Party, any other Person, has used, released, discharged, generated, manufactured, produced, stored or disposed of in, on, under or about the Project Site or transported thereto or therefrom, any Hazardous Substances that could reasonably be expected to form the basis of an Environmental Claim related to the Project site or cause any of the Clean Line Parties or the Project Site to be subject to any restrictions arising under Environmental Laws or otherwise have a material adverse environmental or social effect which is prohibited under Applicable Law, except as could not reasonably be expected to result, individually or in the aggregate, in a Clean Line Material Adverse Effect or an Adverse DOE Impact.

(v) No Clean Line Party has received any letter or request for information under Section 104 of the Comprehensive Environmental Response Compensation and Liability Act (42 U.S.C. Sections 9640 *et seq*.) or comparable state laws, and, to the Knowledge of each of the Clean Line Parties, none of the operations of any of the Clean Line Parties relating to the Project is the subject of any investigation by a Governmental Authority evaluating whether any remedial action is needed to respond to a Release or threatened Release of any Hazardous Substances relating to the Project or the Project Site or at any other location, including any location to which any Clean Line Party has transported, or arranged for the transportation of, any Hazardous Substances with respect to the Project Site.

(m) Insolvency Events; Solvency.

(i) None of the Clean Line Parties is subject to any pending or to the Knowledge of each of the Clean Line Parties, threatened, Insolvency Event.

(ii) The Clean Line Parties, on a consolidated basis, are Solvent.

(n) No Defaults. No Default or Event of Default has occurred and is continuing.

(o) Full Disclosure.

(i) All written information contained in all documents, reports or other written information pertaining to the Project (other than any projections or forward-looking statements), together with all written updates of such information from time to time (collectively, the "Information"), that have been furnished by or on behalf of the Clean Line Parties to DOE, are, as of the date such information was so furnished and taken as a whole, true and correct in all material respects and do not contain any material misstatement of fact or omit to state a material fact or any fact necessary to make the statements contained therein not materially misleading in light of the circumstances in which they were made; provided, that with respect to any Information that is expressly identified as being obtained from a publicly-available third-party source, this representation is made only to the Knowledge of the Clean Line Parties.

(ii) As of the date of this Agreement, to the Knowledge of each of the Clean Line Parties it is technically feasible for the Project to be constructed, completed, operated and maintained in all material respects in accordance with the specifications and other information contained in that 1222 Program - Part 2 Application submitted by the Clean Line Parties to DOE in January 2015.

(p) Security Interests; Liens.

(i) The Security Documents that have been delivered on or prior to the applicable Representation Date are effective to create, in favor of DOE, a legal, valid and enforceable Lien on and security interest in all of the Collateral purported to be covered thereby, and all necessary recordings and filings with respect to such Security Documents have been made in all necessary public offices, and all other necessary and appropriate action has been taken, so that the security interest created by such Security Document is a perfected Lien on and security interest in all right, title and interest of the applicable Clean Line Entity in the Collateral purported to be covered thereby, prior and superior to all other Liens other than Permitted Liens (provided, with respect to the Second Lien Collateral, the Clean Line Entities shall not be obligated to make any filings or recordings or take any other action necessary to create or perfect a Lien that are not required in respect of the first priority security interest granted in favor of the Project Financing Parties).

(ii) No Lien (other than a Permitted Lien) or other instrument or recordation covering all or any part of the Collateral purported to be covered by the Security Documents on or prior to the applicable Representation Date is on file in any recording office or public registry.

(iii) Except for Permitted Liens, no Clean Line Entity has created and is not under any obligation to create, and has not entered into any Contractual Obligation that would, or could reasonably be likely to, result in the imposition of, any Lien upon any of its Properties.

(q) Insurance. Following adoption of the Insurance Agreement, the Clean Line Entities' insurance coverage for the Project required pursuant to the Insurance Agreement to be in effect at such time is in full force and effect, and all premiums then due and payable under the applicable policies have been paid.

(r) Business.

(i) None of the Clean Line Parties has conducted any business, other than the business contemplated by the Transaction Documents and the other Clean Line Documents, the Project Contracts, the Project Equity Commitments, the Project Financing Commitments, the Project Financing Documents and such other business as may be related to the Project and the Other Facilities.

(ii) None of the Clean Line Parties has any outstanding Indebtedness other than Permitted Indebtedness.

(iii) None of the Project Subsidiaries owns (A) any real Property rights other than those relating to the Project and (B) any Equity Interests other than Equity Interests in any other Subsidiary of Holdings that is also a Project Subsidiary.

(iv) None of the Project Subsidiaries is a party to or bound by any Contractual Obligation other than (A) the Transaction Documents, (B) the Project Contracts, (C) the Project Financing Documents and (D) any other Contractual Obligation that relates to the ownership, development, construction, procurement, operation, management or maintenance of the Project and the Other Facilities.

(s) United States Government Requirements.

(i) Davis-Bacon Requirements. If the Davis-Bacon Act has been determined by DOE or the Department of Labor, as the case may be, to be applicable to the Project, each Clean Line Party is in compliance with all applicable Davis-Bacon Requirements. To the extent the Davis-Bacon Act applies to the Project, each applicable contract for construction, as defined in Department of Labor regulations at 29 C.F.R. § 5.2(j), includes the Davis-Bacon Requirement provisions set forth in Schedule 15 hereto (as such Schedule is supplemented from time to time in accordance with Section 8.24(b)).

(ii) Prohibited Persons. (A) None of the Clean Line Parties, any Controlling Person of any Clean Line Party or any Principal Person of any Clean Line Party or any Principal Person of any Controlling Person of a Clean Line Party is a Prohibited Person, (B) to each Clean Line Party's Knowledge no event has occurred and no condition exists that is likely to result in any Clean Line

Party, any Controlling Person of any Clean Line Party or any Principal Person of a Clean Line Party or any Principal Person of any Controlling Person of a Clean Line Party becoming a Prohibited Person and (C) to each Clean Line Party's Knowledge, no Project Participant is a Prohibited Person.

(iii) Anti-Corrupt Practices Laws, Etc. (A) Each Clean Line Party, each Controlling Person of a Clean Line Party and each Principal Person, employee and agent of each Clean Line Party and each Controlling Person of a Clean Line Party have complied with all AM Laws, Anti-Corruption Laws and Sanctions and (B) each Clean Line Party has implemented and maintains in effect policies and procedures reasonably designed to ensure compliance by such Clean Line Party and its respective Principal Persons with AM Law, Anti-Corruption Laws and Sanctions.

(t) Energy Regulatory Status.

(i) Federal Energy Regulatory Status.

(A) The appropriate Clean Line Party or Clean Line Parties are authorized, pursuant to Section 205 of the FPA, to charge negotiated rates for transmission rights on the Project and such authorization is in full force and effect.

(B) As of the Effective Date and until the earlier of (i) the date on which any of the Project Facilities are energized, (ii) the date of FERC's order accepting the rate schedule or OATT filed by the appropriate Clean Line Party or Clean Line Parties or (iii) the effective date of the rate schedule or OATT filed by the appropriate Clean Line Party or Clean Line Parties, none of CLEP (solely as a result of the Project) or any of the Clean Line Parties is or will be a "public utility" under the FPA.

(C) As of the Effective Date and until the date on which any of the Project Facilities are energized, none of CLEP (solely as a result of the Project) or any of the Clean Line Parties is or will be subject to regulation under PUHCA.

(D) As of the earlier of (i) the date on which any of the Project Facilities are energized, (ii) the date of FERC's order accepting the rate schedule or OATT filed by the appropriate Clean Line Party or Clean Line Parties, or (iii) the effective date of the rate schedule or OATT filed by the appropriate Clean Line Party or Clean Line Parties as permitted by FERC, each of the appropriate Clean Line Party or Clean Line Parties will be a "public utility" under the FPA.

(E) As of the date on which any of the Project Facilities are energized, each of the Clean Line Parties will be subject to regulation under PUHCA to the extent applicable.

(ii) State Energy Regulatory Status.

(A) By Order No. 9 issued by the APSC on January 11, 2011, in Docket No. 10-041-AU (the "APSC 2011 Order"), the APSC denied PECL's application for authority to operate as a public utility in the State of Arkansas. The APSC 2011 Order is final and is no longer subject to rehearing before the APSC.

(B) By Order No. 590530 issued by the OCC on October 28, 2011 (the "OCC 2011 Order"), the OCC granted PECL OK's request for authority to operate as a transmission-only public utility in Oklahoma. The OCC 2011 Order is final, in full force and effect, and is no longer subject to rehearing before the OCC. PECL is in compliance with the OCC 2011 Order in all material respects.

(C) By order issued by the Tennessee Regulatory Authority on May 5, 2015, in Docket No. 14-00036 (the "TRA 2015 Order"), PECL has been granted a Certificate of Public Convenience and Necessity to construct the transmission facilities in Tennessee that will interconnect with the Project. The TRA 2015 Order of the TRA is in full force and effect and is no longer subject to rehearing before the TRA. PECL is in compliance with the TRA 2015 Order in all material respects.

(u) Investment Company Act. No Clean Line Party is required to register as an "investment company" as defined in, or subject to regulation under, the Investment Company Act.

(v) Required Approvals.

(i) Except as set forth in Schedule 16 (as such Schedule may be updated in accordance with Section 12.3), each Required Approval that is necessary for the Project in light of the current stage of construction, management and/or operation of the Project as of the applicable Representation Date, except for any *de minimis* Required Approval that is of a routine nature and obtainable in the ordinary course of business, (A) has been obtained, filed or made with the corresponding Governmental Authority, (B) is validly issued and in full force and effect and (C) there are no proceedings pending, or to any Clean Line Entity's Knowledge, threatened, seeking to rescind, terminate, adversely and materially modify, suspend, revoke or invalidate such Required Approval, except where such event or circumstance could not reasonably be expected to result, individually or in the aggregate, in a Clean Line Material Adverse Effect or an Adverse DOE Impact.

(ii) None of the Clean Line Entities has any credible reason to believe that any Required Approval, that is not necessary for the Project in light of the current stage of construction, management and/or operation as of the applicable Representation Date but which will be required in the future, will not be obtained on terms and conditions that are not materially inconsistent with the Clean Line Entities' performance under the Clean Line Documents on or prior to the date required or necessary for the continued construction, management and/or operation of the Project in accordance therewith.

(iii) Each of the Clean Line Entities is in compliance in all material respects with each Required Approval that has been issued to it as of the applicable Representation Date.

12.2 Survival. The representations and warranties contained herein shall survive the execution and delivery of this Agreement.

12.3 Disclosure Schedule. The Clean Line Parties may, on any Representation Date, update, supplement or amend Schedules 3, 5, 9, 10, 11 and 16 (collectively the "Disclosure Schedules"), to correct any matter that would otherwise constitute a breach of any representation or warranty contained herein. If the matter or event giving rise to such an updated, supplemented or amended Disclosure Schedule, when taken together with all other matters and events that have given rise to updated, supplemented or amended Disclosure Schedules, could reasonably be expected, individually or in the aggregate, to result in a Clean Line Material Adverse Effect or an Adverse DOE Impact, then the Clean Line Parties shall not have the right to make any such update, supplement or amendment without the consent of DOE. Certain information set forth in the Disclosure Schedule is included solely for informational purposes and is not an admission of liability with respect to the matters covered by the information.

ARTICLE XIII
MISCELLANEOUS TERMS AND PROVISIONS

13.1 Notices; Consents; Approvals.

(a) The names and addresses of the Clean Line Parties and DOE for the purpose of receiving notices, invoices, payments and other communications required or permitted under this Agreement and the other Transaction Documents are as set forth below, which addresses may be changed from time to time by written notice to the other Party as provided herein.

Clean Line Parties: Plains and Eastern Clean Line Holdings LLC
1001 McKinney, Suite 700
Houston, Texas 77002
Attention: Cary Kottler
Telephone: 832-319-6320
Facsimile: 832-319-6311
Email: CKottler@cleanlineenergy.com

With copies to: Latham & Watkins LLP
555 Eleventh Street NW
Suite 1000
Washington, DC 20004
Attention: Paul J. Hunt

Telephone: 202-637-2241
Facsimile: 202-637-2201
Email: Paul.Hunt@lw.com

DOE: U.S. Department of Energy
Office of the General Counsel
1000 Independence Ave., SW
Washington, DC, 20585
Attention: Samuel Walsh – Deputy General Counsel for Energy Policy
Telephone: 202-586-6732
Facsimile: 202-586-4116
Email: Samuel.walsh@hq.doe.gov

With a copy to: Southwestern Power Administration
One West Third Street
Tulsa, OK 74103-3502
Attention: Scott Carpenter – Administrator of Southwestern Power Administration
Telephone: 918-595-6601
Facsimile: 918-595-6755
Email: scott.carpenter@swpa.gov

(b) All notices or other communications required or permitted under this Agreement shall be in writing, properly addressed as provided in paragraph (a) above, and given by (i) hand delivery, (ii) a national overnight courier service, (iii) confirmed facsimile transmission, followed by a hard copy, or (iv) certified or registered mail, return receipt requested, and postage pre-paid. Any such notice or other communication shall be deemed to have been duly given (A) as of the date delivered if by hand delivery, national overnight courier service, email or confirmed facsimile transmission (provided a hard copy promptly follows by other means provided herein within five (5) days of the facsimile transmission), or (B) five (5) days after mailing if by certified or registered mail.

(c) Time is of the essence under this Agreement. Wherever in this Agreement provision is made for the giving of consent or approval by either Party, unless otherwise specified, such consent or approval shall be (i) provided as soon as reasonably practicable following the request for such consent or approval and (ii) be in writing as provided above.

13.2 Further Assurances. Each Party shall, at the request of the other Party, execute and deliver or cause to be executed and delivered such documents and instruments as reasonably requested; provided that such documents and instruments are reasonably acceptable to the Party to whom the request is directed and are not otherwise specified herein, and take or cause to be taken all such other reasonable actions, as may be necessary to more fully and effectively carry out the intent and purposes of this Agreement.

13.3 Amendment; Waiver. No amendment or other modification of any provision of this Agreement shall be valid or binding unless it is in writing and signed by each of the Parties. No waiver of any provision of this Agreement shall be valid or binding unless it is in writing and signed by the applicable Party waiving compliance with such provision. No delay or omission in exercising any right, power, privilege or remedy under this Agreement or any other Transaction Document, including any rights and remedies in connection with the occurrence of an Event of Default or any right of termination shall impair any such right, power, privilege or remedy of DOE nor shall it be construed to be a waiver of any right, power, privilege or remedy or of any breach or default, or an acquiescence therein, or in any similar breach or default thereafter occurring, nor shall any waiver of any single right, power, privilege or remedy, or of any breach or default be deemed a waiver of any other right, power, privilege or remedy or of any other breach or default therefore or thereafter occurring.

13.4 Lender-and Financing-Related Provisions. Subject to DOE's rights and obligations under Applicable Law and the terms and conditions of this Agreement, at the request of Holdings, DOE shall agree to execute and deliver to the Project Financing Parties the DOE Direct Agreement, the Intercreditor Agreement and such other ancillary documents customary and reasonable for financing projects of a type similar to the Project reasonably requested by the Project Financing Parties and reasonably acceptable to DOE, all at the cost and expense of the Clean Line Entities; provided that neither DOE nor any of its counsel shall be obligated to provide any legal opinion related to the Project to any Project Financing party or any other Person other than the Section 1222 Decision.

13.5 Project Financing Document Provisions.

(a) The Clean Line Entities shall be solely responsible for obtaining (and repaying) any necessary financing for the development, design, engineering, construction, ownership, operation, maintenance and management or any Capital Repair relating to the Project at its own cost and risk and without recourse to DOE, the Project or any other Covered Party. None of the Covered Parties shall have any obligation to pay any debt service or repay any Indebtedness issued or incurred by any Clean Line Party or any of its Affiliates or any other Person in connection with the Project or any of the transactions contemplated by the Transaction Documents.

(b) The Project Financing Documents shall include the terms and conditions set forth in Schedule 2.

(c) For the avoidance of doubt, subject to Section 6.4(a)(ii), nothing in this Agreement shall require that the Clean Line Entities fund Construction Costs or Project Costs with Project Financing or to enter into any Project Financing Documents, so long as the Project Equity Commitments are sufficient to fund all Construction Costs and to enable the Clean Line Entities to otherwise satisfy its obligations under the Transaction Documents.

13.6 Grant of Security Interest. The Clean Line Entities may grant security interests in, or assign the entirety of the Clean Line Entities' interests in and under the Transaction Documents to the Project Financing Parties for purposes of securing the Project Financing, subject to any terms and conditions contained in the Transaction Documents, the Intercreditor Agreement and the DOE Direct Agreement. The Clean Line Entities shall be strictly prohibited from pledging or encumbering its interest under the Transaction Documents to secure any Indebtedness or any other obligations other than the Project Financing (except for Permitted Liens).

13.7 DOE Review Standard. Except as otherwise set forth in this Agreement, to the extent that any document, agreement, report, certificate, opinion or other evidence of any matter or condition is required to be delivered to DOE pursuant to the terms of this Agreement or any other Transaction Document, such document, agreement, report, certificate, opinion or other evidence shall be required to be in form and substance that is satisfactory to DOE. In addition, to the extent that: (a) any document or agreement is required to be executed by DOE, (b) any determination is contemplated to be made by DOE or (c) any condition is required to be satisfied or waived pursuant to the terms of this Agreement or any other Transaction Document, DOE shall make such determination or confirm satisfaction or waiver of any such condition acting in its sole and absolute discretion.

13.8 DOE Delegation. DOE shall be entitled to execute or perform any of its rights, remedies, power, privileges, duties or obligations under this Agreement, any other Transaction Document or, to the extent applicable, any Required Approval through any of its nominees (including any other federal agency) or agents.

13.9 Assignments. Except as otherwise expressly permitted pursuant to Section 13.6, no Party may assign its rights and obligations under this Agreement or any other Transaction Document without the prior written consent of the other Parties.

13.10 Successors and Assigns. Each and all of the covenants, terms, provisions and agreements contained in this Agreement shall be binding upon and inure to the benefit of the Parties hereto and, to the extent permitted by this Agreement, their respective successors and permitted assigns.

13.11 Joint and Several Obligations. Notwithstanding anything to the contrary in this Agreement, each Clean Line Party shall be jointly and severally liable for all obligations of each other Clean Line Party under this Agreement and each Clean Line Entity shall be jointly and severally liable for all obligations of each other Clean Line Entity under this Agreement.

13.12 Right to Intervene. Nothing in this Agreement shall prohibit any Party from intervening in any regulatory proceeding relating to the Project or the Other Facilities and taking any position in any such proceeding that it deems appropriate.

13.13 Publication; Public Statements. None of the Clean Line Parties or any of its representatives may issue any press release or make any other public statement directly or indirectly relating to DOE, this Agreement, the other Transaction Documents and DOE's involvement in the transaction contemplated thereby without DOE's prior written consent (other than information that is generally available to the public and background or summary information of a general nature concerning the Project).

13.14 Third Parties. Except as expressly provided otherwise in this Agreement (including the provisions for the protection of all Covered Parties), none of the promises, rights or obligations contained in this Agreement shall inure to the benefit of any Person that is not a Party to this Agreement, and no action may be commenced or prosecuted against any Party by any third Person claiming to be a third-person beneficiary of this Agreement or the transactions contemplated thereby.

13.15 Independent Contractor Status.

(a) The Clean Line Parties' interests under this Agreement and any other Transaction Document shall be solely those of an independent contractor, and the Clean Line Parties and DOE are not in a relationship of co-venturers, partners, lessor-lessee or principal-agent (except to the extent that the Transaction Documents expressly appoint any Clean Line Entity as DOE's agent for specified purposes (including for purposes of the Construction Contracts)).

(b) Nothing contained in this Agreement or in any other Transaction Document shall be deemed or construed to create a partnership, tenancy in common, joint tenancy, joint venture or co-ownership by, between or among DOE or any other Covered Party and the Clean Line Parties, or any other Person.

13.16 TN and TX Facilities. Except to the extent expressly set forth in this Agreement, none of the TN Facilities or the TX Facilities are covered by, or shall be subject to, this Agreement or any other Transaction Document.

13.17 Governing Law. This Agreement shall be governed by, and construed and interpreted in accordance with, the Federal law of the United States of America. To the extent that Federal law does not specify the appropriate rule of decision for a particular matter at issue, it is the intention and agreement of the parties thereto that the laws of the State of New York shall be adopted as the governing Federal rule of decision.

13.18 Jurisdiction. Each Clean Line Party irrevocably and unconditionally:

(a) submits itself and its Properties, in any legal action or proceeding against it arising out of or in connection with this Agreement or any other Transaction Document or for recognition and enforcement of any judgment in respect thereof, to the non-exclusive general jurisdiction of (i) the courts of the United States of America for the District of Columbia; (ii) the courts of the United States of America in and for the Southern District of New York; (iii) any other federal court of competent jurisdiction in any other jurisdiction where it or any of its Property may be found; and (iv) appellate courts from any of the foregoing;

(b) consents that any such action or proceeding may be brought in or removed to such courts, and waives any objection, or right to stay or dismiss any action or proceeding, that it may now or hereafter have to the venue of any such action or proceeding in any such court or that such action or proceeding was brought in an inconvenient court and agrees not to plead or claim the same;

(c) agrees that service of process in any such action or proceeding may be effected by mailing a copy thereof by registered or certified mail (or any substantially similar form of mail), postage prepaid, to any Clean Line Party at its address set forth in Section 13.1 or at such other address that it shall notify DOE hereunder;

(d) agrees that nothing herein shall (i) affect the right of any Covered Party to effect service of process in any other manner permitted by law; or (ii) limit the right of any Covered Party to commence proceedings against or otherwise sue the Clean Line Parties or any other Person in any other court of competent jurisdiction, nor shall the commencement of proceedings in any one or more jurisdictions preclude the commencement of proceedings in any other jurisdiction (whether concurrently or not) if, and to the extent, permitted by the Applicable Laws; and

(e) subject to rights to appeal in accordance with Applicable Laws, agrees that judgment against it in any such action or proceeding shall be conclusive and may be enforced in any other jurisdiction within or without the U.S. by suit on the judgment or otherwise as provided by law, a certified or exemplified copy of which judgment shall be conclusive evidence of the fact and amount of the Clean Line Parties' obligation.

13.19 Dispute Resolution.

(a) If both Holdings and DOE agree, the Parties may first attempt in good faith to resolve any dispute under this Agreement and any other Transaction Document through informal negotiations by their respective representatives on the Coordination Committee, which can be escalated to the senior officers of each party if necessary or desirable.

(b) For disputes that are construction-related, operational-related or in respect of technical, financial or accounting issues, the Parties shall have the right to appoint an independent technical or financial expert to assist in resolving any such dispute. The Clean Line Entities shall bear the cost of such independent technical or financial expert.

13.20 Waiver of Jury Trial. EACH PARTY HEREBY EXPRESSLY WAIVES ANY RIGHT TO TRIAL BY JURY OF ANY CLAIM, DEMAND, ACTION OR CAUSE OF ACTION, OR IN ANY PROCEEDING RELATED THERETO, ARISING UNDER THIS AGREEMENT OR THE TRANSACTIONS RELATED HERETO, WHETHER NOW EXISTING OR HEREAFTER ARISING, WHETHER FOUNDED IN CONTRACT OR TORT OR OTHERWISE. EACH PARTY AGREES THAT IT WILL NOT SEEK A TRIAL BY JURY IN RESPECT OF ANY SUCH CLAIM, DEMAND, ACTION, CAUSE OF ACTION OR PROCEEDING.

13.21 Negotiation and Documentation of this Agreement. Each of the Parties acknowledges and agrees that it has had the opportunity to have its legal counsel review this Agreement and participate in the negotiation and documentation hereof, and the Parties are fully familiar with each of the provisions of this Agreement and the effect thereof.

13.22 Severability. In the event any one or more of the provisions contained in this Agreement should be held invalid, illegal or unenforceable in any respect, the validity, legality and enforceability of the remaining provisions contained herein shall not in any way be affected or impaired thereby.

13.23 Counterparts. This Agreement may be executed by the Parties in two or more separate counterparts (including by PDF or facsimile transmission), each of which shall be deemed an original, and all of said counterparts taken together shall be deemed to constitute one and the same instrument.

13.24 Entire Agreement. This Agreement contains the entire agreement and understanding of the Parties with respect to the subject matter hereof and supersedes all prior agreements and understandings, whether written or oral, of the Parties relating to the subject matter hereof. Any oral or written representation, warranty, course of dealing or trade usage not contained or referenced herein shall not be binding on either Party.

13.25 Time is of the Essence. Each of the Parties acknowledges that timely achievement of commercial operation of the Project is essential, and therefore time is of the essence in performing all obligations set forth herein.

13.26 Confidentiality of Information. Each of the Parties agrees that it shall treat all information exchanged or provided by and among the Parties in connection with the Project as confidential and shall not disclose any such information to any other Person except (a) to the extent such information is required to be disclosed pursuant to Applicable Laws (including the Freedom of Information Act, 5 U.S.C. §552 and DOE's implementing regulations set forth in 10 C.F.R. Part 1004), (b) to the extent such information is required to be disclosed by any Governmental Authority, (c) to any officer, director, employee, advisor, agent or representative of such Party, solely in the context of such Party's evaluation, consideration and participation of the Project, (d) to other Persons that agree to be bound by obligations of confidentiality at least as restrictive as this Section 13.26 or (e) as otherwise agreed in writing by the Parties from time to time; provided, however, that nothing herein shall prohibit disclosure of any information that (i) is or becomes generally available to the public other than as a result of disclosure by a Party in violation of this Section 13.26 or (ii) was known to the disclosing Party through means independent of receipt of such information by another Party; provided further that the Parties hereby agree that the terms and conditions of this Agreement shall not be treated as "information" subject to the provisions of this Section 13.26 and that the Parties shall be entitled to freely disclose the terms and conditions of this Agreement.

13.27 Non-Exclusivity.

(a) Notwithstanding anything to the contrary in this Agreement, the Clean Line Parties agree and acknowledge that each of DOE and each other Covered Party will have the unfettered right in its sole discretion, at any time and without liability, regardless of impacts on the Project or the Other Facilities, to finance, develop, approve, expand, improve, modify, upgrade, add capacity to, reconstruct, rehabilitate, restore, renew and replace any existing and new transmission lines or other facilities. Such right extends to facilities whether adjacent to, nearby or otherwise located as to affect the Project, its operation and maintenance and/or its revenues.

(b) The foregoing facilities include those owned or operated by (i) DOE, including those owned or operated by a private entity pursuant to a contract with DOE, (ii) a joint powers authority or similar entity to which DOE is a member, (iii) a Governmental Authority pursuant to a contract with DOE and (iv) a Governmental Authority with respect to which DOE has contributed funds, in-kind contributions or other financial or administrative support.

(c) DOE will have the right, without liability, to make discretionary and non-discretionary distributions of federal and other funds for any transmission projects, programs and planning, and to exercise all its authority to advise and recommend on transmission and energy planning, development and funding.

[*Signature Pages Follow***]**

IN WITNESS WHEREOF, the Parties have caused this Agreement to be duly executed by their officers thereunto duly authorized as of the day and year first above written.

U.S. DEPARTMENT OF ENERGY

By: ____________________

Name: Ernest J. Moniz

Title: Secretary of Energy

[Signature Page to Participation Agreement]

PLAINS AND EASTERN CLEAN LINE HOLDINGS LLC

By: ______________________

Name: Michael Skelly

Title: President

ARKANSAS CLEAN LINE LLC

By: ______________________

Name: Michael Skelly

Title: President

PLAINS AND EASTERN CLEAN LINE OKLAHOMA LLC

By: ______________________

Name: Michael Skelly

Title: President

OKLAHOMA LAND ACQUISITION COMPANY LLC

By: ______________________

Name: Michael Skelly

Title: President

PLAINS AND EASTERN CLEAN LINE LLC

By: ______________________

Name: Michael Skelly

Title: President

[Signature Page to Participation Agreement]

Schedules
to Participation Agreement

This document constitutes all of the schedules (the "Schedules") referenced in the Participation Agreement, dated as of March 2 , 2016 (as amended, modified or restated from time to time, this "Participation Agreement"), by and among the United States Department of Energy, Plains and Eastern Clean Line Holdings LLC, Arkansas Clean Line LLC, Plains and Eastern Clean Line Oklahoma LLC, Oklahoma Land Acquisition Company LLC and Plains and Eastern Clean Line LLC. Unless otherwise defined in the Schedules, all capitalized names and terms set forth herein and not otherwise defined herein will have the same meanings as set forth in the Participation Agreement.

The captions appearing herein are for the convenience of the Parties only and will not be construed to affect the meaning of the provisions of the Participation Agreement.

With respect to the Disclosure Schedules only:

(a) The inclusion of any contract, lease, document, claim, action or any other item (individually, an "Item") on any Disclosure Schedule will not constitute a representation by any Clean Line Party that such Item is material, or that the non-inclusion of such Item on such Disclosure Schedule (or any other Schedule) would result in a misrepresentation or breach of warranty on the part of the Clean Line Parties;

(b) Any Item set forth in the Disclosure Schedules that is not required to be disclosed pursuant to the Participation Agreement has been disclosed solely for informational purposes and such disclosure will not be construed to broaden the scope of any representation or warranty;

(c) No disclosure in any Disclosure Schedule relating to any possible breach or violation of any agreement, law, regulation or other legal requirement will be construed as an admission or indication that any such breach or violation exists or has actually occurred; and

(d) Inclusion of an Item under one Disclosure Schedule shall be deemed to be an inclusion of such Item on one or more other Disclosure Schedules where it is reasonably apparent from the text of such disclosure.

Schedule 1
to the Participation Agreement

Clean Line Entities Real Estate Rights Acquisition Procedures

In connection with the Clean Line Entities' acquisition of any Project Real Estate Rights, each Clean Line Entity shall comply in all material respects with the Routing and ROW Plan and all other procedures set forth in this Agreement (including this Schedule 1) prior to any such Project Real Estate Right being deemed to be a DOE Delegated Real Estate Right.

In connection with any acquisition of a Project Real Estate Right, each Clean Line Entity shall comply with the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970, as amended (42 U.S.C. § 4601 *et seq.*) and the regulations promulgated thereunder and set forth in 49 C.F.R. Part 24 (collectively, the "Uniform Act"), DOE Policies and all other Applicable Laws. The Routing and ROW Plan shall be agreed between the Parties as a condition to the occurrence of the Commencement Date. Any amendments or modifications to the Routing and ROW Plan or the Project Plans shall be subject to the terms of this Agreement. The Routing and ROW Plan shall include, among other requirements and procedures, the requirements and procedures set forth herein and in the Clean Line Uniform Act Execution Plan set forth as Schedule 17. To the extent of any conflict or inconsistency between this Schedule 1 and Schedule 17, the provisions set forth in this Schedule 1 shall control. To the extent of any conflict or inconsistency between this Schedule 1 and the Uniform Act, the requirements of the Uniform Act shall control.

1. Defined Terms. For purposes of this Schedule 1, capitalized terms shall have the meanings defined for such terms in Article I of the Agreement. In addition, the following capitalized terms shall have the following meanings:

"Curative Party" means any Person from whom any consent or other necessary action is required in order for the applicable Landowner to be able to grant or convey a clean or marketable Project Real Estate Right in favor of the Clean Line Entities without any clouds or defects on title.

"Documentation Package" means, with respect to any Project Real Estate Right, a comprehensive written file maintained by the Clean Line Entities documenting all activities undertaken by the Clean Line Entities with respect to the acquisition of such Project Real Estate Right, including: (a) the relevant Title Search, (b) contact information in respect of any applicable Landowner, Curative Party or tenant, (c) any related market data studies, (d) all appraisals undertaken in respect of such Project Real Estate Right, (e) surveys in respect of such Project Real Estate Right, (f) any additional title searches related to such Project Real Estate Right, (g) minutes of all meetings, discussions and telephone calls held by any Clean Line Entity with the applicable Landowner, any applicable Curative Party or any applicable tenant and (h) all other communication and correspondence received or sent by any Clean Line Entity in connection with its acquisition of such Project Real Estate Right.

"Landowner" means, with respect to any Project Real Estate Right, the Person (or Persons) that own the fee simple or leasehold or other applicable Real Estate Right to which such Project Real Estate Right relates.

"Title Defect" means any Lien, easement, mortgage, encumbrance or other restriction (whether contractual or otherwise) that affects or limits the ability of any Landowner to grant or convey a clean and marketable Project Real Estate Right in favor of the Clean Line Entities.

"Waiver Parcel" means any Project Real Estate Right that is determined to be a "Waiver Parcel" in accordance with the provisions set forth in Schedule 17.

2. Title Searches, Identification of Title Issues and Location of Landowner. For each Project Real Estate Right, the Clean Line Entities shall obtain a thirty (30) year title search or limited certificate of title from a reputable national title company or reputable land acquisition company (a "Title Search") in order to enable it to identify the current Landowner in respect of the underlying Real Estate Right and any applicable Title Defects. The Clean Line Entities shall use all commercially reasonable efforts to locate each applicable Landowner through any available search methods, including through a tax record search, review of publicly available information, using a private investigator to conduct a search for such Landowner, inquiries with relatives, neighbors or other individuals that could reasonably be likely to know the location of such Landowner and/or publication of a notice or advertisement in a newspaper. The Clean Line Entities shall attempt to contact any applicable Landowner by at least three (3) different forms of contact including by phone, in person, first class mail, certified mail or leaving messages with a neighbor or family member of the applicable Landowner.

3. Negotiations; Appraisal and Offer.

(a) Initial Notice and Landowner Materials. The Clean Line Entities shall notify any applicable Landowner of their interest in acquiring a Project Real Estate Right and offer to meet with such Landowner in person. In connection with its efforts to acquire any Project Real Estate Right, the Clean Line Entities shall provide each applicable Landowner with:

(i) a proposed form of easement and/or other applicable documentation relating to the conveyance of the proposed Project Real Estate Right;

(ii) a payment calculation sheet or other documentation in respect of any compensation proposed to be paid to such Landowner in connection with the applicable Project Real Estate Right; provided, however, that with respect to any parcel that is not a Waiver Parcel, such payment calculation sheet or other documentation shall only be provided after the appraisal has been performed;

(iii) a sketch identifying the boundaries and the nature of the applicable Project Real Estate Right;

(iv) a construction questionnaire designed to gather necessary information in respect of conditions at the location of the applicable Project Real Estate Right;

(v) a copy of the Clean Line Entities' Codes of Conduct for acquisitions of Project Real Estate Rights (which is attached as Schedule 12 to this Agreement);

(vi) a request for permission to conduct a survey of the applicable Project Real Estate Right; and

(vii) in respect of any Project Real Estate Right located in Oklahoma, a copy of the Private Rights Settlement Agreement, dated January 14, 2011 (the "Private Rights Settlement Agreement"), and the Order from the OCC, dated October 28, 2011, approving the PECL OK's application to conduct business as a public utility in Oklahoma.

The initial notice and materials sent to any applicable Landowner shall otherwise comply with the requirements set forth in the Uniform Act and Schedule 17.

(b) The Clean Line Entities shall follow the provisions and procedures set forth in Schedule 17 for purposes of determining whether any applicable Project Real Estate Right shall be treated as a Waiver Parcel or whether an appraisal is required in respect of such Project Real Estate Right. In all instances involving an appraisal, the Clean Line Entities shall ensure that such appraisal is undertaken by a certified independent reputable appraiser and that the applicable Landowner shall be given the opportunity to actively participate in, and be present for, the appraisal process as well as communicate with the applicable appraiser. Each appraisal will be further reviewed and confirmed by a separate independent reputable appraiser. The appraisal process in respect of any Project Real Estate Right that has not been determined to be a Waiver Parcel shall otherwise be undertaken in accordance with the provisions of the Uniform Act and Schedule 17.

(c) The Clean Line Entities shall make an offer to acquire any applicable Project Real Estate Right pursuant to a settlement offer that shall include an offer to pay just compensation to the applicable Landowner in accordance with the Uniform Act and Schedule 17 in connection with its conveyance of such Project Real Estate Right. Compensation payable in connection with the acquisition of any applicable Project Real Estate Right shall include compensation in respect of: (i) the area comprising the applicable Project Real Estate Right (which amount shall not be less than the market value or appraised value, as applicable, of the Project Real Estate Right being conveyed, taking into consideration impacts (if any) on any adjacent or surrounding Real Estate Rights of the applicable Landowner that are not specifically contemplated to be included in the Project Real Estate Rights), (ii) each structure or improvement located on the applicable Project Real Estate Right, (iii) any damage to any crops, timber, livestock, structures or improvements of the Landowner that are reasonably likely to arise as a result of the conveyance of the applicable Project Real Estate Right and the Project and (iv) if applicable, removal and relocation costs as a result of the Project. An offer by a Clean Line Entity to acquire a Project Real Estate Right shall also include the terms set forth on Appendix A to this Schedule 1.

(d) The Clean Line Entities shall make no less than three (3) attempts to meet with any affected Landowner personally to discuss its offer to acquire any applicable Project

Real Estate Rights and, to the extent that such Landowner cannot be contacted personally, the Clean Line Entities shall ensure that a copy of the notice of offer and all other required documentation relating thereto is delivered via certified mail or registered-first class mail-return receipt requested to the applicable Landowner. The Clean Line Entities shall use all other commercially reasonable efforts to acquire any Project Real Estate Rights and shall give any applicable Landowner or related tenant a reasonable opportunity to review and discuss any proposed offer to acquire such Project Real Estate Rights. The Clean Line Entities shall give full and fair consideration to any comments, questions or suggestions of any Landowner in respect of the proposed conveyance of the applicable Project Real Estate Rights including review and consideration of any materials any Landowner may provide as relevant to the determination of the value of such Project Real Estate Rights. Each Landowner shall be given a reasonable opportunity (including a period of reasonable length) to consider any offer to acquire any Project Real Estate Rights.

4. Multiple Landowners. The Clean Line Entities shall negotiate with all applicable Landowners in respect of its acquisition of any Project Real Estate Rights in accordance with the terms hereof. To the extent that the Clean Line Entities are unable to locate all applicable Landowners or any applicable Landowners are not willing to agree (or are restricted from agreeing) to the conveyance of a Project Real Estate Right, the Clean Line Entities shall use all commercially reasonable efforts to enter into a voluntary agreement with any Landowner that has been located and is otherwise willing to agree to convey a Project Real Estate Right to the Clean Line Entities in accordance with the terms of this Agreement prior to any such Project Real Estate Right being designated a DOE Delegated Real Estate Right.

5. Title Defects; Tenants.

(a) To the extent that any Title Search identifies any Title Defects, then if determined appropriate in the reasonable judgment of the Clean Line Entities, the Clean Line Entities shall retain reputable local real estate counsel to determine what measures are available with respect to removing or addressing such Title Defect. The Clean Line Entities shall use all commercially reasonable efforts to locate any Curative Party through any available search methods, including through a tax record search, review of publicly available information, using a private investigator to conduct a search for such Curative Party, inquiries with relatives, neighbors or other individuals that could reasonably be likely to know the location of such Curative Party and/or publication of a notice or advertisement in a newspaper. Upon locating any Curative Party, the Clean Line Entities shall use all commercially reasonable efforts to obtain any consent from or other necessary action by any Curative Party to enable the applicable Landowner to convey a Project Real Estate Right to the Clean Line Entities.

(b) To the extent that any tenant is present on any Project Real Estate Right, the Clean Line Entities shall use all commercially reasonable efforts to meet with such tenant to discuss any concerns or issues relating to the tenant. The Clean Line Entities shall compensate any tenant for any potential loss or damage to such tenant that could reasonably be anticipated to result from the conveyance of the applicable Project Real Estate Right to the Clean Line Entities, including any reasonable costs or expenses to the tenant associated with relocation or damage to crops or improvements.

6. Commercially Reasonable Efforts; Course of Conduct.

(a) For purposes of complying with the terms hereof, the Clean Line Entities' use of "commercially reasonable efforts" (other than with respect to locating Persons) shall include:

(i) the Clean Line Entities' prompt and courteous response to any applicable Landowner's, Curative Party's or tenant's (or their designated representative or counsel) inquiry, comments or questions;

(ii) in the case of any Landowner, the Clean Line Entities' offer to pay compensation to such Landowner for the conveyance of the applicable Project Real Estate Right as contemplated herein;

(iii) in the case of any Curative Party, the Clean Line Entities' offer of fair compensation to such Curative Party in respect of any reasonable legal costs or other out-of-pocket costs or expenses incurred by such Curative Party in connection with any action requested of such Curative Party;

(iv) the Clean Line Entities' meeting with (either in person or by phone) any applicable Landowner, Curative Party or tenant (or their designated representative or counsel) to the extent reasonably possible or requested and providing an overview of the Project and the Clean Line Entities' applicable policies and procedures in respect thereof;

(v) in Oklahoma, to the extent that the Clean Line Entities and any Landowner have reached agreement on the form of any acquisition of a Project Real Estate Right but have been unable to reach agreement as to the appropriate compensation payable in respect thereof, at the request of any applicable Landowner, the Clean Line Entities' submission to binding arbitration in respect of the amount of compensation payable to such Landowner in accordance with the terms of the Private Rights Settlement Agreement;

(vi) engaging with any representative (including counsel) of the applicable Landowner in respect of the acquisition of the applicable Project Real Estate Right; and

(vii) any other commercially reasonable efforts under Prudent Utility Practice that the Clean Line Entities determine in their reasonable judgment is capable of taking under Applicable Law that could reasonably be expected to result in the conveyance of the applicable Project Real Estate Right to the Clean Line Entities for commercially reasonable terms.

(b) Each of the Clean Line Entities shall be entitled to perform its obligations hereunder through any agent or designee; provided that no Clean Line Entities shall be relieved from compliance with the terms hereof due to any action or inaction by any such agent or designee. Each Clean Line Entities shall make it or its agents or designees available for in-person meetings with any Landowner, Curative Party or tenant, or any of their respective agents or representatives, as may be reasonably necessary to acquire any Project Real Estate Right.

(c) No Clean Line Entity shall engage in any coercive action with respect to any Landowner, Curative Party or tenant in respect of the undertakings required hereby.

(d) The Clean Line Entities shall develop a standard script of talking points (subject to DOE's approval) describing DOE's participation in the Project and DOE's obligations in connection with any acquisition of Project Real Estate Rights, which standard script shall be applied and followed by each Clean Line Entity and its contractors in material respects in all communications and correspondence with any Landowner, Curative Party or tenant.

7. <u>Designation of Any Project Real Estate Right as a DOE Delegated Real Estate Right</u>.

(a) Prior to designating any Project Real Estate Right as a DOE Delegated Real Estate Right, the Clean Line Entities shall notify the applicable Landowner (to the extent located) and Curative Party that it is making a "final" offer for the acquisition of the applicable Project Real Estate Right and indicating the terms thereof. Such "final" offer shall indicate that the Clean Line Entities will thereafter turn negotiations in respect of acquiring such Project Real Estate Right over to DOE.

(b) Any designation by the Clean Line Entities of a Project Real Estate Right as a DOE Delegated Real Estate Right shall be made by written notice to DOE and shall be accompanied by a comprehensive Documentation Package in respect of the underlying Real Estate Right.

(c) Following receipt by DOE of a written notice of a designation by Holdings of a Project Real Estate Right as a DOE Delegated Real Estate Right, DOE shall review the applicable Documentation Package and shall be entitled to discuss any questions or concerns it may have with respect thereto with Holdings and its agents and designees involved in the acquisition process. Promptly following such review and discussion, DOE shall notify Holdings in writing that either (i) DOE agrees with Holdings' designation of such Project Real Estate Right as a DOE Delegated Real Estate Right, in which case the Clean Line Entities shall thereafter cease to be responsible for the acquisition of such Project Real Estate Right, or (ii) DOE does not agree with Holdings' designation of such Project Real Estate Right as a DOE Delegated Real Estate Right, in which case such notification shall set forth the additional actions, steps, requirements or information that DOE requires be taken or provided by the Clean Line Entities, as applicable, prior to such Project Real Estate Right being approved as a DOE Delegated Real Estate Right and the Clean Line Entities ceasing to be responsible for the acquisition of such Project Real Estate Right; <u>provided</u>, <u>however</u>, DOE shall not be entitled to require any further actions, steps, requirements or information other than what is provided for herein, under the Uniform Act and in Schedule 17.

8. <u>Documentation Package, Etc.</u> With respect to any Project Real Estate Right that the Clean Line Entities anticipate may be designated as a DOE Delegated Real Estate Right, the

Clean Line Entities shall maintain a comprehensive written Documentation Package in respect of the underlying Real Estate Right. To the extent not inconsistent with the foregoing, the Clean Line Entities shall comply with all data and information maintenance requirements contemplated by Schedule 17, and DOE shall have access to all such data and information as it may request from time to time.

9. Relocations. In the event that residences or Persons are required to be relocated as a result of the Project, the Clean Line Entities will draft relocation policies and procedures that follow the Uniform Act, which policies and procedures will be submitted to DOE for review and approval.

Appendix A to
Schedule 1 of the Participation Agreement

Plains & Eastern Clean Line Compensation

1. Clean Line Compensation Package

a. Easement Payment

Landowners will receive a $/per acre payment for the total acreage comprising the easement area. The $/per acre price shall be based on 100% of the fair market value of the fee title of the land traversed by the easement area, rather than a typical discounted fair market value for an easement. In order to determine the fair market fee title value of land, Clean Line has engaged a real estate appraisal firm to provide county wide market data studies, which studies have produced an average fair market value for fee title to land for specific land uses in each county (the "Average Fair Market Per Acre Value), all as more particularly described in the Clean Line Uniform Act Execution Plan attached as Schedule 17 to this Agreement.

For purposes of the $/per acre payment, Clean Line will pay Landowners *the greater* of the following: (i) the Average Fair Market Per Acre Value, or (ii) if an appraisal is required under the Uniform Act, the appraised value[1] of the easement determined by such appraisal.

b. Structure Payment

Landowners will receive a payment for each structure that is located within the easement area. The structure payment is calculated based on the type and number of structures. The Landowner has the right to elect to receive a one-time payment or annual payments. If selected, the annual payment will include a 2% annual escalator. Payments for structure types are as follows:

Type of Structure	One-Time Payment	Annual Payment
Monopole or Lattice Mast Structure	$ 6,000	$ 500
Lattice Structure	$ 18,000	$ 1,500
Guyed Lattice Structure	$ 24,000	$ 2,000

[1] In calculating the appraised value of the easement, the appraiser will consider the per acre value of the easement strip of land (typically a discounted value from the fee sales price) *plus* the amount of any damages to the remainder of the landowner's property resulting from the presence of the easement.

c. Damages Payment

Clean Line will pay Landowners for any damages to crops, timber, livestock, structures or improvements resulting from the construction, maintenance or operation of the Project, regardless of when they occur and without any cap on the amount of such damages. For example, if the Landowner experiences a loss in crop yields that is attributed to the operation of the Project (*i.e.*, an inability to spray certain rows of crops due to the presence of the transmission line) then Clean Line will pay the value of such loss in yield for so long as such losses occur. In other words, the intent is that the Landowner be made whole for any damages or losses that occur as a result of the Project at any time.

2. Minimum Payments

Some of the Project Real Estate Rights to be acquired may be very small in size. Therefore, in order to incentivize Landowners that might otherwise receive a very small payment, Landowners will receive a minimum payment of $2,000 per parcel, regardless of the size of the easement area on their land. In addition, in the event that no structures are constructed on a Landowner's parcel, such Landowner will also receive a minimum structure payment. For such minimum structure payment, the Landowner will have the right to elect either (i) a one-time payment equal to $1,500 or (ii) an annual payment equal to $125, with a 2% annual escalator.

3. Arbitration

If Clean Line and a Landowner have reached agreement on the form of any easement or other document evidencing the Project Real Estate Right, but are unable to reach agreement on the appropriate compensation, at such Landowner's request, Clean Line will submit the issue of Landowner compensation to binding arbitration. Arbitration shall be administered by the American Arbitration Association (the "AAA") in accordance with its Commercial Arbitration Rules. Arbitration shall take place in, and shall be conducted in accordance with the laws of, the state in which the Project Real Estate Right is located. Arbitrators shall be appointed as provided in the AAA Commercial Arbitration Rules, but in all events shall be selected from a pool of qualified arbitrators within the state in which the Project Real Estate Right is located.

Schedule 2
to the Participation Agreement

<u>Provisions Required to be Incorporated into Project Financing Documents</u>

The Project Financing Documents and any amendments or supplements thereto, shall comply with the following terms and conditions:

1. The proceeds of the Project Financing are obligated to be used exclusively for the purposes of (a) acquiring, designing, permitting, developing, constructing, equipping, improving, modifying, operating, owning, maintaining, reconstructing, restoring, rehabilitating, renewing or replacing the Project, or any Capital Repair relating to the Project, (b) paying principal and interest on the Project Financing, (c) paying premiums or costs for insurance, bonds and other performance security or paying reasonable development fees to the Clean Line Entities or to any Project Participant or its Affiliates for services related to the Project, (d) paying fees and premiums to any Project Financing Party or such Project Financing Party's agents in consideration for the Project Financing or the commitment thereof, (e) paying costs and fees in connection with the closing of the Project Financing, including fees and costs of counsel and consultants, (f) funding of the Advance Funding Account, Capital Repairs Reserve Account and Wind-Up Reserve Account and making payments and other amounts due to DOE and the Covered Parties under the Transaction Documents, (g) funding reserves required under the Project Financing Documents or Applicable Law, including securities laws and Environmental Laws, (h) payment of interest on subordinated debt and other financing costs (such as fees on letters of credit to the extent used to secure deferred equity contributions), (i) such other uses as are customary and permitted under the terms of the Project Financing Documents and (j) refinancing the Project Financing under clauses (a) through (i) above.

2. The Project Financing Documents (including any accounts or depositary agreement) shall provide that all amounts due and payable to DOE by any Clean Line Entity under this Agreement, any Real Estate Rights Agreement and any other Transaction Document (other than the Participation Amount required to be paid pursuant to Section 11.2) shall be paid as operating expenses of the Project at the top of any revenue application waterfall provided for in such Project Financing Documents and at the same priority level as other general operating costs paid in connection with the Project.

3. No Project Financing Document or other instrument purporting to mortgage, pledge, encumber, or create a Lien, charge or security interest on or against any of the Project Facilities owned by the Clean Line Entities or any of the Clean Line Entities' rights and interests in the Project (including the Clean Line Entities' rights and interest in the Transaction Documents) shall extend to or affect DOE's interest in the DOE Acquired Real Property and the AR Facilities, the Account Collateral (other than the Capital Repair Reserve Account) or any of DOE's other rights, privileges and interests under the Transaction Documents.

4. The Project Financing Documents shall include a conspicuous recital or provision to the effect that payment of the principal thereof and interest thereon is a valid claim only as against the Clean Line Entities and the security pledged by the applicable Clean Line Entities in respect thereof and is not an obligation, moral or otherwise, of DOE or any Covered Party, and

neither the full faith and credit nor the taxing power of DOE or Covered Party is pledged to the payment of the principal thereof and interest thereon.

5. Each Project Financing Document containing express provisions regarding default by a Clean Line Entity shall require that if such Clean Line Entity is in default thereunder and the Project Financing Parties (or an agent thereof) give notice of such default to any Clean Line Entity, then the Project Financing Parties (or an agent thereof) shall also give concurrent notice of such default to DOE. Each Project Financing Document that provides remedies to one or more Project Financing Parties for default by a Clean Line Entity or other applicable Person shall require that such Project Financing Parties deliver to DOE, concurrently with delivery to a Clean Line Entity or any other Person, every notice of election to sell, notice of sale or other notice required by Applicable Law or by the Project Financing Documents in connection with the exercise of remedies under the Project Financing Document.

6. The Project Financing Documents shall (a) expressly state that no Project Financing Party shall (i) name or join DOE or any Covered Party in any legal proceeding seeking collection of the Indebtedness incurred under the Project Financing or other obligations secured thereby or the foreclosure or other enforcement of such Project Financing Document (other than in connection with any express obligations of DOE under the DOE Direct Agreement and the Intercreditor Agreement) and (ii) seek any damages or other amounts from DOE or any Covered Party, whether for Indebtedness incurred under any Project Financing Document (other than in connection with any express obligations of DOE under the DOE Direct Agreement and the Intercreditor Agreement) or any other amount and (b) contain a Release Provision as provided in Section 11.10.

7. The DOE Direct Agreement shall expressly state that each Project Financing Party agrees to non-exclusive general jurisdiction and venue in any action by or against DOE or its successors and assigns of (a) the courts of the United States of America for the District of Columbia, (b) the courts of the United States of America in and for the Southern District of New York, (c) any other federal court of competent jurisdiction in any other jurisdiction where any Clean Line Entity or any of its Property may be found and (d) appellate courts from any of the foregoing.

Schedule 3
to Participation Agreement

<u>Existing Indebtedness</u>

None

Schedule 4
to Participation Agreement

LOCAL GOVERNMENT CONTRIBUTION PAYMENTS

Arkansas

1. Arkansas Operations Payments: ACL will make certain payments to each county or appropriate taxing jurisdiction within each county in Arkansas on an annual basis for 40 years ("Arkansas Annual Operations Payments"). A good faith estimate of the Arkansas Annual Operations Payments as of the Effective Date are included in Exhibit A to this Schedule. The estimates will be adjusted based on the final transmission line mileage in each county.

   If ACL becomes subject to property tax in Arkansas, it will pay the assessed taxes in accordance with local and state laws in lieu of the Arkansas Annual Operations Payments outlined in Exhibit A.

2. Arkansas Construction Payment: ACL will pay to each county in Arkansas one-time construction payments ("Arkansas Construction Payments") equal to $7,500 per mile of transmission line in that county. A good faith estimate of the Arkansas Construction Payments as of the Effective Date is included in the table below. Final payment values are subject to the final routing of the transmission line.

County	**Line Length** *(miles)*	**Arkansas Construction Payments** *(one-time payments)*
Cleburne	23.4	$175,500
Conway	21.6	$162,000
Crawford	28.2	$211,500
Cross	16.1	$120,750
Franklin	19.8	$148,500
Jackson	34.3	$257,250
Johnson	27.8	$208,500
Mississippi	16.2	$121,500
Poinsett	31.5	$236,250
Pope	27.6	$207,000
Van Buren	13.2	$99,000
White	17.5	$131,250
TOTAL (all counties)	**277.2**	**$2,079,000**

Oklahoma

1. Oklahoma Construction Payments: PECL OK will pay to each county in Oklahoma one-time construction payments ("Oklahoma Construction Payments") equal to $7,500 per mile of transmission line in that county. A good faith estimate of the Oklahoma Construction Payments as of the Effective Date is included in the table below. Final payment values are subject to the final routing of the transmission line.

County	**Line Length** *(miles)*	**Oklahoma Construction Payments** *(one-time payments)*
Beaver	56	$420,000
Creek	27.5	$206,250
Garfield	22.2	$166,500
Harper	35.6	$267,000
Kingfisher	3.4	$25,500
Lincoln	10.1	$75,750
Logan	20.8	$156,000
Major	52.2	$391,500
Muskogee	39.5	$296,250
Okmulgee	27.7	$207,750
Payne	36.2	$271,500
Sequoyah	40.0	$300,000
Texas	23.9	$179,250
Woodward	32.4	$243,000
TOTAL (all counties)	**427.5**	**$3,206,250**

2. PECL OK will own all Project facilities located in Oklahoma and will make all applicable ad valorem tax payments to local jurisdictions, in accordance with local and state laws.

<u>EXHIBIT A</u>
Payment Schedule

Year	Crawford	Franklin	Johnson	Pope	Conway	Van Buren	Cleburne	White	Jackson	Poinsett	Cross	Mississippi
1	$ 529,062	$ 367,588	$ 486,911	$ 1,467,731	$ 393,463	$ 230,061	$ 381,305	$ 286,636	$ 607,090	$ 501,936	$ 311,977	$ 320,708
2	$ 518,952	$ 360,564	$ 477,607	$ 1,439,685	$ 385,944	$ 225,665	$ 374,019	$ 281,159	$ 595,489	$ 492,345	$ 306,016	$ 314,580
3	$ 508,843	$ 353,540	$ 468,303	$ 1,411,639	$ 378,426	$ 221,269	$ 366,733	$ 275,682	$ 583,889	$ 482,754	$ 300,054	$ 308,451
4	$ 498,733	$ 346,516	$ 458,999	$ 1,383,594	$ 370,908	$ 216,873	$ 359,446	$ 270,205	$ 572,288	$ 473,163	$ 294,093	$ 302,323
5	$ 488,624	$ 339,492	$ 449,695	$ 1,355,548	$ 363,389	$ 212,477	$ 352,160	$ 264,728	$ 560,688	$ 463,572	$ 288,132	$ 296,195
6	$ 478,514	$ 332,468	$ 440,391	$ 1,327,502	$ 355,871	$ 208,081	$ 344,874	$ 259,251	$ 549,087	$ 453,981	$ 282,170	$ 290,067
7	$ 468,405	$ 325,444	$ 431,087	$ 1,299,456	$ 348,352	$ 203,685	$ 337,588	$ 253,774	$ 537,487	$ 444,390	$ 276,209	$ 283,939
8	$ 458,296	$ 318,420	$ 421,783	$ 1,271,410	$ 340,834	$ 199,289	$ 330,302	$ 248,297	$ 525,887	$ 434,798	$ 270,248	$ 277,811
9	$ 448,186	$ 311,396	$ 412,479	$ 1,243,364	$ 333,316	$ 194,893	$ 323,016	$ 242,819	$ 514,286	$ 425,207	$ 264,286	$ 271,682
10	$ 438,077	$ 304,372	$ 403,175	$ 1,215,319	$ 325,797	$ 190,496	$ 315,730	$ 237,342	$ 502,686	$ 415,616	$ 258,325	$ 265,554
11	$ 427,967	$ 297,348	$ 393,871	$ 1,187,273	$ 318,279	$ 186,100	$ 308,444	$ 231,865	$ 491,085	$ 406,025	$ 252,364	$ 259,426
12	$ 417,858	$ 290,324	$ 384,567	$ 1,159,227	$ 310,760	$ 181,704	$ 301,158	$ 226,388	$ 479,485	$ 396,434	$ 246,402	$ 253,298
13	$ 407,748	$ 283,300	$ 375,263	$ 1,131,181	$ 303,242	$ 177,308	$ 293,872	$ 220,911	$ 467,884	$ 386,843	$ 240,441	$ 247,170
14	$ 397,639	$ 276,276	$ 365,959	$ 1,103,135	$ 295,724	$ 172,912	$ 286,586	$ 215,434	$ 456,284	$ 377,252	$ 234,480	$ 241,042
15	$ 387,529	$ 269,252	$ 356,655	$ 1,075,090	$ 288,205	$ 168,516	$ 279,300	$ 209,957	$ 444,683	$ 367,660	$ 228,518	$ 234,913
16	$ 377,420	$ 262,228	$ 347,351	$ 1,047,044	$ 280,687	$ 164,120	$ 272,014	$ 204,480	$ 433,083	$ 358,069	$ 222,557	$ 228,785
17	$ 367,310	$ 255,204	$ 338,047	$ 1,018,998	$ 273,168	$ 159,724	$ 264,727	$ 199,002	$ 421,483	$ 348,478	$ 216,596	$ 222,657
18	$ 357,201	$ 248,180	$ 328,743	$ 990,952	$ 265,650	$ 155,328	$ 257,441	$ 193,525	$ 409,882	$ 338,887	$ 210,634	$ 216,529
19	$ 347,091	$ 241,156	$ 319,439	$ 962,906	$ 258,132	$ 150,932	$ 250,155	$ 188,048	$ 398,282	$ 329,296	$ 204,673	$ 210,401
20	$ 336,982	$ 234,133	$ 310,135	$ 934,861	$ 250,613	$ 146,536	$ 242,869	$ 182,571	$ 386,681	$ 319,705	$ 198,712	$ 204,273
21	$ 326,873	$ 227,109	$ 300,831	$ 906,815	$ 243,095	$ 142,140	$ 235,583	$ 177,094	$ 375,081	$ 310,114	$ 192,750	$ 198,144
22	$ 316,763	$ 220,085	$ 291,527	$ 878,769	$ 235,576	$ 137,744	$ 228,297	$ 171,617	$ 363,480	$ 300,522	$ 186,789	$ 192,016
23	$ 306,654	$ 213,061	$ 282,223	$ 850,723	$ 228,058	$ 133,348	$ 221,011	$ 166,140	$ 351,880	$ 290,931	$ 180,827	$ 185,888
24	$ 296,544	$ 206,037	$ 272,919	$ 822,677	$ 220,540	$ 128,951	$ 213,725	$ 160,662	$ 340,280	$ 281,340	$ 174,866	$ 179,760
25	$ 286,435	$ 199,013	$ 263,614	$ 794,631	$ 213,021	$ 124,555	$ 206,439	$ 155,185	$ 328,679	$ 271,749	$ 168,905	$ 173,632
26	$ 276,325	$ 191,989	$ 254,310	$ 766,586	$ 205,503	$ 120,159	$ 199,153	$ 149,708	$ 317,079	$ 262,158	$ 162,943	$ 167,503
27	$ 266,216	$ 184,965	$ 245,006	$ 738,540	$ 197,984	$ 115,763	$ 191,867	$ 144,231	$ 305,478	$ 252,567	$ 156,982	$ 161,375
28	$ 256,106	$ 177,941	$ 235,702	$ 710,494	$ 190,466	$ 111,367	$ 184,581	$ 138,754	$ 293,878	$ 242,976	$ 151,021	$ 155,247
29	$ 245,997	$ 170,917	$ 226,398	$ 682,448	$ 182,948	$ 106,971	$ 177,295	$ 133,277	$ 282,277	$ 233,384	$ 145,059	$ 149,119
30	$ 235,887	$ 163,893	$ 217,094	$ 654,402	$ 175,429	$ 102,575	$ 170,008	$ 127,800	$ 270,677	$ 223,793	$ 139,098	$ 142,991
31	$ 225,778	$ 156,869	$ 207,790	$ 626,357	$ 167,911	$ 98,179	$ 162,722	$ 122,323	$ 259,076	$ 214,202	$ 133,137	$ 136,863
32	$ 215,668	$ 149,845	$ 198,486	$ 598,311	$ 160,392	$ 93,783	$ 155,436	$ 116,845	$ 247,476	$ 204,611	$ 127,175	$ 130,734
33	$ 205,559	$ 142,821	$ 189,182	$ 570,265	$ 152,874	$ 89,387	$ 148,150	$ 111,368	$ 235,876	$ 195,020	$ 121,214	$ 124,606
34	$ 195,450	$ 135,797	$ 179,878	$ 542,219	$ 145,356	$ 84,991	$ 140,864	$ 105,891	$ 224,275	$ 185,429	$ 115,253	$ 118,478
35	$ 185,340	$ 128,773	$ 170,574	$ 514,173	$ 137,837	$ 80,595	$ 133,578	$ 100,414	$ 212,675	$ 175,838	$ 109,291	$ 112,350
36	$ 175,231	$ 121,749	$ 161,270	$ 486,127	$ 130,319	$ 76,199	$ 126,292	$ 94,937	$ 201,074	$ 166,246	$ 103,330	$ 106,222
37	$ 165,121	$ 114,725	$ 151,966	$ 458,082	$ 122,800	$ 71,803	$ 119,006	$ 89,460	$ 189,474	$ 156,655	$ 97,369	$ 100,094
38	$ 155,012	$ 107,701	$ 142,662	$ 430,036	$ 115,282	$ 67,406	$ 111,720	$ 83,983	$ 177,873	$ 147,064	$ 91,407	$ 93,965
39	$ 144,902	$ 100,677	$ 133,358	$ 401,990	$ 107,764	$ 63,010	$ 104,434	$ 78,506	$ 166,273	$ 137,473	$ 85,446	$ 87,837
40	$ 134,793	$ 93,653	$ 124,054	$ 373,944	$ 100,245	$ 58,614	$ 97,148	$ 73,028	$ 154,673	$ 127,882	$ 79,485	$ 81,709

Schedule 5
to Participation Agreement

<u>Capitalization</u>

None

Schedule 6
to the Participation Agreement

Officer's Certificate Regarding DOE Delegated Real Estate Rights

[DATE]

The undersigned, [NAME], [TITLE] of Plains and Eastern Clean Line Holdings LLC (the "Company") does hereby certify on behalf of the Company, pursuant to Section 6.2(c) of the Participation Agreement dated as of [DATE] (the "Participation Agreement"), by and among the Company, Arkansas Clean Line LLC, Plains and Eastern Clean Line Oklahoma LLC, Oklahoma Land Acquisition Company LLC, Plains and Eastern Clean Line LLC, and the United States Department of Energy, as follows:

(i) the Clean Line Entities have complied with all of the requirements and procedures set forth in Schedule 1 to the Participation Agreement with respect to the DOE Delegated Real Estate Rights to be acquired;

(ii) Acceptable Transmission Services Agreements and Acceptable Permitted Project Investment Commitments in respect of not less than 1,500 MW of the Electrical Capacity in the aggregate (calculated as the sum of (A) with respect to Acceptable Permitted Project Investments, the sum of each portion of the Electrical Capacity transferred (and for which the Clean Line Entities have received payment or will receive payment within three (3) years after the date of such Permitted Project Investment) pursuant to each Acceptable Permitted Project Investment Commitment and (B) with respect to the Acceptable Transmission Services Agreements, the sum of the average Electrical Capacity committed in the initial five (5) years of the term for each such Acceptable Transmission Services Agreement) are in full force and effect and no event has occurred or is continuing (whether as a result of a default or the failure of a condition precedent or otherwise) that gives the Project Participant party thereto the right to terminate such Acceptable Transmission Services Agreement or such Acceptable Permitted Project Investment Commitment;

(iii) **[**the Converter Station Real Estate Rights Agreements are in full force and effect**]**[the Clean Line Entities own in fee free and clear of all Liens other than Permitted Liens all Real Estate Rights necessary for the construction of the Converter Station Facility and the Intermediate Converter Station**]**[1];

(iv) the executed Interconnection Agreements for interconnection of the Project with the SPP-controlled transmission system and the MISO-controlled transmission system and the executed Project Work Agreement or Interconnection Agreement for interconnection of the TN Facilities with the TVA transmission system are in full force and effect and no event has occurred and is continuing (whether as a result of a default or the failure of a condition precedent or otherwise) that gives the Project Participant party thereto the right to terminate such Interconnection Agreements or

[1] Insert as appropriate.

Project Work Agreement (except to the extent the Project Work Agreement has been replaced by an Interconnection Agreement with TVA);

(v) **[**the Project Equity Commitments (including Firm Project Equity Commitments that are currently in full force and effect and that provide for commitments (together with amounts on deposit in the Advance Funding Account) in an amount equal to not less than 150% of the Remaining DOE Acquisition Costs as of any date on which any Clean Line Entity designates any Project Real Estate Right as a DOE Delegated Real Estate Right), Project Financing Commitments and any letters of intent delivered as a condition to the occurrence of the Commencement Date are in full force and effect**][**the Financing Condition is satisfied**]**[2];

(vi) (A) no Governmental Order is in effect nor has any Change of Law occurred that, in either case, as applicable, sets aside, enjoins or legally prohibits (1) DOE's performance under the Participation Agreement or any other Transaction Document currently in effect or (2) DOE's participation in the Project and (B) no other final and non-appealable Governmental Order is in effect nor has any Change of Law occurred that, in either case, as applicable, (1) sets aside, enjoins or legally prohibits any Clean Line Entity's performance under the Participation Agreement or any other Transaction Document currently in effect or any Clean Line Entity's performance in any material respect under any Material Project Contract to which it is a party or (2) affects in any material respect the legality, validity or enforceability of any of the Transaction Documents, any Project Equity Commitment or any of the Material Project Contracts currently in effect; and

(vii) no Event of Default has occurred and is continuing.

It is expressly understood that this Officer's Certificate is being executed by the undersigned authorized signatory solely on behalf of the Company, and not in a personal capacity. Capitalized terms used but not defined herein shall have the meanings given to them in the Participation Agreement.

[Signature on following page]

[2] Insert as appropriate.

IN WITNESS WHEREOF, the undersigned has executed this Officer's Certificate on behalf of the Company as of the date first above written.

____
Name:
Title:

Schedule 7
to the Participation Agreement

Officer's Certificate Regarding Acquisitions by Condemnation

[DATE]

The undersigned, [NAME], [TITLE] of Plains and Eastern Clean Line Holdings LLC (the "Company") does hereby certify on behalf of the Company, pursuant to Section 6.3(c) of the Participation Agreement dated as of [DATE] (the "Participation Agreement"), by and among the Company, Arkansas Clean Line LLC, Plains and Eastern Clean Line Oklahoma LLC, Oklahoma Land Acquisition Company LLC, Plains and Eastern Clean Line LLC, and the United States Department of Energy, as follows:

(i) the Clean Line Entities have complied with all of the requirements and procedures set forth in Schedule 1 to the Participation Agreement with respect to the DOE Delegated Real Estate Rights to be acquired;

(ii) Acceptable Transmission Services Agreements and Acceptable Permitted Project Investment Commitments in respect of not less than 2,000 MW of the Electrical Capacity in the aggregate (calculated as the sum of (A) with respect to Acceptable Permitted Project Investments, the sum of each portion of the Electrical Capacity transferred (and for which the Clean Line Entities have received payment or will receive payment within three (3) years after the date of such Permitted Project Investment) pursuant to each Acceptable Permitted Project Investment Commitment and (B) with respect to the Acceptable Transmission Services Agreements, the sum of the average Electrical Capacity committed in the initial five (5) years of the term for each such Acceptable Transmission Services Agreement) are in full force and effect and no event has occurred and is continuing (whether as a result of a default or the failure of a condition precedent or otherwise) that gives the Project Participant party thereto the right to terminate such Acceptable Transmission Services Agreement or such Acceptable Permitted Project Investment Commitment;

(iii) **[**the Converter Station Real Estate Rights Agreements delivered pursuant to the foregoing conditions precedent are in full force and effect and neither any Clean Line Entity nor any other Person party thereto is in default thereunder**][**the Clean Line Entities own in fee free and clear of Liens other than Permitted Liens all Real Estate Rights necessary for the construction of the Converter Station Facility and the Intermediate Converter Station**]**[1];

(iv) the Interconnection Agreements delivered by the Company pursuant to Section 6.3(a)(vi) of the Participation Agreement are in full force and effect and neither any Clean Line Entity nor any other Person or party thereto is in default thereunder;

(v) the Financing Condition is satisfied;

[1] Insert as appropriate.

(vi) (A) no Governmental Order is in effect nor has any Change of Law occurred that, in either case, as applicable, sets aside, enjoins or legally prohibits (1) DOE's performance under the Participation Agreement or any other Transaction Document currently in effect or (2) DOE's participation in the Project and (B) no other final and non-appealable Governmental Order is in effect nor has any Change of Law occurred that, in either case, as applicable, (1) sets aside, enjoins or legally prohibits any Clean Line Entity's performance under the Participation Agreement or any other Transaction Document currently in effect or any Clean Line Entity's performance in any material respect under any Material Project Contract to which it is a party or (2) affects in any material respect the legality, validity or enforceability of any of the Transaction Documents, any Project Equity Commitment or any of the Material Project Contracts currently in effect; and

(vii) no Event of Default has occurred and is continuing.

It is expressly understood that this Officer's Certificate is being executed by the undersigned authorized signatory solely on behalf of the Company, and not in a personal capacity. Capitalized terms used but not defined herein shall have the meanings given to them in the Participation Agreement.

[Signature on following page]

IN WITNESS WHEREOF, the undersigned has executed this Officer's Certificate on behalf of the Company as of the date first above written.

____
Name:
Title:

Schedule 8
to Participation Agreement

<u>Reserved</u>

Schedule 9
to Participation Agreement

Litigation

None

Schedule 10
to Participation Agreement

Environmental Matters

None

Schedule 11
to Participation Agreement

Governmental Approvals

1. Section 1222 Decision

Schedule 12
to Participation Agreement

<u>Code of Conduct for Acquisitions of Project Real Estate Rights</u>

[Attached]

PLAINS AND EASTERN CLEAN LINE OKLAHOMA LLC
CODE OF CONDUCT FOR EMPLOYEES, RIGHT-OF-WAY AGENTS AND SUBCONTRACTOR EMPLOYEES

This Code of Conduct applies to all communications and interactions with property owners and occupants of property by all employees, right-of-way agents and subcontractor employees representing Plains and Eastern Clean Line Oklahoma LLC ("Plains & Eastern") in the negotiation of right-of-way and the performance of surveying, environmental assessments and the other activities for the Plains & Eastern project (the "Project") on property not owned by Plains & Eastern.

I. All communications with property owners and occupants must be factually correct and made in good faith.
   a. Do provide maps and documents necessary to keep the landowner properly informed.
   b. Do not make false or misleading statements.
   c. Do not purposely or intentionally misrepresent any fact.
   d. If you do not know the answer to a question, do not speculate about the answer. Advise the property owner that you will investigate the question and provide an answer later.
   e. Follow-up in a timely manner on all commitments to provide additional information.
   f. Do not send written communications suggesting an agreement has been reached when, in fact, an agreement has not been reached.
   g. If information provided is subsequently determined to be incorrect, follow up with the landowner as soon as practical to provide the corrected information.
   h. Do provide the landowner with appropriate contact information should additional contacts be necessary.

II. All communications and interactions with property owners and occupants of property must be respectful and reflect fair dealing.
   a. When contacting a property owner in person, promptly identify yourself as representing Plains & Eastern.
   b. When contacting a property owner by telephone, promptly identify yourself as representing Plains & Eastern.
   c. Do not engage in behavior that may be considered harassing, coercive, manipulative, intimidating or causing undue pressure.
   d. All communications by a property owner, whether in person, by telephone or in writing, in which the property owner indicates that he or she does not want to negotiate or does not want to give permission for surveying or other work on his or her property, must be respected and politely accepted without argument. Unless specifically authorized by Plains & Eastern, do not contact the property owner again regarding negotiations or requests for permission.
   e. When asked to leave the property, promptly leave and do not return unless specifically authorized by Plains & Eastern.
   f. If discussions with the property owner become acrimonious, politely discontinue the discussion and withdraw from the situation.
   g. Obtain unequivocal permission to enter the property for purposes of surveying or conducting environmental assessments or other activities. Clearly explain to the property owner the scope of the work to be conducted based on the permission given.

Attempt to notify the occupant of the property each time you enter the property based on this permission.

h. Do not represent that a relative, neighbor and/or friend have signed a document or reached an agreement with Plains & Eastern.
i. Do not ask a relative, neighbor and/or friend of a property owner to convince the property owner to take any action.
j. Do not represent that a relative, neighbor and/or friend supports or opposes the Project.
k. Do not suggest that any person should be ashamed of or embarrassed by his or her opposition to the Project or that such opposition is inappropriate.
l. Do not suggest that an offer is "take it or leave it."
m. Do not argue with property owners about the merits of the Project.
n. Do not threaten to call law enforcement officers or obtain court orders.
o. Avoid discussing a property owner's failure to note an existing easement when purchasing the property and other comments about the property owner's acquisition of the property.
p. Do not threaten the use of eminent domain.

III. All communications and interactions with property owners and occupants of property must respect the privacy of property owners and other persons.

a. Discussions with property owners and occupants are to remain confidential.
b. Do not discuss your negotiations or interactions with other property owners or other persons unaffiliated with Plains & Eastern.
c. Do not ask relatives, neighbors and/or friends to influence the property owner or any other person.

ARKANSAS CLEAN LINE LLC
CODE OF CONDUCT FOR EMPLOYEES, RIGHT-OF-WAY AGENTS AND SUBCONTRACTOR EMPLOYEES

This Code of Conduct applies to all communications and interactions with property owners and occupants of property by all employees, right-of-way agents and subcontractor employees representing Arkansas Clean Line LLC ("Plains & Eastern") in the negotiation of right-of-way and the performance of surveying, environmental assessments and the other activities for the Plains & Eastern project (the "Project") on property not owned by Plains & Eastern.

I. All communications with property owners and occupants must be factually correct and made in good faith.
   a. Do provide maps and documents necessary to keep the landowner properly informed.
   b. Do not make false or misleading statements.
   c. Do not purposely or intentionally misrepresent any fact.
   d. If you do not know the answer to a question, do not speculate about the answer. Advise the property owner that you will investigate the question and provide an answer later.
   e. Follow-up in a timely manner on all commitments to provide additional information.
   f. Do not send written communications suggesting an agreement has been reached when, in fact, an agreement has not been reached.
   g. If information provided is subsequently determined to be incorrect, follow up with the landowner as soon as practical to provide the corrected information.
   h. Do provide the landowner with appropriate contact information should additional contacts be necessary.

II. All communications and interactions with property owners and occupants of property must be respectful and reflect fair dealing.
   a. When contacting a property owner in person, promptly identify yourself as representing Plains & Eastern.
   b. When contacting a property owner by telephone, promptly identify yourself as representing Plains & Eastern.
   c. Do not engage in behavior that may be considered harassing, coercive, manipulative, intimidating or causing undue pressure.
   d. All communications by a property owner, whether in person, by telephone or in writing, in which the property owner indicates that he or she does not want to negotiate or does not want to give permission for surveying or other work on his or her property, must be respected and politely accepted without argument. Unless specifically authorized by Plains & Eastern, do not contact the property owner again regarding negotiations or requests for permission.
   e. When asked to leave the property, promptly leave and do not return unless specifically authorized by Plains & Eastern.
   f. If discussions with the property owner become acrimonious, politely discontinue the discussion and withdraw from the situation.
   g. Obtain unequivocal permission to enter the property for purposes of surveying or conducting environmental assessments or other activities. Clearly explain to the property owner the scope of the work to be conducted based on the permission given.

Attempt to notify the occupant of the property each time you enter the property based on this permission.

h. Do not represent that a relative, neighbor and/or friend have signed a document or reached an agreement with Plains & Eastern.
i. Do not ask a relative, neighbor and/or friend of a property owner to convince the property owner to take any action.
j. Do not represent that a relative, neighbor and/or friend supports or opposes the Project.
k. Do not suggest that any person should be ashamed of or embarrassed by his or her opposition to the Project or that such opposition is inappropriate.
l. Do not suggest that an offer is "take it or leave it."
m. Do not argue with property owners about the merits of the Project.
n. Do not threaten to call law enforcement officers or obtain court orders.
o. Avoid discussing a property owner's failure to note an existing easement when purchasing the property and other comments about the property owner's acquisition of the property.
p. Do not threaten the use of eminent domain.

III. All communications and interactions with property owners and occupants of property must respect the privacy of property owners and other persons.
a. Discussions with property owners and occupants are to remain confidential.
b. Do not discuss your negotiations or interactions with other property owners or other persons unaffiliated with Plains & Eastern.
c. Do not ask relatives, neighbors and/or friends to influence the property owner or any other person.

Schedule 13
to Participation Agreement

<u>Permitted Project Investments Representations and Warranties and Covenants</u>

Each Person that makes a Permitted Project Investment in the Project (such Person, an "Investor") shall be required to make the following representations and warranties and agree to the following covenants for the benefit of DOE in the connection with such Permitted Project Investment:

Representations and Warranties:

<u>Prohibited Persons</u>. (a) None of the Investor, any Controlling Person of such Investor or any Principal Person of such Investor or any Principal Person of such Controlling Person of such Investor is a Prohibited Person and (b) to such Investor's knowledge, no event has occurred and no condition exists that is likely to result in such Investor, any Controlling Person of such Investor, any Principal Person of such Investor or any Principal Person of such Controlling Person of such Investor becoming a Prohibited Person.

<u>Anti-Corrupt Practices Laws, Etc</u>. (a) The Investor, each Controlling Person of such Investor and each Principal Person, employee and agent of such Investor and each Principal Person of each Controlling Person of such Investor have complied with all AM Laws, Anti-Corruption Laws and Sanctions and (b) such Investor has implemented and maintains in effect policies and procedures reasonably designed to ensure compliance by such Investor and its Principal Persons with AM Law, Anti-Corruption Laws and Sanctions.

Covenants:

<u>Prohibited Persons.</u>

(a) The Investor shall provide immediate written notice (including a brief description relating thereto) to DOE if, at any time, it learns that the representations made with respect to Prohibited Persons (including in respect of the Debarment Regulations) were erroneous when made or have become erroneous by reason of changed circumstances.

(b) If any Person that controls the Investor or any of their respective Principal Persons becomes a Prohibited Person, the Investor shall, within sixty (60) days of knowing that such Person has become a Prohibited Person, engage and continue to engage in constructive discussions with DOE regarding the removal or replacement of such Person or, if such removal or replacement is not reasonably feasible, the implementation of other mitigation matters.

<u>AM Laws, Anti-Corruption Laws Etc.</u>

The Investor shall and shall cause its Principal Persons, employees and agents to (a) comply with all applicable AM Laws and Anti-Corruption Laws, (b) conduct its business in compliance with all applicable AM Laws and Anti-Corruption Laws and (c) maintain internal management and accounting practices and controls that are adequate to ensure the Investor's compliance with all applicable AM Laws and Anti-Corruption Laws.

Definitions:

"Affiliate" means with respect to any Person, any other Person that directly or indirectly Controls, or is under common Control with, or is Controlled by, such Person and, if such Person is an individual, any member of the immediate family of such individual and any trust whose principal beneficiary is such individual or one or more members of such immediate family and any Person who is Controlled by any such member or trust.

"AM Laws" means, with respect to any Person, all applicable laws concerning or relating to anti-money laundering.

"Anti-Corruption Laws" means, with respect to any Person, all Applicable Laws concerning or relating to bribery or corruption, including, the Foreign Corrupt Practices Act of 1977 (Pub. L. No. 95 213, §§101-104).

"Control" means (including, with its correlative meanings, "Controlled by" and "under common Control with") as used with respect to any Person, possession, directly or indirectly, of the power to direct or cause the direction of management or policies of such Person (whether through ownership of voting securities or partnership or other ownership interests, by contract or otherwise); provided, that any Person that owns directly or indirectly ten percent (10%) or more of the equity interests having ordinary voting powers for the election of directors or other applicable governing body of another Person (but excluding limited partnership or similar types of ownership interests and tax equity investors) shall be deemed to Control such other Person.

"Controlling Person" means, with respect to any Person, any other Person that, directly or indirectly Controls such Person.

"Debarment Regulations" means (a) the Government-wide Debarment and Suspension (Non procurement) regulations (Common Rule), 53 Fed. Reg. 19204 (May 26, 1988), (b) Subpart 9.4 (Debarment, Suspension, and Ineligibility) of the Federal Acquisition Regulations, 48 C.F.R. §§ 9.400 – 9.409 and (c) the revised Government-wide Debarment and Suspension (Non-procurement) regulations (Common Rule), 60 Fed. Reg. 33037 (June 26, 1995).

"Governmental Authority" means any federal, state, county, municipal, or regional authority, or any other entity of a similar nature, exercising any executive, legislative, judicial (including any court of competent jurisdiction), regulatory, or administrative function of government.

"Governmental Order" means with respect to any Person, any judgment, order, decision, or decree, or any action of a similar nature, of or by a Governmental Authority having competent jurisdiction over such Person or any of its properties.

"OFAC" means the Office of Foreign Assets Control, an agency of the U.S. Department of the Treasury under the auspices of the Under Secretary of the Treasury for Terrorism and Financial Intelligence.

"OFAC-Listed Person" has the meaning set forth in clause (a) of the definition of Prohibited Person.

"OFAC Sanctions Program" means any economic or trade sanction that OFAC is responsible for administering and enforcing. A list of OFAC Sanctions Programs may be found at http://www.treasury.gov/resource-center/sanctions/Programs/Pages/Programs.aspx.

"Person" means any individual, entity, firm, corporation, company, voluntary association, partnership, limited liability company, joint venture, trust, unincorporated organization, Governmental Authority, committee, department, authority or any other body, incorporated or unincorporated, whether having distinct legal personality or not.

"Principal Person" means, with respect to any Person, any officer, director, owner, key employee or other Person with primary management or supervisory responsibilities with respect to such Person or any other Person (whether or not an employee) who has critical influence on or substantive control over such Person.

"Prohibited Person" means any Person (or any Person that is an Affiliate of a Person) that is:

(a) named, identified or described on the list of "Specially Designated Nationals and Blocked Persons" as published by OFAC (an "OFAC-Listed Person");

(b) is an agent, department or instrumentality of, or is otherwise beneficially owned by, Controlled by or acting on behalf of, directly or indirectly, (i) an OFAC-Listed Person or (ii) any Person, organization, foreign country or regime that is subject to any Sanctions;

(c) is debarred, suspended, proposed for debarment with a final determination still pending, declared ineligible or voluntarily excluded (as such terms are defined in the Debarment Regulations) from contracting with any United States federal government department or any agency or instrumentality thereof or otherwise participating in procurement or non-procurement transactions with any United States federal government or agency pursuant to any of the Debarment Regulations;

(d) indicted, convicted or had a final and non-appealable Governmental Order rendered against it for any of the offenses listed in any of the Debarment Regulations; or

(e) otherwise blocked, subject to sanctions under or engaged in any activity in violation of other United States economic sanctions, including but not limited to, the Trading with the Enemy Act, the International Emergency Economic Powers Act, the Comprehensive Iran Sanctions, Accountability and Divestment Act or any similar law or regulation with respect to Iran or any other country, the Sudan Accountability and Divestment Act, any OFAC Sanctions Program, or any economic sanctions regulations administered and enforced by the United States or any enabling legislation or executive order relating to any of the foregoing.

"Sanctions" means economic or financial sanctions or trade embargoes or restrictive measures enacted, imposed, administered or enforced from time to time by (a) the United States government, including those administered by OFAC, the U.S. Department of State or the U.S. Department of Commerce, (b) the United Nations Security Council, (c) the European Union or any of its member states or (d) any other applicable Governmental Authority and including, for the avoidance of doubt, the Trading with the Enemy Act, the International Emergency Economic Powers Act, the Comprehensive Iran Sanctions, Accountability and Divestment Act and the Sudan Accountability and Divestment Act.

Schedule 14
to the Participation Agreement

<u>Conditions in Acceptable Transmission Services Agreements and Acceptable Permitted Project Investment Commitments</u>

<u>Part A</u>

Acceptable Transmission Services Agreements

Acceptable Transmission Services Agreements delivered pursuant to Sections 6.2(a)(iv), 6.2(b)(ii), 6.3(a)(v), 6.3(b)(ii) and 6.4(a)(ii) of the Agreement may be subject to conditions to their effectiveness or commencement of transmission service thereunder similar in substance to the following:

1. <u>FERC Approval</u>. FERC has issued one or more orders under Section 205 of the FPA accepting the Acceptable Transmission Services Agreement for filing without substantial condition or modification that is materially adverse to either the Clean Line Parties or the customer under the Acceptable Transmission Services Agreement.

2. <u>State Regulatory Approval</u>. Any necessary approvals from state public utility regulatory bodies have been obtained, made or given authorizing all transactions and payments contemplated in the Acceptable Transmission Services Agreement, including the approval of power purchase agreements, as applicable, on terms that are acceptable to the customer and the Clean Line Parties.

3. <u>Applicable Federal Regulatory Approvals</u>.

(a) If and to the extent that the customer under an Acceptable Transmission Services Agreement is a federal entity that must comply with certain federal environmental or regulatory reviews and approvals prior to the effectiveness of an Acceptable Transmission Services Agreement, the effectiveness of such Acceptable Transmission Services Agreement may be conditioned upon completion of such federal or environmental regulatory reviews and approvals and such reviews and approvals not being subject to judicial review.

(b) If the Acceptable Transmission Services Agreement will involve a source of energy that must receive Governmental Approvals prior to the initiation of commercial operation and generation of electricity for delivery to, and transmittal over, the Project; such Acceptable Transmission Services Agreement may be conditioned upon Governmental Approvals having been duly obtained, in full force and effect and not subject to any pending or threatened challenges or judicial review.

4. <u>OATT</u>. FERC has issued an order under Section 205 of the FPA accepting the rate schedule or OATT filed by the Clean Line Parties without substantial condition or modification that is materially adverse to either the Clean Line Parties or the customer under the Acceptable Transmission Services Agreement.

5. Interconnection Agreements. All necessary interconnection agreements involving the interconnection of the generation facilities under contract with or owned or operated by the customer under the Acceptable Transmission Services Agreement to the Project have been executed and are in full force and effect.

6. Governmental Approvals. All non-ministerial Governmental Approvals required for the construction and operation of the Project have been duly obtained and are in full force and effect and shall not be subject to any pending or threatened challenge or judicial review.

7. Material Contracts. All material contracts needed to construct and operate the Project, including interconnection agreements involving the interconnection of the Project to the transmission systems under the operational control of MISO, SPP and TVA have been executed and are in full force and effect.

8. Notice to Proceed. A full notice to proceed has been issued under each material construction contract with respect to the Project.

9. Project Financial Close. Project Financial Close has occurred or shall occur simultaneously with the effectiveness of the Acceptable Transmission Services Agreement.

10. Representations and Warranties. Each of the applicable representations and warranties of the Clean Line Parties made pursuant to the Acceptable Transmission Services Agreement or any related agreement is true and correct in all material respects, except to the extent that any such representation or warranty is expressly made only as of another date, in which case such representation and warranty shall be true and correct in all material respects as of such other date.

11. Performance of Obligations. Each Clean Line Party shall have performed in all material respects all obligations required to be performed by such party under the Acceptable Transmission Services Agreement (and any related agreements) and under any applicable transaction documents pertaining to the Project or the Other Facilities.

12. Security. Any necessary security or collateral among and between the Clean Line Parties and the customer under the Acceptable Transmission Services Agreement is effective.

13. General Open Access Terms and Conditions. The Acceptable Transmission Services Agreement will include, either directly or by reference, general terms and conditions consistent with FERC's open access transmission rules and policies as applied to firm point-to-point transmission service under the rate schedule or OATT filed by the Clean Line Parties (e.g., sale or assignment of transmission service).

14. Insurance. The Clean Line Parties have delivered to the customer certificates evidencing all insurance required to be obtained by the Clean Line Parties under the Acceptable Transmission Services Agreement.

15. Commercial Operation. The Project (a) has commenced commercial operation and has satisfied the requirements for "substantial completion" (or term of similar import) as defined in and in accordance with all Construction Contracts and the initial Electrical Capacity

(as specified in the definition thereof) of the Project has been certified by an Independent Engineer, (b) has safely and reliably energized and energy may be delivered across the Project Facilities to SPP's, MISO's and TVA's transmission systems in accordance with the Interconnection Agreements and (c) otherwise complies with the design criteria, system performance and testing requirements and operating standards set forth in the Acceptable Transmission Services Agreement and the Clean Line Parties have delivered to the customer a certificate certifying, or the customer has approved, the same.

16. Legal Opinion. Delivery by the Clean Line Parties to the customer of an opinion of legal counsel that all Governmental Approvals required for the Clean Line Parties to own, construct and operate the Project and to perform their respective obligations under the Acceptable Transmission Services Agreement have been obtained.

Acceptable Permitted Project Investment Commitments

Acceptable Permitted Project Investment Commitments delivered pursuant to Sections 6.2(a)(iv), 6.2(b)(ii), 6.3(a)(v), 6.3(b)(ii) and 6.4(a)(ii) of the Agreement may be subject to conditions to their effectiveness thereunder similar in substance to the following:

1. FERC Approval. FERC has issued one or more orders approving the Permitted Project Investment without substantial condition or modification that is materially adverse to either the Clean Line Parties or Permitted Project Investment counterparty.

2. State Regulatory Approval. Any necessary approvals from state public utility regulatory bodies have been obtained, made or given authorizing all transactions and payments contemplated in Permitted Project Investment on terms that are acceptable to the Permitted Project Investment counterparty and the Clean Line Parties.

3. Interconnection Agreements. All necessary interconnection agreements involving the interconnection of the generation facilities under contract with or owned or operated by the Permitted Project Investment counterparty to the Project have been executed and are in full force and effect.

4. Governmental Approvals. All non-ministerial Governmental Approvals required for the construction and operation of the Project have been duly obtained and are in full force and effect and shall not be subject to any pending or threatened challenge or judicial review.

5. Material Contracts. All material contracts needed to construct and operate the Project, including interconnection agreements involving the interconnection of the Project to the transmission systems under the operational control of MISO, SPP and TVA have been executed and are in full force and effect.

6. Notice to Proceed. A full notice to proceed has been issued under each material construction contract with respect to the Project.

7. Project Financial Close. Project Financial Close has occurred or shall occur simultaneously with the effectiveness of the Permitted Project Investment.

8. Representations and Warranties. Each of the applicable representations and warranties of the Clean Line Parties made pursuant to the Permitted Project Investment or any related agreement is true and correct in all material respects, except to the extent that any such representation or warranty is expressly made only as of another date, in which case such representation and warranty shall be true and correct in all material respects as of such other date.

9. Performance of Obligations. Each Clean Line Party shall have performed in all material respects all obligations required to be performed by such party under the Permitted Project Investment (and any related agreements) and under any applicable transaction documents pertaining to the Project or the Other Facilities.

10. Security. Any necessary security or collateral among and between the Clean Line Parties and the Permitted Project Investment counterparty under the Permitted Project Investment (and any related agreements) is effective.

11. Insurance. The Clean Line Parties have delivered to the Permitted Project Investment counterparty certificates evidencing all insurance required to be obtained by the Clean Line Parties under the Permitted Project Investment (and any related agreements).

12. Commercial Operation. The Project (a) has commenced commercial operation and has satisfied the requirements for "substantial completion" (or term of similar import) as defined in and in accordance with all Construction Contracts and the initial Electrical Capacity (as specified in the definition thereof) of the Project has been certified by an Independent Engineer, (b) has safely and reliably energized and energy may be delivered across the Project Facilities to SPP's, MISO's and TVA's transmission systems in accordance with the Interconnection Agreements and (c) otherwise complies with the design criteria, system performance and testing requirements and operating standards set forth in the Permitted Project Investment and the Clean Line Parties have delivered to the Permitted Project Investment counterparty a certificate certifying, or the Permitted Project Investment counterparty has approved, the same.

13. Legal Opinion. Delivery by the Clean Line Parties to the Permitted Project Investment counterparty of an opinion of legal counsel that all Governmental Approvals required for the Clean Line Parties to own, construct and operate the Project and to perform their respective obligations under the Permitted Project Investment (and any related agreements) have been obtained.

<u>Part B</u>

Acceptable Transmission Services Agreements delivered pursuant to Sections 6.2(a)(iv), 6.2(b)(ii), 6.3(a)(v), 6.3(b)(ii) and 6.4(a)(ii) of the Agreement shall not be terminated before the end of the term except as set forth below:

1. <u>Failure to Perform</u>. The Acceptable Counterparty shall have the right to terminate in the event another party to the Acceptable Transmission Services Agreement has failed to perform a material obligation under the Acceptable Transmission Services Agreement and the other party has not cured such failure within a reasonable period of time.

DAVIS-BACON ACT REQUIREMENTS

SECTION 1.

(a) Minimum wages.

(i) All laborers and mechanics employed or working upon the site of the work (or under the United States Housing Act of 1937 or under the Housing Act of 1949 in the construction or development of the project), will be paid unconditionally and not less often than once a week, and without subsequent deduction or rebate on any account (except such payroll deductions as are permitted by regulations issued by the Secretary of Labor under the Copeland Act (29 CFR part 3)), the full amount of wages and bona fide fringe benefits (or cash equivalents thereof) due at time of payment computed at rates not less than those contained in the wage determination of the Secretary of Labor which is attached hereto and made a part hereof, regardless of any contractual relationship which may be alleged to exist between the contractor and such laborers and mechanics.

Contributions made or costs reasonably anticipated for bona fide fringe benefits under section 1(b)(2) of the Davis-Bacon Act on behalf of laborers or mechanics are considered wages paid to such laborers or mechanics, subject to the provisions of Section 1(a)(iv) of this Schedule 15; also, regular contributions made or costs incurred for more than a weekly period (but not less often than quarterly) under plans, funds, or programs which cover the particular weekly period, are deemed to be constructively made or incurred during such weekly period. Such laborers and mechanics shall be paid the appropriate wage rate and fringe benefits on the wage determination for the classification of work actually performed, without regard to skill, except as provided in Section 1(d) below. Laborers or mechanics performing work in more than one classification may be compensated at the rate specified for each classification for the time actually worked therein; provided, that the employer's payroll records accurately set forth the time spent in each classification in which work is performed. The wage determination (including any additional classification and wage rates conformed under Section 1(a)(ii) of this Schedule 15) and the Davis-Bacon poster (WH–1321) shall be posted at all times by the contractor and its subcontractors at the site of the work in a prominent and accessible place where it can be easily seen by the workers.

(ii) (A) The contracting officer shall require that any class of laborers or mechanics, including helpers, which is not listed in the wage determination and which is to be employed under the contract shall be classified in conformance with the wage determination. The contracting officer shall approve an additional classification and wage rate and fringe benefits therefore only when the following criteria have been met:

(1) The work to be performed by the classification requested is not performed by a classification in the wage determination;

(2) The classification is utilized in the area by the construction industry; and

(3) The proposed wage rate, including any bona fide fringe benefits, bears a reasonable relationship to the wage rates contained in the wage determination.

(B) If the contractor and the laborers and mechanics to be employed in the classification (if known), or their representatives, and the contracting officer agree on the classification and wage rate (including the amount designated for fringe benefits where appropriate), a report of the action taken shall be sent by the contracting officer to the Administrator of the Wage and Hour Division, Employment Standards Administration, U.S. Department of Labor, Washington, DC 20210. The Administrator, or an authorized representative, will approve, modify, or disapprove every additional classification action within 30 days of receipt and so advise the contracting officer or will notify the contracting officer within the 30-day period that additional time is necessary.

(C) In the event the contractor, the laborers or mechanics to be employed in the classification or their representatives, and the contracting officer do not agree on the proposed classification and wage rate (including the amount designated for fringe benefits, where appropriate), the contracting officer shall refer the questions, including the views of all interested parties and the recommendation of the contracting officer, to the Administrator for determination. The Administrator, or an authorized representative, will issue a determination within 30 days of receipt and so advise the contracting officer or will notify the contracting officer within the 30-day period that additional time is necessary.

(D) The wage rate (including fringe benefits where appropriate) determined pursuant to Sections 1(a)(ii)(B) or (C) of this Schedule 15, shall be paid to all workers performing work in the classification under this contract from the first day on which work is performed in the classification.

(iii) Whenever the minimum wage rate prescribed in the contract for a class of laborers or mechanics includes a fringe benefit which is not expressed as an hourly rate, the contractor shall either pay the benefit as stated in the wage determination or shall pay another bona fide fringe benefit or an hourly cash equivalent thereof.

(iv) If the contractor does not make payments to a trustee or other third person, the contractor may consider as part of the wages of any laborer or mechanic the amount of any costs reasonably anticipated in providing bona fide fringe benefits under a plan or program; provided, that the Secretary of Labor has found, upon the written request of the contractor, that the applicable standards of the Davis-Bacon Act have been met. The Secretary of Labor may require the contractor to set aside in a separate account assets for the meeting of obligations under the plan or program.

(b) Withholding. The Department of Energy shall upon its own action or upon written request of an authorized representative of the Department of Labor withhold or cause to be withheld from the contractor under this contract or any other Federal contract with the same prime contractor, or any other federally-assisted contract subject to Davis-Bacon prevailing wage requirements, which is held by the same prime contractor, so much of the accrued payments or advances as may be considered necessary to pay laborers and mechanics, including apprentices, trainees, and helpers, employed by the contractor or any subcontractor the full amount of wages required by the contract. In the event of failure to pay any laborer or mechanic, including any apprentice, trainee, or helper, employed or working on the site of the work (or under the United States Housing Act of 1937 or under the Housing Act of 1949 in the construction or development of the project), all or part of the wages required by the contract, the Department of Energy may, after written notice to the contractor, sponsor, applicant, or owner, take such action as may be necessary to cause the suspension of any further payment, advance, or guarantee of funds until such violations have ceased.

(c) Payrolls and basic records.

(i) Payrolls and basic records relating thereto shall be maintained by the contractor during the course of the work and preserved for a period of three years thereafter for all laborers and mechanics working at the site of the work (or under the United States Housing Act of 1937, or under the Housing Act of 1949, in the construction or development of the project). Such records shall contain the name, address, and social security number of each such worker, his or her correct classification, hourly rates of wages paid (including rates of contributions or costs anticipated for bona fide fringe benefits or cash equivalents thereof of the types described in section 1(b)(2)(B) of the Davis-Bacon Act), daily and weekly number of hours worked, deductions made and actual wages paid. Whenever the Secretary of Labor has found under 29 CFR 5.5(a)(1)(iv) that the wages of any laborer or mechanic include the amount of any costs reasonably anticipated in providing benefits under a plan or program described in section 1(b)(2)(B) of the Davis-Bacon Act, the contractor shall maintain records which show that the commitment to provide such benefits is enforceable, that the plan or program is financially responsible, and that the plan or program has been communicated in writing to the laborers or mechanics affected, and records which show the costs anticipated or the actual cost incurred in providing such benefits. Contractors employing apprentices or trainees under approved programs shall maintain written evidence of the registration of apprenticeship programs and certification of trainee programs, the registration of the apprentices and trainees, and the ratios and wage rates prescribed in the applicable programs.

(ii) (A) The contractor shall submit weekly for each week in which any contract work is performed a copy of all payrolls to the (write in name of appropriate federal agency) if the agency is a party to the contract, but if the agency is not such a party, the contractor will submit the payrolls to the applicant, sponsor, or owner, as the case may be, for transmission to the Department of Energy. The payrolls submitted shall set out accurately and completely all of the information required to be maintained under Section 1(c)(i) of this Schedule 15, except that full social security numbers and home addresses shall not be included on weekly transmittals. Instead the payrolls shall only need to include an individually identifying number for each employee (e.g., the last four digits of the employee's social security number). The required weekly payroll information may be submitted in any form desired. Optional Form WH–347 is available for this purpose from the Wage and Hour Division Web site at http://www.dol.gov/esa/whd/forms/wh347instr.htm or its successor site. The prime contractor is responsible for the submission of copies of payrolls by all subcontractors. Contractors and subcontractors shall maintain the full social security number and current address of each covered worker, and shall provide them upon request to the (write in name of appropriate federal agency) if the agency is a party to the contract, but if the agency is not such a party, the contractor will submit them to the applicant, sponsor, or owner, as the case may be, for transmission to theDepartment of Energy, the contractor, or the Wage and Hour Division of the Department of Labor for purposes of an investigation or audit of compliance with prevailing wage requirements. It is not a violation of this Section 1(c)(ii)(A) of this Schedule 15 for a prime contractor to require a subcontractor to provide addresses and social security numbers to the prime contractor for its own records, without weekly submission to the sponsoring government agency (or the applicant, sponsor, or owner).

(B) Each payroll submitted shall be accompanied by a "Statement of Compliance," signed by the contractor or subcontractor or his or her agent who pays or supervises the payment of the persons employed under the contract and shall certify the following:

(1) That the payroll for the payroll period contains the information required to be provided under Section 1(c)(ii) of this Schedule 15, the appropriate information is being maintained under Section 1(c)(i) of this Schedule 15, and that such information is correct and complete;

(2) That each laborer or mechanic (including each helper, apprentice, and trainee) employed on the contract during the payroll period has been paid the full weekly wages earned, without rebate, either directly or indirectly, and that no deductions have been made either directly or indirectly from the full wages earned, other than permissible deductions as set forth in Regulations, 29 CFR part 3;

(3) That each laborer or mechanic has been paid not less than the applicable wage rates and fringe benefits or cash equivalents for the classification of work performed, as specified in the applicable wage determination incorporated into the contract.

(C) The weekly submission of a properly executed certification set forth on the reverse side of Optional Form WH– 347 shall satisfy the requirement for submission of the “Statement of Compliance” required by Section 1(c)(ii)(B) of this Schedule 15.

(D) The falsification of any of the above certifications may subject the contractor or subcontractor to civil or criminal prosecution under section 1001 of title 18 and section 231 of title 31 of the United States Code.

(iii) The contractor or subcontractor shall make the records required under Section 1(c)(i) of this Schedule 15 available for inspection, copying, or transcription by authorized representatives of the Department of Energy or the Department of Labor, and shall permit such representatives to interview employees during working hours on the job. If the contractor or subcontractor fails to submit the required records or to make them available, the Department of Energy may, after written notice to the contractor, sponsor, applicant, or owner, take such action as may be necessary to cause the suspension of any further payment, advance, or guarantee of funds. Furthermore, failure to submit the required records upon request or to make such records available may be grounds for debarment action pursuant to 29 CFR 5.12.

(d) Apprentices and trainees.

(i) Apprentices. Apprentices will be permitted to work at less than the predetermined rate for the work they performed when they are employed pursuant to and individually registered in a bona fide apprenticeship program registered with the U.S. Department of Labor, Employment and Training Administration, Office of Apprenticeship Training, Employer and Labor Services, or with a State Apprenticeship Agency recognized by the Office, or if a person is employed in his or her first 90 days of probationary employment as an apprentice in such an apprenticeship program, who is not individually registered in the program, but who has been certified by the Office of Apprenticeship Training, Employer and Labor Services or a State Apprenticeship Agency (where appropriate) to be eligible for probationary employment as an apprentice. The allowable ratio of apprentices to journeymen on the job site in any craft classification shall not be greater than the ratio permitted to the contractor as to the entire work force under the registered program. Any worker listed on a payroll at an apprentice wage rate, who is not registered or otherwise employed as stated above, shall be paid not less than the applicable wage rate on the wage determination for the classification of work actually performed. In addition, any apprentice performing work on the job site in excess of the ratio permitted under the registered program shall be paid not less than the applicable wage rate on the wage determination for the work actually performed. Where a contractor is performing construction on a project in a locality other than that in which its program is registered, the ratios and wage rates (expressed in percentages of the journeyman’s hourly rate) specified in the contractor’s or subcontractor’s registered program shall be observed. Every apprentice must be paid at not less than the rate specified in the registered program for the apprentice's level of progress, expressed as a percentage of the journeymen hourly rate specified in the applicable wage determination. Apprentices shall be paid fringe benefits in accordance with the provisions of the apprenticeship program. If the apprenticeship program does not specify fringe benefits, apprentices must be paid the full amount of fringe benefits listed on the wage determination for the applicable classification. If the Administrator determines that a different practice prevails for the applicable apprentice classification, fringes shall be paid in accordance with that determination. In the event the Office of Apprenticeship Training, Employer and Labor Services, or a State Apprenticeship Agency recognized by the Office, withdraws approval of an apprenticeship program, the contractor will no longer be permitted to utilize apprentices at less than the applicable predetermined rate for the work performed until an acceptable program is approved.

(ii) Trainees. Except as provided in 29 CFR 5.16, trainees will not be permitted to work at less than the predetermined rate for the work performed unless they are employed pursuant to and individually registered in a program which has received prior approval, evidenced by formal certification by the U.S. Department of Labor, Employment and Training Administration. The ratio of trainees to journeymen on the job site shall not be greater than permitted under the plan approved by the Employment and Training Administration. Every trainee must be paid at not less than the rate specified in the approved program for the trainee's level of progress, expressed as a percentage of the journeyman hourly rate specified in the applicable wage determination. Trainees shall be paid fringe benefits in accordance with the provisions of the trainee program. If the trainee program does not mention fringe benefits, trainees shall be paid the full amount of fringe benefits listed on the wage determination unless the Administrator of the Wage and Hour Division determines that there is an apprenticeship program associated with the corresponding journeyman wage rate on the wage determination which provides for less than full fringe benefits for apprentices. Any employee listed on the payroll at a trainee rate who is not registered and participating in a training plan approved by the Employment and Training Administration shall be paid not less than the applicable wage rate on the wage determination for the classification of work actually performed. In addition, any trainee performing work on the job site in excess of the ratio permitted under the registered program shall be paid not less than the applicable wage rate on the wage determination for the work actually performed. In the event the Employment and Training Administration withdraws approval of a training program, the contractor will no longer be permitted to utilize trainees at less than the applicable predetermined rate for the work performed until an acceptable program is approved.

(iii) Equal employment opportunity. The utilization of apprentices, trainees and journeymen under this part shall be in conformity with the equal employment opportunity requirements of Executive Order 11246, as amended, and 29 CFR part 30.

(e) Compliance with Copeland Act requirements. The contractor shall comply with the requirements of 29 CFR part 3, which are incorporated by reference in this contract.

(f) Subcontracts. The contractor or subcontractor shall insert in any subcontracts the clauses contained in Sections 1(a) through (j) of this Schedule 15 and such other clauses as the Department of Energy may by appropriate instructions require, and also a clause requiring the subcontractors to include these clauses in any lower tier subcontracts. The prime contractor shall be responsible for the compliance by any subcontractor or lower tier subcontractor with all the contract clauses in 29 CFR 5.5.

(g) Contract termination: debarment. A breach of the contract clauses in 29 CFR 5.5 may be grounds for termination of the contract, and for debarment as a contractor and a subcontractor as provided in 29 CFR 5.12.

(h) Compliance with Davis-Bacon and Related Act requirements. All rulings and interpretations of the Davis-Bacon and Related Acts contained in 29 CFR parts 1, 3, and 5 are herein incorporated by reference in this contract.

(i) Disputes concerning labor standards. Disputes arising out of the labor standards provisions of this contract shall not be subject to the general disputes clause of this contract. Such disputes shall be resolved in accordance with the procedures of the Department of Labor set forth in 29 CFR parts 5, 6, and 7. Disputes within the meaning of this clause include disputes between the contractor (or any of its subcontractors) and the contracting agency, the U.S. Department of Labor, or the employees or their representatives.

(j) Certification of eligibility.

(i) By entering into this contract, the contractor certifies that neither it (nor he or she) nor any person or firm who has an interest in the contractor’s firm is a person or firm ineligible to be awarded Government contracts by virtue of section 3(a) of the Davis-Bacon Act or 29 CFR 5.12(a)(1).

(ii) No part of this contract shall be subcontracted to any person or firm ineligible for award of a Government contract by virtue of section 3(a) of the Davis-Bacon Act or 29 CFR 5.12(a)(1).

(iii) The penalty for making false statements is prescribed in the U.S. Criminal Code, 18 U.S.C. 1001.

SECTION 2.

(a) Overtime Requirements. No contractor or subcontractor contracting for any part of the contract work which may require or involve the employment of laborers or mechanics shall require or permit any such laborer or mechanic in any workweek in which he or she is employed on such work to work in excess of forty hours in such workweek unless such laborer or mechanic receives compensation at a rate not less than one and one-half times the basic rate of pay for all hours worked in excess of forty hours in such workweek.

(b) Violation; liability for unpaid wages; liquidated damages. In the event of any violation of the clause set forth in Section 2(a) of this Schedule 15 the contractor and any subcontractor responsible therefor shall be liable for the unpaid wages. In addition, such contractor and subcontractor shall be liable to the United States (in the case of work done under contract for the District of Columbia or a territory, to such District or to such territory), for liquidated damages. Such liquidated damages shall be computed with respect to each individual laborer or mechanic, including watchmen and guards, employed in violation of the clause set forth in Section 2(a) of this Schedule 15, in the sum of $10 for each calendar day on which such individual was required or permitted to work in excess of the standard workweek of forty hours without payment of the overtime wages required by the clause set forth in Section 2(a) of this Schedule 15.

(c) Withholding for unpaid wages and liquidated damages. The Department of Energy shall upon its own action or upon written request of an authorized representative of the Department of Labor withhold or cause to be withheld, from any moneys payable on account of work performed by the contractor or subcontractor under any such contract or any other Federal contract with the same prime contractor, or any other federally-assisted contract subject to the Contract Work Hours and Safety Standards Act, which is held by the same prime contractor, such sums as may be determined to be necessary to satisfy any liabilities of such contractor or subcontractor for unpaid wages and liquidated damages as provided in the clause set forth in Section 2(b) of this Schedule 15.

(d) Subcontracts. The contractor or subcontractor shall insert in any subcontracts the clauses set forth in Sections 2(a) through (d) of this Schedule 15 and also a clause requiring the subcontractors to include these clauses in any lower tier subcontracts. The prime contractor shall be responsible for compliance by any subcontractor or lower tier subcontractor with the clauses set forth in Sections 2(a) through (d) of this Schedule 15.

Schedule 16
to Participation Agreement

Required Approvals

1. Section 1222 Decision

CLEAN LINE UNIFORM ACT EXECUTION PLAN

The following materials set out the guidelines and procedures that the Clean Line Entities will follow for acquisition of Project Real Estate Rights in a manner that meets the requirements of the Uniform Act.

INDEX

I. Market Data Studies and Determination of Average Fair Market Per Acre Value

Market data studies, from a qualified real estate appraisal firm, either have been or will be ordered during the course of the Project to assist in determining the current market value of the land along the proposed route for the Project.

1. The Clean Line Entities will engage a real estate appraisal firm with experience in linear infrastructure projects (the "Appraisal Firm") to perform county-wide market data studies, appraisals and other related tasks, all consistent with the standards set forth in the Uniform Standards of Professional Appraisal Practice ("USPAP"). The Clean Line Entities will provide the Appraisal Firm with the list of counties traversed by the Project Area ROW (as defined below). The Appraisal Firm will provide property sales data within such counties to establish fair market value of various land types for the parcels on which the Clean Line Entities would like to pursue easement acquisition (the "Project Area ROW").

2. The Appraisal Firm will review and compile all of the relevant recent property sales within the county, for each county traversed by the Project Area ROW.

3. In addition to its review and compilation of the sales data for each county, the Appraisal Firm will analyze the sales data to determine property value trends. For example, in Texas County, Oklahoma, the Appraisal Firm determined that land value trends were based not just on the land use, but also on land parcel size.

4. Based on the sales data collection and analysis conducted by the Appraisal Firm, the Clean Line Entities and a second qualified party (the "Market Data Analyst")[1] will review all of the data provided and determine the average per acre value for specific land types within each county.[2] The Market Data Analyst will have sufficient understanding of real estate valuation in general, knowledge of the real estate market within the geographic areas where the Project Area ROW is located in particular, and experience with easement acquisition under the Uniform Act. Generally the Market Data Analyst will review only the sales data for the most recent 12 months, unless there is insufficient data for that period, in which case the Market Data Analyst will review the sales data for

[1] The original market analysis was performed by Contract Land Staff, a national ROW acquisition firm with experience in acquiring right-of-way ("ROW") for linear infrastructure projects throughout the United States and Canada, including several projects that involved ROW acquisition under the Uniform Act. Clean Line may engage Contract Land Staff, or other experienced acquisition firms to manage the ROW acquisition on the Project under the direction of Clean Line's Vice President of Land. Other Market Data Analysts may be used from time to time to provide updated analysis of the market data, provided, however, in all events all such Market Data Analysts must be similarly qualified and will be supervised by the Clean Line Entities.

[2] Land types may differ in each county (depending on the terrain and typical uses of land within the county) but some examples of typical land use types encountered are crop, pasture, timber, residential, hobby farm, etc.

the most recent three years to determine the average historical per acre value.[3] Once an average historical per acre value is determined for each land use type in the county, those per acre values will be increased by ten percent (10%). The resulting per acre value will be used as the average fair market value for each land use type within each county (the "Average Fair Market Per Acre Value").

5. The Average Fair Market Per Acre Value for each land use type within in each county will be used as part of the process of determining which parcels crossed by the Project Area ROW may qualify as Waiver Parcels, as described in Section III below.

6. The Clean Line Entities will analyze, and update if necessary, the sales data and market data analysis from time to time as land values increase or decrease in order to determine if the Average Fair Market Value for each land type should change.

[3] When reviewing sales data for both the previous 12 months and 36 months, the Market Data Analyst will compare the averages of sales within each such period and will use the average value that is higher.

II. Initial Notice to Landowners

Consistent with § 24.102(b) of the Uniform Act, the Clean Line Entities will notify potentially affected landowners in writing of their interest in acquiring an easement.[4]

1. Prior to the initiation of formal negotiations with landowners, the Clean Line Entities will provide notice of their intent to acquire an easement (the "Formal Notice Letter"); such notification will also include a summary of the basic protections provided to the landowner under the Uniform Act (the "Landowner Brochure"). The Formal Notice and Landowner Brochure will either be hand delivered to the landowner by land agents of the ROW acquisition company (the "Land Agent") or employees of the Clean Line Entities or mailed via certified mail, return receipt requested, or mailed via registered mail. Once delivered, a copy of the Formal Notice Letter will be placed in the office file for the landowner tract.

2. The Formal Notice Letter will be written in English in plain, understandable language and will include the name and telephone number of a person who may be contacted for answers to questions or if additional assistance is needed.

3. As part of each Formal Notice Letter, the Clean Line Entities will offer foreign-speaking landowners and any other landowners requiring special assistance, appropriate resources to enable the landowner to read and understand the Formal Notice Letter, as well as any subsequent communications and proposed easement terms. If a Land Agent determines upon first contact with a landowner that the landowner does not speak or read English, or requires any other form of special assistance, the Land Agent will notify the Clean Line Entities, and the Clean Line Entities will ensure that a trained agent or employee is available to assist the landowner as needed.

[4] The Clean Line Entities will also take appropriate steps, consistent with the Uniform Act, to notify and engage with tenants where acquisition of the easement would affect any tenant rights or tenant-owned property.

III. Appraisal Waiver - Valuation Review

The Uniform Act provides that an appraisal is not required for parcels that: (i) have an anticipated easement acquisition cost of $10,000 or less, and (ii) for which the valuation analysis is uncomplicated. If both criteria are met, the parcel will be deemed a "Waiver Parcel".

Clean Line will review the parcels within the Project Area ROW to determine if any such parcels meet the criteria for waiving an appraisal ("Waiver Valuation Review"). The Waiver Valuation Review will be performed by the Market Data Analyst or other qualified party designated by the Clean Line Entities (the "Valuation Reviewer"). The Valuation Reviewer will have sufficient understanding of real estate valuation in general, knowledge of the real estate market within the geographic areas where the Project Area ROW is located in particular, and experience with waiver valuation under the Uniform Act. The Waiver Valuation Review process and criteria for designation of a Waiver Parcel is further described below.

1. Determination of easement compensation of $10,000 or less.

    (a) The Valuation Reviewer will first determine whether contiguous individual tax parcels within the Project Area ROW should be combined or merged into a single parcel for purposes of the Waiver Valuation Review. This process will be performed by utilizing the merge function from the land tracking software (the "Land Database")[5]. The merge function groups multiple contiguous tax parcels owned by the same person (by name and address) within the same county into one larger single tract.

    (b) Next, the Valuation Reviewer will review aerial imagery maps to determine if multiple tax parcels in common ownership are also in common use (i.e., being farmed as one contiguous parcel). If the Valuation Reviewer has determined that multiple tax parcels are in both common ownership and common use, then the multiple tax parcels will be combined into one parcel for the purpose of evaluating whether such parcel meets the $10,000 threshold for a Waiver Parcel.

    (c) Finally, the Valuation Reviewer will multiply the total acreage of the easement sought over the newly combined parcel by the county Average Fair Market Per Acre Value for the parcel's land type to determine if the total fair market value for the easement over such parcel is $10,000 or less. If the value is $10,000 or less, then the parcel will have met the first of the two requirements to be treated as a Waiver Parcel.

[5] The Land Database is used to track, among many other things, names, addresses, tax parcel numbers, contacts, statuses, activity notes, etc., for each of the parcels within the Project Area ROW.

2. Determination if the valuation analysis is uncomplicated. The Valuation Reviewer will consider the following criteria to determine if the valuation analysis is uncomplicated:

   (a) Is the acquisition of the parcel simple (i.e., a fee purchase vs. an easement purchase)?
   (b) What are the damages, if any, to the remainder of the landowner's property?
   (c) Are there any buildings, structures or improvements located in the easement area?
   (d) Will the acquisition involve any relocation?

   If the valuation analysis is determined to be uncomplicated, then the parcel has met the second requirement to be treated as a Waiver Parcel.

3. Once the Valuation Reviewer determines that a parcel has met the two requirements for a Waiver Parcel, the Valuation Reviewer will indicate that the parcel is qualified as a Waiver Parcel on the Land Offer Summary spreadsheet, which is described in further detail in Section IV below.

4. In accordance with § 24.102(c)(2)(ii)(C) of the Uniform Act, the Clean Line Entities may approve exceeding the $10,000 threshold for a Waiver Parcel, up to a maximum of $25,000, provided that the Clean Line Entities offer the landowner the option of having the Clean Line Entities obtain an Appraisal (as defined in Section V below) for the parcel. If a Landowner requests an Appraisal for any parcel where the easement is valued between $10,000 and $25,000, then the Clean Line Entities shall obtain an Appraisal.

IV. Determining Settlement Offer Amounts for Waiver Parcels

1. The Clean Line Entities and the Valuation Reviewer will create a spreadsheet, titled the "Land Offer Summary", for each county that provides the following information for each parcel or the merged/combined parcels:

   (a) Tract Name
   (b) Tax ID Numbers
   (c) Owner Name
   (d) Width and Length of the Easement Area
   (e) Total Acres within the Easement Area
   (f) Average Fair Market Per Acre Value for the applicable land use type (100%—representing the fair market value for fee title)
   (g) Average Fair Market Per Acre Value for the applicable land use type (75%—representing the fair market value for an easement)
   (h) Settlement Offer (see below)
   (i) Notation as to whether the parcel qualifies as a Waiver Parcel
   (j) Notation as to whether an Appraisal is required

   The "Settlement Offer" for each parcel or merged/combined parcel will be derived by multiplying the total acreage of the Easement Area by the applicable Average Fair Market Per Acre Value.[6] Because many parcels are irregular in size and shape (i.e. not a perfect square or rectangle), the total acreage of each parcel shall be calculated by using appropriate software. An example of a Land Offer Summary for Texas County, Oklahoma is attached hereto as Exhibit A.

2. The Valuation Reviewer will prepare a memorandum to file for each county (the "Valuation Memorandum") certifying that the Valuation Reviewer has reviewed the Land Offer Summary and all other relevant background data. The Valuation Memorandum will include at a minimum the following documents:

   (a) A description of the Project as it pertains to the specific county
   (b) The market data study for the county
   (c) Land Offer Summary

[6] The Clean Line Entities have elected to base a Settlement Offer on 100% of fee market value for the subject parcel, even though the acquisition of easement rights is traditionally valued by appraisers between 40 – 90% of fee.

For each Waiver Parcel, the Valuation Reviewer will certify in the Valuation Memorandum that, based on his or her review of the relevant data, that (i) the proposed Settlement Offer represents just compensation for the subject easement, and (ii) an appraisal is unnecessary because the valuation is uncomplicated and the anticipated value of the proposed acquisition is estimated at $10,000 or less (or if applicable, up to $25,000), based on a review of available data. See Exhibit B attached hereto for the form of Valuation Memorandum.

3. The Vice President of Land for the Clean Line Entities will review the findings as determined by the Valuation Reviewer and will sign the Valuation Memorandum to confirm his or her approval of such findings. Upon approval, a status of "Meets Waiver Requirements" will be entered for each Waiver Parcel in the Land Database.[7]

4. An Appraisal will be ordered for any parcel which does not qualify as a Waiver Parcel, as discussed in Section V below.

[7] The Land Database is used for the digital record keeping and tracking of parcels within the Project Area ROW. The Clean Line Entities have created a list of "statuses" within the Land Database in order to easily identify or track parcels that may fall within the same type of category (i.e., "Survey Permission Granted", "Meets Waiver Requirements", "Easement Signed", etc.).

V. Appraisals

Parcels that do not qualify as a Waiver Parcel will require a full appraisal by a state licensed/certified independent real estate appraiser (the "Appraiser"), qualified to conduct appraisals in accordance with the requirements of the Uniform Act. The Appraiser shall not have an interest, direct or indirect, in the property being evaluated.

1. An appraisal will be ordered for each parcel or the merged/combined parcel that does not qualify as a Waiver Parcel (an "Appraisal"). Once an Appraisal is ordered, a status of "Appraisal Ordered" will be entered into the Land Database for the relevant parcel.

2. The Clean Line Entities or the Land Agent will contact the landowner to determine if the landowner would like to accompany the Appraiser during the site inspection of the property. The landowner will be given the opportunity to present information and material for consideration by the Appraiser that the landowner believes is relevant to determining the value of the easement property. All such information and material received from the landowner by the Clean Line Entities , the Land Agent or any other contract employees will be provided to the Appraiser for consideration.

3. The Appraiser will be informed by an employee or representative of the Clean Line Entities (the "Appraisal Coordinator") as to whether the landowner wants to be present during the Appraiser's site inspection of the property.

4. The Appraiser will prepare Appraisals according to and consistent with the requirements of USPAP and relevant state and local requirements. The Appraiser will be provided with the following information before beginning the appraisal process for each parcel or merged/combined parcel:

   (a) Name, address and phone number(s) of the landowner

      i. The Appraiser will contact the landowner if it was determined that the landowner wants to be present during the inspection.
      ii. In the event the landowner cannot be reached via phone or via mail, the Appraiser will contact the Appraisal Coordinator, and the Appraisal Coordinator will communicate with the landowner to determine if the landowner wishes to be present. The Appraisal Coordinator will communicate its findings to the Appraiser in an expeditious manner.

   (b) Vesting deeds or title report, if available

(c) Sketch of the proposed easement area
(d) Sample Easement Agreement

5. Upon completion of the Appraisal, an electronic copy of the Appraisal will be delivered to the Clean Line Entities, the Appraisal Coordinator, and the Review Appraiser (as defined in Section VI below) and a status will be entered into the Land Database of "Appraisal Received."

VI. Review Appraisal Process

A review appraiser ("Review Appraiser") is an appraiser who examines the reports of other appraisers to ascertain whether their conclusions are consistent with the data reports and with other generally known information about the parcel. The Review Appraiser will review and analyze the relevant facts assembled by the Appraiser using reason, judgment, and a review of supporting documentation and drawings in order to form an opinion or conclusion with respect to the findings contained in the Appraisal.

1. The Clean Line Entities will hire a qualified appraiser to act as the Review Appraiser for the Project. The Review Appraiser will (a) be a state-certified real estate appraiser who has past experience and knowledge of appraisals and USPAP guidelines, (b) be familiar with the Project, appraisal reports and the real estate market for the area, and (c) not have any interest, direct or indirect, in the property being evaluated for the easement. The Review Appraiser will do a desk review property inspection of the property covered by the Appraisal.

2. At a minimum, in the evaluation of the Appraisal, the Review Appraiser will:

   (a) Read the Appraisal in its entirety, taking notes on items which may require further evaluation
   (b) Review the current alignment of the subject parcel and legal description
   (c) Review and analyze the appraised value in light of comparable sales data used in the analysis
   (d) Review aerial maps of the property
   (e) Check calculations in the report for accuracy
   (f) Evaluate appraisal principle application and techniques
   (g) Determine if the facts cited in the Appraisal are correct and the approaches and sales data that were used to determine value are reasonable
   (h) Determine if the Appraiser appropriately applied the tests of highest and best use,
   (i) Ensure that the Appraisal follows the requirements set forth in the Uniform Act
   (j) Understand and ensure that any special valuation peculiarities are identified and that they are justified and reasonable
   (k) Ensure compliance with the Clean Line Entities' policies and requirements

3. Upon conclusion of the detailed review, the Review Appraiser will sign a statement certifying that (a) he or she made a thorough and detailed analysis of the Appraisal, (b) he or she either agrees or disagrees with the content and facts, and (c) the Appraisal is in compliance with USPAP and other applicable standards. If the Review Appraiser

requires corrections or revisions, they will be outlined in the Technical Review Report (as defined below). Finally, the Review Appraiser will either accept the contents and comments of the Appraisal or will disapprove the Appraisal. The two possible conclusions of the Review Appraiser are:

(a) Approval – the Appraiser approves the Appraisal as written.
(b) Disapproval – the Appraisal does not meet with the acceptable standards for a specific reason(s) such as content, valuation or other conditions as delineated in a Technical Review Report.

4. The Review Appraiser will prepare a "Technical Review Report" and document the validity and findings of the Appraisal. Examples of Technical Review Reports are attached hereto as Exhibit C and Exhibit D.

5. A status in the Land Database will be entered of either "Review Appraisal Approved" or "Review Appraisal Denied".

6. In the event that the Review Appraiser rejects the Appraisal, either:

(a) The Appraisal will be sent back to the original Appraiser for revisions based on the appraisal review and then resubmitted through the review process as outlined above; or
(b) A meeting will be held between the Appraiser and Review Appraiser to gather more facts regarding the subject parcel to formalize a joint appraisal analysis.

VII. Landowner Negotiations

Landowners will be treated fairly and consistently across the Project when negotiating for easement rights that affect their property.

A. Landowner Negotiations—Waiver Parcels

1. Employees of the Clean Line Entities or Land Agents[8] will personally contact landowners whenever possible to discuss the Project and how it may impact their property. If any landowner cannot be contacted personally, the Land Agent will deliver the information via First Class Mail (and with respect to the Formal Notice Letter and any final Settlement Offer, via Certified Mail or registered first-class mail—return receipt requested).

2. Following delivery of the Formal Notice Letter, as described in Section II above, Land Agents will contact the landowner to provide the following information:

   (a) The proposed form of Easement Agreement
   (b) A sketch of the easement area on the landowner's property
   (c) A Construction Questionnaire, which is a document designed to obtain information about the property, such as land uses, irrigation, utilities, structures, gates and fences, etc. The Clean Line Entities endeavor to obtain this information early in the development process so that it can be taken into consideration during construction planning.
   (d) A Survey Permission Form that allows the Clean Line Entities to perform surveys (if the landowner had not previously granted the Clean Line Entities survey access rights)
   (e) A compensation worksheet, which provides (i) a description of the size of the easement on the property, (ii) the Settlement Offer, and (iii) how such Settlement Offer was calculated (the "Easement Calculation Worksheet"). The form of Easement Calculation Worksheet is attached hereto as Exhibit E.
   (f) A Structure and Damages Calculation Worksheet
   (g) A copy of the Clean Line Entites' Code of Conduct
   (h) In Texas, the Landowner Bill of Rights
   (i) In Oklahoma, a full and complete copy of (i) the Private Rights Settlement Agreement dated January 14, 2011, and (ii) the Oklahoma Corporation Commission's October 28, 2011 order approving Plains and Eastern Clean Line Oklahoma LLC's application to conduct business as a public utility in Oklahoma

[8] In some instances contact or negotiations with the landowner may be performed by Clean Line employees, rather than Land Agents; as used hereinafter, the term "Land Agent" shall be deemed to include, when applicable, employees of Clean Line.

3. When meeting with a landowner, the Land Agent will make every reasonable effort to: (a) discuss the Settlement Offer, including explanations as to the basis for the Settlement Offer, (b) explain the Project, (c) explain the Clean Line Entities' policies and procedures (including payment of incidental expenses when applicable), and (d) generally be available to answer any questions or concerns expressed by the landowner. The landowner will be given reasonable opportunity to consider the Settlement Offer and present material which the landowner believes relevant to determining the value of the easement property and to suggest modifications in the proposed terms and conditions of the easement. Land Agents and Clean Line will give full and fair consideration to landowner's comments and suggestions. Land Agents will not use coercive action to induce an agreement on price or terms. Land Agents will exhaust all reasonable negotiations with landowners and will strive to come to voluntary agreement with all landowners.

4. In the event that the Clean Line Entities or the Land Agent determines that there is a tenant on the property, the Land Agent will contact the tenant to discuss tenant-related issues and will ensure that the tenant is compensated for crops or other tenant-owned property as required under the Uniform Act.

5. When the landowner accepts the Settlement Offer, the landowner and the Clean Line Entities will execute the following documents:

   (a) Easement Agreement
   (b) Easement Calculation Worksheet
   (c) Structure and Damages Calculation Worksheet

6. Land Agents will document in the Land Database a summary of all contacts and interactions made with landowners, tenants and other interested parties with respect to each parcel or merged/combined parcel of land within the Project Area ROW.

7. Statuses will be entered in the Land Database to track the following information:

   (a) Date the offer was made to the landowner
   (b) Amount of the offer
   (c) Any landowner counter offers
   (d) Date the Easement Agreement was signed by the landowner
   (e) Amount of the check written
   (f) Amount of the balance payment due, if any
   (g) Date that the balance payment is due, if applicable

B. Landowner Negotiations—Appraisal Parcels

1. Land Agents will personally contact landowners whenever possible to discuss the Project and how it may impact their property. If any landowner cannot be contacted personally, the Land Agent will deliver the information via First Class Mail (and with respect to the Formal Notice Letter and any final Settlement Offer, via Certified Mail or registered first-class mail—return receipt requested).

2. Following delivery of the Formal Notice Letter, as described in Section II above, Land Agents will contact the landowner to provide the following information:

   (a) The proposed form of Easement Agreement
   (b) A sketch of the easement area on the landowner's property
   (c) A Construction Questionnaire, which is a document designed to obtain information about the property, such as land uses, irrigation, utilities, structures, gates and fences, etc. The Clean Line Entites endeavor to obtain this information early in the development process so that it can be taken into consideration during construction planning.
   (d) A Survey Permission Form that allows the Clean Line Entities to perform surveys (if the landowner had not previously granted the Clean Line Entities survey access rights)
   (e) A Structure and Damages Calculation Worksheet
   (f) A copy of Clean Line's Code of Conduct
   (g) In Texas, the Landowner Bill of Rights
   (h) In Oklahoma, a full and complete copy of (i) the Private Rights Settlement Agreement dated January 14, 2011, and (ii) the Oklahoma Corporation Commission's October 28, 2011 order approving Plains and Eastern Clean Line Oklahoma LLC's application to conduct business as a public utility in Oklahoma.

3. The Land Agent will ask the landowner if they want to be present during any on-site inspections of the property with the Appraiser. The Land Agent will document in the Land Database the requirement of either "Wishes to Accompany the Appraiser" or "Does Not Wish to be Present for Appraisal On-site Inspections". If the landowner does not wish to be present for any on-site inspections, the Land Agent will request that the landowner sign another Survey Permission Form that acknowledges that they have waived this right to accompany the Appraiser.

4. In the event the landowner wishes to be present during the Appraisal, the Appraiser will notify the landowner of the date and time of the site inspection. The Appraisal is performed on the property by a state certified/licensed Appraiser (refer to Section V above for more detail).

5. When the Appraisal is completed, the Land Agent will meet with the landowner and present the following documents:

   (a) Copy of the Appraisal
   (b) The Easement Calculation Worksheet.

6. When meeting with a landowner, the Land Agent will make every reasonable effort to: (a) discuss the Settlement Offer, including explanations as to the basis for the Settlement Offer of just compensation, (b) explain the Project, (c) explain the Clean Line Entities' policies and procedures (including payment of incidental expenses when applicable) and (d) generally be available to answer any questions or concerns expressed by the landowner. The landowner will be given reasonable opportunity to consider the Settlement Offer and present material which the landowner believes relevant to determining the value of the easement property and to suggest modifications in the proposed terms and conditions of the easement. Land Agents and the Clean Line Entities will give full and fair consideration to landowner's comments and suggestions. Land Agents will not use coercive action to induce an agreement on price or terms. Land Agents will exhaust all reasonable negotiations with landowners and will strive to come to voluntary agreement with all landowners.

7. In the event that the Clean Line Entities or the Land Agent determines that there is a tenant on the property, the Land Agent will contact the tenant to discuss any crops or other tenant-owned property and will ensure that the tenant is compensated for crops or other tenant-owned property as required under the Uniform Act.

8. When the landowner accepts the Settlement Offer, the landowner and Clean Line will execute the following documents:

   (a) Easement Agreement
   (b) Easement Calculation Worksheet
   (c) Structure and Damages Calculation Worksheet

9. Land Agents will document, in the Land Database, a summary of all contacts and interactions made with landowners, tenants and other interested parties with respect to each parcel or merged/combined parcel of land within the Project Area ROW.

10. Statuses will be entered in the Land Database to track the following information:

   (a) Date the offer was made to the landowner
   (b) Amount of the offer
   (c) Any landowner counter offers

(d) Date the Easement Agreement was signed
(e) Amount of the check written
(f) Amount of the balance payment due, if any
(g) Date that the balance payment is due, if applicable

VIII. RELOCATIONS

At this time the Clean Line Entities do not anticipate that any residences or persons will be relocated as a result of the Project. In the event circumstances change and relocation is required, the Clean Line Entities will draft policies and procedures that follow the Uniform Act for this process.

IX. EXHIBITS

Exhibit A – Land Offer Summary (example)
Exhibit B – Valuation Memorandum (form)
Exhibit C – Technical Review Report (example)
Exhibit D – Technical Review Report (example)
Exhibit E – Easement Calculation Worksheet- (form)

OK-TE Land Offer Summary 11/5/2015

TractName	Actual Width (150ft corridor)	Length	Easement Acres	Fee Price Per Acre	Settlement Price Per Acre	75% Easement Offer	Settlement Offer	Qualified for Waiver	Appraisal Per CLE	Date Last Reviewed for Waivers
OK-TE-002.000	150	5251	18	$2,500	$2,500	$33,903	$45,204	**No**	**Yes**	4/16/2015
OK-TE-003.000	150	4931	17	$2,500	$2,500	$31,830	$42,440	**No**	**Yes**	4/16/2015
OK-TE-004.000	150	2701	9	$2,500	$2,500	$17,435	$23,247	**No**	**Yes**	4/16/2015
OK-TE-005.000	146	295	1	$2,500	$2,500	$1,856	$2,475	**No**	**Yes**	4/16/2015
OK-TE-006.000	150	5224	18	$2,500	$2,500	$33,731	$44,975	**No**	**Yes**	4/16/2015
OK-TE-009.000	150	2624	9	$2,500	$2,500	$16,945	$22,594	**No**	**Yes**	4/16/2015
OK-TE-011.000	150	2624	9	$1,760	$1,760	$11,930	$15,906	**No**	**Yes**	4/16/2015
OK-TE-013.000	150	2615	9	$1,760	$1,760	$11,885	$15,847	**No**	**Yes**	4/16/2015
OK-TE-014.000	14	1856	1	$840	$840	$365	$487	**No**	**Yes**	4/16/2015
OK-TE-015.000	144	2615	9	$1,760	$1,760	$11,409	$15,212	**No**	**Yes**	4/16/2015
OK-TE-016.000	150	5189	18	$840	$840	$11,258	$15,011	**No**	**Yes**	4/16/2015
OK-TE-017.000	13	1832	1	$840	$840	$355	$473	**No**	**Yes**	4/16/2015
OK-TE-019.000	150	2608	9	$840	$840	$5,658	$7,544	**No**	**Yes**	4/16/2015
OK-TE-021.000	150	2608	9	$840	$840	$5,658	$7,544	**Yes**	**Yes**	4/16/2015
OK-TE-023.000	150	5085	18	$840	$840	$11,031	$14,708	**No**	**No**	4/16/2015
OK-TE-025.000	150	2883	10	$840	$840	$6,255	$8,340	**No**	**Yes**	4/16/2015
OK-TE-026.000	150	5205	18	$840	$840	$11,291	$15,054	**No**	**Yes**	4/16/2015
OK-TE-028.000	150	2614	9	$840	$840	$5,670	$7,561	**Yes**	**No**	4/16/2015
OK-TE-029.000	150	2630	9	$840	$840	$5,706	$7,608	**Yes**	**No**	4/16/2015
OK-TE-030.000	150	2627	9	$840	$840	$5,699	$7,598	**Yes**	**No**	4/16/2015
OK-TE-031.000	150	2632	9	$840	$840	$5,709	$7,612	**Yes**	**No**	4/16/2015

OK-TE Land Offer Summary 11/5/2015

TractName	Actual Width (150ft corridor)	Length	Easement Acres	Fee Price Per Acre	Settlement Price Per Acre	75% Easement Offer	Settlement Offer	Qualified for Waiver	Appraisal Per CLE	Date Last Reviewed for Waivers
OK-TE-032.000	150	2574	9	$840	$840	$5,584	$7,445	**Yes**	**No**	4/16/2015
OK-TE-033.000	150	2615	9	$840	$840	$5,674	$7,565	**No**	**Yes**	4/16/2015
OK-TE-034.000	150	1318	5	$840	$840	$2,859	$3,812	**No**	**Yes**	4/16/2015
OK-TE-035.000	150	1318	5	$840	$840	$2,859	$3,812	**No**	**Yes**	4/16/2015
OK-TE-036.000	150	2636	9	$840	$840	$5,718	$7,624	**No**	**Yes**	4/16/2015
OK-TE-037.000	150	2608	9	$840	$840	$5,659	$7,545	**No**	**Yes**	4/16/2015
OK-TE-038.000	150	2608	9	$840	$840	$5,659	$7,545	**Yes**	**Yes**	4/16/2015
OK-TE-039.000	150	5208	18	$840	$840	$11,298	$15,064	**No**	**Yes**	4/16/2015
OK-TE-040.000	150	2615	9	$840	$840	$5,674	$7,565	**No**	**Yes**	4/16/2015
OK-TE-041.000	150	2615	9	$840	$840	$5,674	$7,565	**No**	**Yes**	4/16/2015
OK-TE-042.000	150	2609	9	$840	$840	$5,661	$7,548	**No**	**Yes**	4/16/2015
OK-TE-043.000	150	2609	9	$840	$840	$5,661	$7,548	**No**	**Yes**	4/16/2015
OK-TE-044.000	150	2634	9	$840	$840	$5,714	$7,618	**Yes**	**No**	4/16/2015
OK-TE-045.000	150	1308	5	$840	$840	$2,837	$3,782	**Yes**	**Yes**	4/16/2015
OK-TE-046.000	150	1308	5	$840	$840	$2,837	$3,782	**Yes**	**Yes**	4/16/2015
OK-TE-047.000	150	1314	5	$840	$840	$2,850	$3,799	**Yes**	**No**	4/16/2015
OK-TE-048.000	150	2627	9	$840	$840	$5,699	$7,599	**Yes**	**No**	4/16/2015
OK-TE-049.000	150	1314	5	$840	$840	$2,850	$3,799	**Yes**	**Yes**	4/16/2015
OK-TE-050.000	150	2624	9	$840	$840	$5,693	$7,591	**No**	**Yes**	4/16/2015
OK-TE-051.000	150	2624	9	$840	$840	$5,693	$7,591	**No**	**Yes**	4/16/2015
OK-TE-052.000	150	3929	14	$840	$840	$8,523	$11,364	**No**	**Yes**	4/16/2015

OK-TE Land Offer Summary 11/5/2015

TractName	Actual Width (150ft corridor)	Length	Easement Acres	Fee Price Per Acre	Settlement Price Per Acre	75% Easement Offer	Settlement Offer	Qualified for Waiver	Appraisal Per CLE	Date Last Reviewed for Waivers
OK-TE-053.000	150	1310	5	$840	$840	$2,841	$3,788	**Yes**	**No**	4/16/2015
OK-TE-054.000	150	1305	4	$840	$840	$2,832	$3,776	**Yes**	**No**	4/16/2015
OK-TE-055.000	150	3916	13	$840	$840	$8,495	$11,327	**No**	**Yes**	4/16/2015
OK-TE-056.000	150	2599	9	$840	$840	$5,638	$7,517	**Yes**	**No**	4/16/2015
OK-TE-057.000	150	2608	9	$1,760	$1,760	$11,856	$15,808	**No**	**Yes**	4/16/2015

Exhibit "B"

PLAINS & EASTERN CLEAN LINE

VALUATION MEMORANDUM

State of _______, _______County

Waiver Valuation Analysis

To: Deann Lanz, Vice President of Land
From: [Name] [Title]
Date: ___________________, 20_____

RE: Compensation Valuation Review of Parcels in [County], [State]

The Plains and Eastern project is a linear DC electric transmission line that will cross the county approximately ______ miles. The project will seek 150 - 200 foot wide easements in which to construct, operate and maintain the proposed transmission system. A desktop review of aerial imagery and other available geo-referenced data available by public sources along with the Market Data Study, prepared by ___________________, was utilized in the evaluation of determining and establishing Settlement Offer compensation.

Attached to this document are the following documents to establish and document the methodology and logic of the Settlement Offers.

- Market Data Study of Comparable Sales
- Land Offer Summary

I hereby certify that based on my review of the data, the proposed Settlement Offer for Waiver Parcels set forth in the Land Offer Summary is fair and just compensation and recommend that no appraisal be required for such Waiver Parcels.

Valuation Reviewer:

____
By: _________________________
Title:________________________

Date:________________________

Approved:

____
By: Deann Lanz
Title: Vice President of Land

Date:________________________

Exhibit "C"
TECHNICAL REVIEW REPORT

Tract #: ____
Tax ID #: ______________________________________
Owners of Record: ____

I am in receipt of that certain appraisal report dated ____________ (the "Appraisal"), prepared by ________________ of Integra Realty Resources (the "Appraiser") for the property located in [Section/Township/Range] (the "Property"), as substantially shown as Exhibit _______ in the Appraisal. The Appraisal was prepared for and on behalf of the Plains and Eastern Clean Line LLC ("Clean Line") to utilize and rely on for purposes of negotiating with landowners for easements of DC electric transmission lines.

Appraisal Summary:

- Size of the taking for the easement area
- Highest and best uses and the before and after taking
- Any improvements
- Date of the valuation and the valuation
- Value of the total property or larger parcel and include major items such as timber, improvements and damages

Scope of Review:

- I have made a thorough review of the Appraisal and my opinions are based on the materials submitted in the Appraisal, discussions with the Appraiser and discussions with Clean Line (and any other individuals that are pertinent to the review) and my personal knowledge of the local real estate markets. As the Review Appraiser I performed a desk review only of the Appraisal.

Property Data Summary:

- Brief description of the size, location of the easement and anything that has influences on the value of the easement. State the current use of the Property and summarize the adequacy of the highest and best use analysis.

Area Appraised:

- Define the easement and easement area to be taken

Valuation:

- Include approaches to value, last sale of the subject Property, number of sales, factors that influence value, Appraiser's analysis and value opinions.

Comments and Recommendations:

- Comments on overall quality of the Appraisal and market support for conclusions. Cite high and low points, if applicable. Recommend/approve the opinion of value, or if appropriate, disapprove or provide a different valuation and your basis of the change.

Certification:

- Include a signed certification in compliance with the standards under which the appraisal review report was prepared.

Conclusion:

- A short section on what your actions were in regards to the Appraisal reviewed.

____
Review Appraiser

____
Appraisal Certification #

____
Date

EXHIBIT “D”
TECHNICAL REVIEW REPORT

1. IDENTIFICATION:
Report reviewed: By [redacted], MAI, CCIM, Oklahoma Certified General Appraiser No. [redacted] and Mr. [redacted], Oklahoma Certified General Appraiser No. [redacted] both appraisers employed with [redacted] advisors/ [redacted].

Real estate and real property interest being appraised: a contiguous tract owned by [redacted] with 435,144sf or 9.99 ac. gross or 413,364sf or 9.49 ac. net being appraised at full fee value. The Legal Description is NE/4NE/4NE/4 of Sec. [redacted], Township 19 N. R. 1 E. [redacted] County, Oklahoma. The property address is [redacted] OK 74074 and Identified as **Parcel#A-001**. The property interest appraised is partial fee value for the utility and temporary easements.

Effective date of Report: September 12, 2014 signed by [redacted] on October 3, 2014.

Effective date for review: November 21, 2014.

Intended use and purpose of the review: To express an opinion as to the appropriateness and validity of the appraisers’ reports, including their techniques, analysis and conclusions.

2. EXTENT OF THE REVIEW PROCESS:

The reviewer conducted a desk and field review of the appraisal report. The appraisal is being reviewed for its completeness of content, supporting data and analysis to sufficiently support the appraisers’ values and conclusions and appropriateness of the techniques used by the appraisers. The report is also being reviewed for its compliance with the Uniform Standards of Professional Appraisal Practice (USPAP) and the Scope of Services provided by the client, which is essentially the same as required by the regulations of the Uniform Relocation Act as embodies in 49CFR 24 and Titles 17 and 69 of the Oklahoma State Statutes regarding valuation for eminent domain.

3. ASSUMPTIONS AND LIMITING CONDITIONS:

The reviewer did not make an independent search of applicable market, cost and income data and assumes that the data provided by the appraiser is a true, accurate and complete representation of the data available for the valuation of the subject property under this review.

The review performed is a desk review. A personal inspection of the subject was not performed. A comparable sales or independent verification of the cost and market data was not performed. This review will only accept or reconcile the appraisers' final valuation to recommend compensation based on the appraisals.

The reviewer will assume that the title and legal description provided by the appraisers are accurate.

The reviewer assumes that all pictorial images of the subject and the comparable sales are accurate.

The appraisal report is of a partial taking of utility easements rather than in full fee title. Therefore, the reviewer will assume that all aspects of the compensation will be considered as damages except for those items that cannot be relocated or replaced.

4. ADEQUACY AND RELEVANCE OF THE DATA AND APPROPRIATENESS OF THE ADJUSTMENTS:

The appraisers have sufficient data with 4 vacant land sales. The sales are all located west of Stillwater with frontage on or near SH-51. The sales therefore, bear a locational similarity to the subject and are relevant to use in the subject's valuation. The sales are moderately inferior and superior to the subject so that the appraisers made only small adjustments to arrive at a value between the extremes of the comparable sales. To bracket the subject with sales that are inferior and superior is an appropriate and relevant technique. The appraisers logically adjusted their high sales downward and the low sales upward. The improvements were valued by using [redacted], a national data source of improvement values that do not usually sell in the open market. Given the age and condition of the buildings, the use of [redacted] was appropriate. As for the fencing, the reviewer would have preferred a quote from a local fencing contractor, but [redacted] is adequate. Ideally, the appraiser would have cited the Section and Page used from [redacted] when valuing the improvements. However, given the detail of the [redacted] work-up in the addenda section of the report, the use of the source had to be legitimate. While the land data is of sufficient quantity and highly relevant with appropriate adjustments, the improvement data is only adequate in the absence of market and local contractors. Therefore, the market of the appraisers is adequate and appropriately adjusted.

5. COMPLETENESS OF THE REPORTS:

To a sufficient extent, the appraisal report contains a sufficient degree of completeness to meet the summary requirements under USPAP Standard 2-2(b). The appraisal report has comparable sales sheets completed with deed and verification data. The Master Addenda has the locator maps and the comp sale photos so that the report with the master addenda is complete as regards the presentation of the data. The report clearly defines the subject being appraised, the rights to be appraised and the definition of the value to be appraised. The report has a relevant scope of work, a description of the subject and the subject neighborhood and an analysis and proper conclusion to the highest and best use of the subject. Both appraisers accompanied their presentation of their data with an analysis before arriving at a conclusion of value. The report has sufficient photos of the subject in both the take area and affected improvements. There are sketches of the improvements affected, but not an overall site sketch. Finally there are the required signed certificates and addenda sections that complete the documentation of both reports. Therefore, the report has a sufficient degree of completeness.

6. APPROPRIATENESS OF APPRAISAL TECHNIQUES AND METHODS:

Both appraisers used a conventional and totally appropriate method to value the subject. The sales selected were on the basis of similarity and direct comparison with the subject. In addition, the appraisers included sales that are slightly inferior and superior to the subject to allow for some bracketing of the sales with the subject also. Bracketing is an appropriate technique, especially if very similar sales for the subject cannot be found. In this case the bracketing is in support of the similar sales that the appraiser were able to make a direct comparison. The use of local contractors is preferable to the use of [redacted] and only for the landscaping/tree was a local contractor used. This method is considered appropriate though; the accuracy of this method diminishes if the quality of the improvements require a large adjustment for depreciation. Given the nature of the improvements that do not sell on the open market, the appraisers had no choice but to use a cost service with a large depreciation factor. It is somewhat surprising that the fencing could not get a local contractor bid. However, it may be possible that no local fencing contractor was available to provide a timely bid within the project time frame. The comparable sales are appropriate by the time frame, location and similarity in features and use to the subject for bracketing or direct comparison. The photos and exhibits also have a sufficient degree of appropriateness, quantity and quality.

7. VALIDITY OF ANALYSIS, OPINIONS AND CONCLUSIONS OF VALUE:

From the above, the reviewer has established that both appraisers have obtained sufficient data and used it appropriately to value the subject. The correct application of appropriate and sufficient data will be reflected in the analysis of the appraisers. The appraisers used a detailed point-by point comparative analysis section supported by a detailed grid showing adjustments to the sales. The appraisers decided on a value towards the upper end of their comparable sales. The basis for this analysis is that the subject has SH-51 frontage with a corner onto Country Club Road. Therefore, the opinion of value logically flows from this analysis and the conclusion of value is valid. The valuation of the improvements is well documented and accepted. The contractor has revised the easement to avoid the shed and residence as well as reduce the area of taking. The appraiser's compensation will be reduced significantly as a result of this revision. Therefore, the recommended value will be set on the following page:

RECOMMEND VALUE AS ACCEPTED MOSTLY IN THE REPORT:

Indicated Value of Subject:	**=$1,306,170**
Damages:	
Land; Utility E'smnt, 21,056sf. @ $3.12/sf.X60%	**=$ 39,417**
Temporary Easement, 10,756sf.	
@ $3.12/sf. X 10%	**=$ 3,359**
Improvements; Replace Metal Gate,	**=$ 500**
Replace Fence, 785lf. @ $5.13/lf.	**=$ 4,028**
Sub-Total Damages:	**=$ 47,304**
Non- Damages (items acquired)	
Pecan tree	**=$ 300**
Barn	**=$ 5,097**
Sub-Total Non-Damages:	**=$ 5,397**
Total Compensation:	**=$ 52,701**
Say:	**=$ 52,700**

The effective date of the appraisal review of the subject property is November 21, 2014.

[redacted]
Review Appraiser
Owner, [redacted]
OREAB#[redacted]

REVIEW APPRAISER'S STANDARD CERTIFICATION

I certify that, to the best of my knowledge and belief:

__ the facts and data reported by the reviewer and used in the review process are true and correct.

__ the analysis, opinions and conclusions in this review report are limited only by the assumptions and limiting conditions stated in this review report and are my personal, impartial and unbiased professional analysis, opinions and conclusions.

_ I have no (or the specified) present or prospective interest in the property that is the subject of the work under review and no (or the specified) personal interest with respect to the parties involved

_ I have not performed a previous appraisal or review of the subject property.

_ I have no bias with respect to the property that is the subject of the work under review or to the parties involved with this assignment.

_ my engagement in this assignment was not contingent upon developing or reporting predetermined results.

_ _ my compensation is not contingent on an action or event resulting from the analysis, opinions or conclusions in this review or from its use.

_ my analyses, opinions and conclusions were developed and this review report was prepared in conformity with the *Uniform Standards of Professional Appraisal Practice.*

_ I have not made a personal inspection of the subject property of the work under review.

_ no one provided significant appraisal, appraisal review, or consulting assistance to the person signing this certification.

Signed and dated this 21st day of November 2014.

[redacted]
Review Appraiser
OREAB[redacted]

Exhibit "E"
Plains and Eastern Clean Line Arkansas LLC
EASEMENT CALCULATION SHEET

This Easement Calculation Sheet is made a part of that certain Transmission Line Easement Agreement ("Easement Agreement") between Landowner and Plains and Eastern Clean Line Arkansas LLC ("Plains and Eastern").

Date __________

Tract Number: ____________________

Landowner Name: ____________________

Permanent Easement 150 ft. (+/-)

Total __________ ft. (+/-)

Land Use Footage

	0.239000	(+/- acres) X		=	$0.00
0	0.000000	(+/- acres) X	$0.00	=	$0.00
			"Total Easement Consideration"		$0.00

<u>The Total Easement Consideration shall be paid as follows:</u>

(A) Initial Payment (30% of the Total Easement Consideration) $0.00

AND

(B) Balance Due prior to the earlier of
(1) the date construction crews access the property to install structures or wires, or (2) ***12-31-2017, (such date, as may be extended pursuant to the Easement Agreement Extension, the "Easement Compensation Deadline")*** $0.00

<u>Easement Agreement Extension</u>

Easement Compensation Deadline may be extended for two additional one-year periods (with 10% of the Total Easement Consideration due by 12-31-2017 for the first extension and due by 12-31-2018 for the second extension) ("*Extension Payment* "). Extension Payment(s) shall not be credited towards the Balance Due. $0.00

- *Initial Payment is paid at time of grant of the Easement Agreement.*
- *If, based on the final legal description, it is determined that the Permanent Easement width is greater or less than 150' and/or the linear footage is greater or less than as shown above, Plains and Eastern shall adjust the Balance Due such that the Total Easement Consideration is based on actual footage and width and calculated using the same formulas as set forth on this Easement Calculation Sheet.*
- *Landowner acknowledges and agrees that Plains and Eastern is under no obligation to pay the Balance Due portion of the Total Easement Consideration and that if Plains and Eastern fails to do so on or before the Easement Compensation Deadline, subject to the cure provision in the Easement Agreement, the Easement Agreement shall terminate. Upon such a termination, Landowner shall retain the Initial Payment and any Extension Payment (if applicable), and Plains and Eastern shall have no further obligation or other liability to Landowner.*
- *Plains and Eastern has the right to extend the Easement Compensation Deadline for two additional one-year periods by payment of the Extension Payment to Landowner prior to the Easement Compensation Deadline. All sums paid by Plains and Eastern for such extension shall be retained by Landowner and are non-refundable, and will not be credited towards the Balance Due.*

<u>Acceptance</u>

LANDOWNER: ____________________ DATE: __________

Plains and Eastern: ____________________ DATE: __________

58. What is the goal of the grid modernization effort? Is there some terminal point to this effort? Is its genesis statutory or something else?

Response: Grid infrastructure must securely deliver reliable and affordable energy to consumers where they want it, when they want it, and how they want it. The technical goal of the Grid Modernization Cross-cut is to develop new tools and technologies to measure, analyze, predict, protect, and control the grid, in order to meet the evolving electricity demands of our Nation's homes and businesses.

Through an integrated Multi-Year Program Plan (MYPP), the Department has identified an aggressive five-year grid modernization strategy. The MYPP includes defined milestones and endpoints. The effort was created to develop a department-wide strategy to eliminate overlap and align research priorities.

There was no statutory command that DOE specifically conduct this activity. Instead, DOE did so pursuant to its statutory general research, policy development and related analyses authorities, including those contained in the Department of Energy Organization Act and the statutory objects of the various Appropriations Acts that fund the Department's activities in this area.

Supplemental Background Information : https://energy.gov/sites/prod/files/2016/01/f28/Grid%20Modernization%20Multi-Year%20Program%20Plan.pdf

59. Who “owns” the Mission Innovation and Clean Energy Ministerial efforts within the Department?

Response: For Mission Innovation, the Secretary of Energy leads efforts on the initiative within the Department. The Secretary of Energy relies on the co-leadership of the Under Secretary for Science and Energy, the Chief Financial Officer, and the Assistant Secretary for International Affairs. Domestically, the cumulative clean energy research & development investment of 12 federal agencies established the baseline. Globally, there are 23 member governments in Mission Innovation – with each member controlling its respective budget.

Regarding the Clean Energy Ministerial (CEM), the Secretary has led efforts within the Department, relying on the leadership of the Assistant Secretary for International Affairs, who in turn has leveraged domestic DOE programs and labs; other country governments; and external stakeholders. While the Office of International Affairs formerly hosted the CEM Secretariat, in 2016 the 25 member governments of CEM voted to move the Secretariat to be hosted at the International Energy Agency in Paris, thereby relieving DOE of this function.

60. Does or can the Department delineate research activities as either basic or applied research?

Response: The Department identifies and reports on its basic and applied research; the categorization follows the definitions for basic and applied research established by OMB Circular A-11. The Department publishes annual tables with program-level funding information for basic research and applied research categories. These numbers are published for the two most recent fiscal years as well as for the President's request on page 266 of Volume 2 of the Department's FY 2017 Congressional Budget Justification. Link: http://energy.gov/sites/prod/files/2016/02/f30/FY2017BudgetVolume2.pdf

Research and Development
Crosscut

The Department of Energy supports research and development (R&D) activities and facilities to ensure that the U.S. remains at the leading edge of discovery and to provide the science and technology to fuel innovation and long-term economic growth. The vast scope of the R&D activities encompasses high priority areas such as advanced manufacturing, clean energy, and climate research; and the operation of a large suite of scientific user facilities in support of the R&D activities.

The Department's R&D reporting is now expanded to include administrative activities necessary to the success of the R&D programs. These activities include program direction, safeguards and security, and infrastructure funding that support the R&D programs. These changes are consistent with government-wide and international R&D reporting practices. This funding was not included in the R&D reporting in the FY 2016 and prior year budget justifications.

Research and Development ($K) [a]

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Basic Research					
Bonneville Power Administration Fund	4,868	4,868	4,868	4,868	0
Science [c]	4,310,357	4,333,630	4,505,148	4,827,314	+322,166
Electricity Delivery and Energy Reliability	7,644	7,428	5,844	8,376	+2,532
Fossil Energy R&D	5,355	5,239	6,057	5,494	-563
Nuclear Energy	35,447	35,970	29,570	8,426	-21,144
Defense Nuclear Nonproliferation	87,205	87,205	60,230	59,351	-879
Weapons Activities	3,677	3,677	0	0	0
Total, Basic Research	4,454,553	4,478,017	4,611,717	4,913,829	+302,112
Applied Research					
Bonneville Power Administration Fund	2,522	2,522	2,522	2,522	0
Science [b]	0	65,075	0	0	0
Electricity Delivery and Energy Reliability	66,813	64,929	78,424	81,096	+2,672
Energy Efficiency and Renewable Energy	594,019	575,776	640,428	996,235	+355,807
Fossil Energy R&D [d]	198,143	193,858	224,113	203,290	-20,823
Nuclear Energy	679,095	672,946	725,811	692,352	-33,459
Advanced Research Project Agency - Energy [c]	140,000	140,000	145,500	250,000	+104,500
Environmental Management	4,620	4,468	5,712	15,840	+10,128
Defense Nuclear Nonproliferation	148,311	148,311	162,913	160,533	-2,380
Weapons Activities	3,738,777	3,738,777	3,338,779	4,572,967	+1,234,188
21st Century Clean Transportation Plan Investments [c]	0	0	0	200,000	+200,000
Total, Applied Research	5,572,300	5,606,662	5,324,202	7,174,835	+1,850,633
Development					
Bonneville Power Administration Fund	8,822	8,822	8,822	8,822	0
Electricity Delivery and Energy Reliability	40,258	39,122	55,244	68,600	+13,356
Energy Efficiency and Renewable Energy	762,546	752,411	765,705	1,111,824	+346,119
Fossil Energy R&D [d]	332,024	324,844	375,540	340,649	-34,891
Nuclear Energy	111,952	110,938	122,057	101,629	-20,428
Advanced Research Project Agency - Energy [c]	140,000	140,000	145,500	250,000	+104,500
Naval Reactors	1,083,500	1,083,500	1,207,606	1,235,028	+27,422
Environmental Management	9,380	9,070	11,598	32,160	+20,562
Defense Nuclear Nonproliferation	47,803	47,803	53,020	52,246	-774
Weapons Activities	803,084	803,084	586,547	677,617	+91,070
21st Century Clean Transportation Plan Investments [c]	0	0	0	300,000	+300,000
Total, Development	3,339,369	3,319,594	3,331,639	3,878,575	+546,936

Research and Development Continued ($K) [a]

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Subtotal, R&D					
Bonneville Power Administration Fund	16,212	16,212	16,212	16,212	0
Science [c]	4,310,357	4,398,705	4,505,148	4,827,314	+322,166
Electricity Delivery and Energy Reliability	114,715	111,479	139,512	158,072	+18,560
Energy Efficiency and Renewable Energy	1,356,565	1,328,187	1,406,133	2,108,059	+701,926
Fossil Energy R&D [d]	535,522	523,941	605,710	549,433	-56,277
Nuclear Energy	826,494	819,854	877,438	802,407	-75,031
Advanced Research Project Agency - Energy [c]	280,000	280,000	291,000	500,000	+209,000
Naval Reactors	1,083,500	1,083,500	1,207,606	1,235,028	+27,422
Environmental Management	14,000	13,538	17,310	48,000	+30,690
Defense Nuclear Nonproliferation	283,319	283,319	276,163	272,130	-4,033
Weapons Activities	4,545,538	4,545,538	3,925,326	5,250,584	+1,325,258
21st Century Clean Transportation Plan Investments [c]	0	0	0	500,000	+500,000
Subtotal, R&D	**13,366,222**	**13,404,273**	**13,267,558**	**15,767,239**	**+2,499,681**
R&D Related Equipment					
Science	182,472	161,849	178,476	161,839	-16,637
Energy Efficiency and Renewable Energy	3,600	3,600	3,600	3,600	0
Fossil Energy R&D [d]	15,782	15,782	15,782	40,682	+24,900
Naval Reactors	17,000	17,000	22,490	13,480	-9,010
Weapons Activities	116,442	116,442	125,808	103,000	-22,808
Total, Equipment	335,296	314,673	346,156	322,601	-23,555
R&D Related Construction					
Science	540,636	537,986	621,772	633,465	+11,693
Naval Reactors	138,000	138,000	145,400	171,612	+26,212
Total, Construction	**678,636**	**675,986**	**767,172**	**805,077**	**+37,905**
Total Department of Energy R&D and R&D Facilities					
Bonneville Power Administration Fund	16,212	16,212	16,212	16,212	0
Science [c]	5,033,465	5,098,540	5,305,396	5,622,618	+317,222
Electricity Delivery and Energy Reliability	114,715	111,479	139,512	158,072	+18,560
Energy Efficiency and Renewable Energy	1,360,165	1,331,787	1,409,733	2,111,659	+701,926
Fossil Energy R&D [d]	551,304	539,723	621,492	590,115	-31,377
Nuclear Energy	826,494	819,854	877,438	802,407	-75,031
Advanced Research Project Agency - Energy [c]	280,000	280,000	291,000	500,000	+209,000
Naval Reactors	1,238,500	1,238,500	1,375,496	1,420,120	+44,624
Environmental Management	14,000	13,538	17,310	48,000	+30,690
Defense Nuclear Nonproliferation	283,319	283,319	276,163	272,130	-4,033
Weapons Activities	4,661,980	4,661,980	4,051,134	5,353,584	+1,302,450
21st Century Clean Transportation Plan Investments [c]	0	0	0	500,000	+500,000
Total, R&D and R&D Facilities	**14,380,154**	**14,394,932**	**14,380,886**	**17,394,917**	**+3,014,031**

[a] Totals may vary slightly from President's Budget Analytical Perspectives to reflect the most current estimates available.
[b] FY 2017 Mandatory funding is included in Science ($100,000,000 Basic Research); Advanced Research Project Agency-Energy ($75,000,000 in Applied Research and $75,000,000 in Development) and the 21st Century Clean Transportation Plan Investments ($200,000,000 in Applied Research and $300,000,000 in Development.)
[c] Applied funding in FY 2015 Office of Science represents SBIR/STTR funding transferred from other DOE programs. No applied funding is shown in FY 2015 or FY 2016 because the transfer from other DOE programs has not yet occurred.
[d] FY 2017 funding for Fossil Energy R&D differs from the totals in the Budget. Totals in the Budget are based on $360 million in new Budget Authority. Estimates here include $240 million in use of prior year balances, for a total program level of $600 million.

61. Is there a readily available list of any technologies or products that have emerged from DOE programs or the labs that are currently offered in the market without any subsidy?

Response: DOE does not have a readily available list of technologies or products that have emerged from DOE or lab efforts. However a listing of examples is included.

Information on the many technologies and products that range from specific materials, lead-free solder, and medical diagnostics tools/accelerators to hydraulic fracturing, clean-room technology and software/modeling tools is routinely made available on specific technologies. These are published by the labs and included in reports such as those from the Office of Technology Transitions, including the report to Congress entitled Technology Transfer and Related Partnering Activities at the National Laboratories and other Facilities for Fiscal Year 2014 available at https://energy.gov/sites/prod/files/2016/06/f33/Technology%20Transfer%20Report%20to%20Congress%20FY14.pdf and for 2009-2013 available at https://energy.gov/sites/prod/files/2016/02/f29/FY%2009-13%20Annual%20Report%20on%20Technology%20Transfer_0.pdf, as well as in the annual report from the National Institute of Standards and Technology, entitled Federal Laboratory Technology Transfer:

Summary Report to the President and Congress, the latest version of which is available at https://www.nist.gov/sites/default/files/documents/2016/10/26/fy2014_federal_tech_transfer_report.pdf.

The DOE EERE Fuel Cell Technologies Office completed an independent study in 2015 that identified over 30 commercial technologies enabled by its programs, available at http://energy.gov/eere/fuelcells/downloads/2015-pathways-commercial-success-technologies-and-products-supported-fuel.

DOE EERE's AMO IMPACTs report: Appendix A lists about 75 technologies that AMO has helped commercialize, all of which are deployed: https://www1.eere.energy.gov/manufacturing/about/pdfs/impacts2010_full_report.pdf.

DOE EERE has developed more than 100 partnerships with the wind industry, which have led to multiple successfully commercialized, produced, and installed wind energy innovations. The Retrospective Benefit-Cost Evaluation of U.S. DOE EERE Wind Energy R&D Program http://energy.gov/eere/analysis/downloads/retrospective-benefit-cost-evaluation-us-doe-wind-energy-rd-program-impact identified 112 wind energy patents resulting from DOE EERE-funded research. Of 695 additional patents assigned to leading wind energy products, 25 percent cite one or more of the EERE-funded patents or papers. Leading wind energy companies (e.g., GE Wind Energy, Clipper Windpower, Distributed Wind Energy, Southwest Windpower and Vestas Wind) own patents with strong linkages back to DOE-funded patents and papers.

Other reports, such as those from DOE EERE, show positive affect on consumers and the economy, such as the February 2016 publication Aggregate Return on Investment for R&D Investments in the U.S. DOE Office of Energy Efficiency and Renewable Energy available at http://energy.gov/sites/prod/files/2016/10/f33/Aggregate%20ROI%20impact%20for%20EERE%20RD%20-%2010-5-16.pdf. EERE seeks to verify the attributed energy cost savings and other outcomes of our investments by commissioning comprehensive impact evaluations that are performed by independent evaluation experts. For example, one-third of EERE's research and development portfolio from 1976-2012 was included in a meta-evaluation of a series of independent, third-party studies. The assessment found that a taxpayer investment of $12 billion into EERE-managed R&D has yielded an estimated net economic benefit to the United States of more than $230 billion, with an overall annual rate of return on investment of more than 20%. The benefit-to-cost ratio of these investments is 7 to 1 (using a 7% discount rate), indicating that benefits have far exceeded the costs of these investments.

SELECTED EXAMPLES

1. SmartTruck UnderTray System: http://smarttruckaero.com. When the entrepreneurs and engineers at Smart Truck Systems, a company in Greenville, South Carolina, were looking to improve the aerodynamics and fuel efficiency of long-haul trailers, they looked to the supercomputers at Oak Ridge National Laboratory. Sophisticated simulations of airflow around the trailers led to the design of unique aerodynamic add-on components called the UnderTray system. The simulations reduced the time from concept to manufacture-ready from three years to 18 months. The system can increase highway fuel efficiency by up to 12 percent, saving thousands in annual fuel cost per truck and leading to potentially dramatic reductions in carbon dioxide emissions.
2. Improved operational settings for radiation portal monitors at U.S. ports of entry. Technology is operational at U.S. ports http://www.pnl.gov/news/release.aspx?id=4245. Developed by PNNL with the U.S. Customs and Border Protection agency, these improved settings have reduced alarm rates due to tile or granite that contain non-threatening, naturally occurring isotopes significantly, freeing officers to focus on other high-priority enforcement duties at an annual cost equivalent value of more than $10 million.
3. xSynchroPET: http://synchropet.com The compact modular PET detector was invented and developed by the collaborative efforts of a team of BNL researchers from the medical, instrumentation, and physics departments. It can be used to study a number of different diseases. (Highlighted in NIST report on federal tech transfer for FY13.)
4. The Entropy Engine is a random number generator that addresses a key fundamental flaw in modern crypto systems – predictability. Commercialized by Whitewood and on the market http://www.whitewoodencryption.com/wp-content/uploads/2016/02/Whitewood_EE_Data_Sheet.pdf. The invention from LANL strengthens the foundation of computer security by producing an inexhaustible supply of pure random numbers at speeds of 200 million bits per second. Entropy Engine uses the unique properties of quantum mechanics to generate true entropy (random numbers) in a way that makes it immune from all external influences. (R&D 100 Awardee)
5. Micro Aerosol Disinfecting System: https://globalbiodefense.com/2016/02/01/killing-pathogens-pnnl-disinfection. The system developed with PNNL turns a simple table salt solution into a fine mist containing natural molecules that disinfect an entire room. Tests have shown the system can kill at

least 99.9999 percent of health-harming microbes. It could be used to disinfect hospitals, gymnasiums, schools and other enclosed spaces. It's far more effective, easier to apply and less expensive than other disinfection methods.

6. Boron Nitride Nanotubes "Fibril BNNT™" was developed at TJNL with NASA's Langley Research Center and is marketed via BNNT, LLC, a startup in Newport News http://www.bnnt.com/company. With similar commercial applications as carbon nanotubes, Boron nitride nanotubes are equally strong yet much more heat resistant and easier to synthesize. Fibril BNNT™ is a super-strong, heat-resistant, textile-like polymer with the appearance of cotton, but a molecular backbone 100 times stronger than steel. It can withstand temperatures over 800 degrees centigrade and is expected to attract a broad range of customers in the nanotube materials sector. Applications are projected to range from aerospace heat shields to cancer therapies as well as to be used as a spray or coating. NASA's 2016 Government Award Winner for Invention of the Year. (Highlighted in NIST report on federal tech transfer for FY13.)

Additional examples are provided in Attachment 1: Fossil Energy and Attachment 2: EERE.

Attachment 1: Examples from Fossil Energy

1. Clean Coal R&D - Improving Plant Efficiency and Performance. DOE's Clean Coal program has historically focused on more efficient power plants and advanced emission control technologies, with strong commercial penetration and success.
    a. Low NOx burners, flue gas desulfurization scrubbers, and other air pollution control devices developed by DOE are installed commercially on about 75% of U.S. coal-fired power plants, and are 50 to 90% cheaper compared to older systems.
    b. Selective Catalytic Reduction (SCR) technologies developed through DOE programs are now commercially installed on about half our nation's coal fleet,
    c. DOE's programs focused on multi-pollutant control technologies including mercury have experienced significant sales in the commercial market. As a result of DOE-funded full-scale field tests at nearly 50 US power plants from 2000 to 2008, mercury control technologies have been installed in around 400 U.S. power plants with an equivalent capacity of 180 GW.
    d. Technologies to help recycle coal combustion products (CCPs) were also developed through DOE-FE programs such as the Combustion Byproducts Recycling Consortium (CBRC). As a result of these efforts, the U.S. now has multi-billion commercial CCP recycling industry and the use of CCPs increased more than 500 percent cumulatively from 1974 to 2013. Apart from the use of CCPs for the construction industry, current DOE-funded research is aimed at extracting economically valuable rare earth elements (global market ~$30 billion), which are used in catalytic converters, batteries, superconductors, lasers, camera lenses and specialized glasses.
    e. To improve the economic and environmental performance of existing coal plants, DOE demonstrated the DryFining process that utilizes waste heat to reduce the moisture content of incoming fuel. With low capital cost and increased operational efficiencies, the original project was quickly replicated by the private sector with good commercial success. This project was also recognized by Power Engineering magazine as the Best Coal-Fired Project of 2010.
    f. Dramatic advancements in gas turbine efficiencies (>60% efficiency) were achieved through a collaborative R&D program run by the Office of Fossil Energy (DOE-FE) and the Office of Energy Efficiency and Renewable Energy (DOE-EERE) from 1992 through 2001. A large suite of highly-efficient U.S.-built OEM gas turbines based on DOE-developed technologies are sold into commercial service today worldwide. The global turbine market was ~$16 billion in 2015. For example, a research project managed by NETL and DOE-FE resulted in new technologies for increasing the efficiency of next-generation industrial gas turbines for power generation. The technologies were conceptualized in 2009 and the first commercial offering will be available in 2017 in natural gas-fired turbines. Technologies developed under this program continue to be deployed in commercial turbines, lowering emissions and increasing efficiency of the existing fleet in addition to enabling transformational turbine platforms.
2. CO_2 Capture. More recently, DOE has developed advanced CO_2 capture technologies that are being commercially deployed without subsidy. For example, the Polaris post-combustion CO_2 capture membrane was developed by Membrane Technology and Research, Inc. with funding support beginning in 2007. The membrane was scaled up from concept to commercial production in 1,000 foot rolls. This technology has recently been deployed on about 10% of the more than 100 current

North American shale gas plays that use fuel gas conditioning membranes, all driven by attractive economics. Although principally intended to capture CO_2 from the flue gas of coal-fired power plants, the technology has found commercial application for industrial use in fuel gas conditioning.

3. DOE has also supported development of other membranes, solvents, and sorbents that are gaining markets in other industrial sectors, such as natural gas processing and conditioning fuel gas from biomass digestion (biogas) and from natural gas. Overall U.S. natural gas processing and conditioning capacity is over 75 billion cubic feet/d and the biogas market is ~5 percent of the natural gas market.
4. CO_2 Utilization and Storage. The industrial partners involved with DOE's Regional Carbon Sequestration Program (RCSP) have acquired highly valuable experience, knowledge, and tools that will be used for commercial oil and gas operations and also demonstrate long-term storage of CO_2. Highlights include:
   a. Denbury Onshore LLC operates the Bell Creek Oilfield, the site of the Plains CO_2 Reduction Partnership (PCOR) large-scale carbon storage field project. The Bell Creek Field Project is successfully demonstrating monitoring and documenting CO_2 storage during Enhanced Oil Recovery (EOR) operations that is injecting over 1 million metric tonnes per year to recover and additional 35 million barrels of oil, which would otherwise be stranded. Through the DOE-funded research, industry will gain insight on how to improve injection efficiency, oil recovery, and CO_2 storage performance.
   b. Distributed Acoustic Sensing (DAS) is a new development in the use of fiber optic cables as receivers to record the signals generated in seismic surveys. Applications include monitoring of CO_2 storage operations as well as oil and gas exploration and production. With DOE support, Silixa LLC teamed up with the Electric Power Research Institute and Lawrence Berkeley National Laboratory to help commercialize DAS to detect CO_2 plumes. Silixa has been providing distributed fiber optic services since 2011. Over 80 surveys have been performed using 90% of them on pre-installed fiber optic cables.
5. Advanced Systems and Sensors. DOE is also developing advanced instrumentation and monitoring systems that can be used to provide reliable energy. One success stemming from this R&D, funded by DOE from 2009 through 2014, is the commercially available Electrical Capacitance Volume Tomography (ECVT) sensor, currently available from Tech4Imaging, LLC. This sensor permits non-invasive, 3-Dimensional imaging for real-time monitoring of flows. Devices such as this that can accurately measure the solid flow rate of an operating system will be of great aid for optimizing and controlling the combustion processes in advanced reactors to improve overall economics. Tech4Imaging, LLC is selling ECVT units at different price points based on the user-requested functionality as well as offering service plans and software upgrade options to customers. Imaging and measuring multiphase flows has been a challenge in many industrial applications. For example, measuring the flow rates of Oil, Water, and Gas of a multiphase flow in the Oil industry is one application that ECVT technology is able to address. A conservative estimate of the market size for a working multiphase flow meter is $6 Billion annually. Another application is in measuring the solids circulation rates in pneumatic conveying systems. This application spans many industries and also has a combined market size in the Billions of Dollars. ECVT is also used by researchers to develop and verify models for design and control of processes.
6. Advanced Computational Tools to Speed Technology Development and Deployment. To speed exploration of new energy technology concepts, to optimize energy systems across time and size

scales, and to quantify the uncertainty in resulting simulations, DOE has developed computational tools such as Aspen r which is now the industry standard for power plants and chemical processes. Aspen® was the first process simulator capable of simultaneously modeling solid, liquid and gaseous streams, which was required for modeling fossil fuel plants. Aspen was subsequently commercialized as AspenPlus® and has become the de facto standard in process simulation, utilized by at least 42 of the world's 50 largest chemical companies. Today around 400,000 engineers worldwide use AspenPlus for process simulation. In addition, DOE has supported the development of multiphase computational fluid dynamics software at NETL, for the simulation of energy devices. The resulting MFIX computer model is today used by almost 3,000 universities and over 600 commercial organizations to design and study fluid bed combustors, gasifiers, as well as processes outside of fossil energy.

7. Shale Oil and Gas Resources The United States is experiencing a natural gas revolution, thanks in no small part to DOE's oil and gas program. In the 1970s, with domestic oil and gas production declining, DOE launched research and development programs to tap the hydrocarbons in unconventional resources, such as low-permeability rocks and shale. This included successful research into areas such as synthetic diamonds, which when combined with matrix metal R&D at labs such as Sandia, became the basis for polycrystalline diamond compact (PDC) drill bits, is a multi-billion dollar annual business growing at 5% per year. PDC bits now constitute close to 70% of all oil and gas footage drilled globally, and are a foundation technology for horizontal wells in shales. Fast forward to today: natural gas production from unconventional resources is booming, U.S. natural gas production is higher than at any other time in history, and the United States is projected to become a net exporter of natural gas by 2018 -- the first time since 1957.
8. DOE's NETL helped to advance foam fracturing technology, oriented coring and fractographic analysis, and large-volume hydraulic fracturing. In 1975, a DOE-industry joint venture drilled the first Appalachian Basin directional wells to tap shale gas, and shortly thereafter completed the first horizontal shale well to employ seven individual hydraulically fractured intervals. The DOE tight gas experiments in the Piceance Basin (1979-88) formed the basis for modern-day well stimulation. While decades of subsequent technological enhancements by industry stand behind the suite of tools and methodologies that make shale gas production possible, publicly funded R&D has played an important and early role.
9. Wellbore Cements. Strength and stability of cements are critical in protecting the environment from leaks and spills wherever drills penetrate the earth in search of oil and gas. NETL researchers polled industry to identify cement integrity issues after the 2010 Deepwater Horizon oil spill in the Gulf of Mexico, and the results led to an intensified effort at NETL to understand how variations in the structure of foamed cements impact wellbore effectiveness. Until NETL led an effort to study foamed cement, there was a lack of knowledge about how they performed in actual wellbore conditions. NETL, in a novel approach, adapted medical diagnostic equipment—CT scanners—to generate data and 3-D images of cement containing various amounts of air or nitrogen at atmospheric and wellbore pressures. The results include the first-ever high resolution 3-D images of foamed cement and assessments of foamed cement structure, quality, and bubble size distribution—knowledge that can lead to better decisions for safer wellbores. Today, drilling and cementing experts worldwide are using NETL research to understand how foamed cement production and placement affect the integrity of oil and gas wells.

Attachment 2: Examples from EERE

This attachment includes a list of some technologies and related links that highlight the results of EERE-sponsored research, partnerships, and programs. Some technologies are described in greater detail than others. The list and descriptions can be refined upon request. The list is not comprehensive.

Some key crosscutting technologies include:

1. Polycrystalline Diamond Compact (PDC) Drill Bits: Approximately 60% of worldwide oil and gas well footage in 2006 was drilled using PDC drill bits, which DOE helped to develop. The main advantage over conventional roller cone bits is that they do not need to be replaced as often as other bits, which keeps costs down. It is estimated that the use of PDC drill bits in offshore applications reduce costs by $59 per foot drilled, yielding a PV cost savings of $15.1 billion over 24 years.
2. Binary Cycle Power Plant Technology: Binary cycle plants, which EERE helped to develop, represent 16% of total geothermal capacity in the United States (as of 2010). Binary cycle geothermal power plant technology enables efficient use of lower temperature resources through a closed loop heat transfer system. The total benefits of geothermal binary cycle plant technology, which include environmental health benefits and conversion efficiency benefits, is estimated to be approximately $3 billion over 24 years.
3. High Temperature Geothermal Well Cements: EERE-funded research led to the patenting and commercialization of a calcium aluminate phosphate (CaP) cement system that is resistant to acidic corrosion and maintains structural integrity at extremely high temperatures. Total benefits from the use of high-temperature cement from 1999 to 2008 are estimated to be $39.3 million, with the 99% of the benefits associated with cost savings to users.
4. EERE International's BIRD Energy Program with Israel has helped commercialize technologies including:
    A. Lipase carriers for enzymatic production of biodiesel
    B. Self-powered, wireless current sensors that facilitate load management strategies in commercial buildings
    C. LIDAR-based system which gathers data using lasers to facilitate wind speed and power output forecasting in wind farms
5. EERE funded commercialization of Wide Bandgap Semiconductors
    A. PowerAmerica Unveils advanced Silicon Carbide-based wide bandgap transistors at XFAB open 150mm SiC foundry in Lubbock, TX (https://www.poweramericainstitute.org/news/poweramerica-unveils-1200-v-mosfet-and-1200-v-integrated-mosfetjbs-sic-fabrication-processes/)
    B. PowerAmerica member AgileSwitch patents game-changing wide bandgap electronic device switching technology (https://www.poweramericainstitute.org/news/poweramerica-member-agileswitch-receives-patent-for-game-changing-wide-bandgap-control-technology/)
    C. PowerAmerica partner Monolith announces production of advanced SiC diodes (http://www.monolithsemi.com/2016_10_06-Monolith-1200V-10A-Diode-Eng-Samples.pdf)
    D. PowerAmerica member spotlight: United Silicon Carbide Inc., Product release coming in early 2017. (https://www.poweramericainstitute.org/news/member-spotlight-usci/)

6. EERE-funded Critical Materials Institute:
    A. Critical Materials Institute Partner ORNL licensees rare earth magnet recycling process to Momentum Technologies (http://phys.org/news/2016-10-ornl-rare-earth-magnet-recycling.html)
    B. Critical Materials Institute partners with INFINIUM to demonstrate production of rare earth magnets sourced and manufactured entirely in the U.S. (https://www.ameslab.gov/news/news-releases/critical-materials-institute-announces-domestic-rare-earth-magnet-partnership)
7. EERE-funded Additive Manufacturing research:
    A. 3D-printing of rare-earth-based magnets in collaboration with ORNL (http://www.economist.com/news/science-and-technology/21710233-3d-printers-promise-better-cheaper-and-more-powerful-magnets-magnetic-moments)
    B. Ingersoll Machine Tools, and ORNL partner to develop very large 3D printing system to advance aerospace, automotive, and defense industries (http://www.compositesworld.com/news/ingersoll-machine-tools-ornl-to-develop-very-large-3d-printing-system)
    C. Cosine Additive partners with ORNL Manufacturing Demonstration facility to develop ultrafast large-scale 3D printer (http://www.3ders.org/articles/20160615-cosine-additive-to-develop-large-scale-am1-3d-printer-in-partnership-with-ornl.html)
    D. ORNL and Boeing partner to develop 100% digitally manufactured molds for aerospace-grade composite parts (http://www.3ders.org/articles/20160506-ornl-and-boeing-perform-first-successful-autoclave-testing-of-3d-printed-tools.html)
8. EERE-funded research in Composite Materials:
    A. ORNL announces licensing opportunity for industrial-grade structural carbon fibers (https://www.ornl.gov/sites/default/files/Licensing%20Brochure.pdf)
    B. LeMond Composites invests $125 million in Oak Ridge, TN as part of licensing agreement with ORNL to manufacture industry-changing high-volume, low-cost carbon fiber (http://iacmi.org/2016/10/13/lemond-composites-marks-opening-oak-ridge/0
    C. ORNL and Boeing receive Guinness World Record for 3D-printed tool used in production of Boeing 777X passenger jet (https://www.ornl.gov/news/3d-printed-tool-building-aircraft-achieves-guinness-world-records-title)
    D. Cincinnati Inc. solidifies resource membership with IACMI after introducing BAAM printer into commercial market. (http://iacmi.org/2016/12/01/cincinnati-incorporated-solidifies-resource-membership-iacmi-composites-institute/)
    E. Leisure Pools partners with IACMI to develop composites-based pools (http://archive.knoxnews.com/business/leisure-pools-may-hire-1000-ep-1324521542-353378921.html)
9. Process Intensification
    A. EERE partners with Praxair and Novamer to demonstrate technology for production of low-energy, cost-effective chemical intermediates (http://energy.gov/eere/amo/articles/amo-success-story-converting-waste-valuable-materials-and-chemicals)

Other EERE funded research in the Transportation sector has led to commercialization of technologies including:

10. Nickel Metal Hydride batteries
11. Lithium-Ion (Nickel-Cobalt-Aluminum) battery technology for Hybrid vehicles
    A. Working with Nextval, Inc., Lawrence Berkeley National Laboratory (LBNL) developed a Conducting Polymer Binder for high-capacity lithium-ion batteries. With a focus on enabling smaller, lighter, and cheaper batteries, LBNL and Nextval researchers developed a new anode (negative electrode) material that is strong, elastic, porous, highly conductive, and can boost power storage capacity by 30%. (https://www.energy.gov/eere/success-stories/articles/eere-success-story-california-conducting-polymer-binder-boosts-storage)
        - LBNL
12. Lithium-ion (mixed Nickel-Manganese-Cobalt cathode) battery technology of plug-in electric vehicles
    A. A battery company supported by the Vehicle Technologies Office (VTO) has an agreement to manufacture silicon nanowire material for lithium-ion batteries on a commercial scale for the first time. OneD Materials, which had a project from 2011 to 2014 with VTO, recently signed a production license and agreement with EaglePicher Technologies, a U.S. company that manufactures battery cells and batteries. (https://www.energy.gov/eere/success-stories/articles/eere-success-story-battery-company-puts-new-nanowire-technology)
    B. Porous Power Technologies, partnered with Oak Ridge National Laboratory (ORNL), developed SYMMETRIX HPX-F, a nanocomposite separator for improved lithium-ion battery technology. This breakthrough membrane technology addresses market demands by lowering lithium-ion battery costs and improving safety through the replacement of polymer separators. (https://www.energy.gov/eere/success-stories/articles/eere-success-story-tennessee-pennsylvania-porous-power-technologies)
        - ORNL
    C. Increasing the number of plug-in electric vehicles on America's roads can help reduce our dependence on petroleum, improving our economic, environmental, and energy security. But without research undertaken at Argonne National Laboratory, supported by EERE's Vehicle Technologies Office (VTO), PEVs may have had a very different, slower introduction to the market. Today, batteries in both the Chevrolet Volt and the Ford Focus EV use technology that was originally developed at Argonne. (https://www.energy.gov/eere/success-stories/articles/eere-success-story-battery-cathode-developed-argonne-powers-plug)
        - ANL
13. Utracapacitor technology for hybrid vehicles
14. Nickel Manganese Cobalt battery cathode material
    A. BASF Catalysts, a battery component manufacturer, is running the largest cathode materials manufacturing facility in the country with support from EERE's Vehicle Technologies Office (VTO). (https://www.energy.gov/eere/success-stories/articles/eere-success-story-basf-catalysts-opens-cathode-production-facility)
15. Computer-Aided Design Tools for Automotive Batteries
    A. The National Renewable Energy Laboratory (NREL) was recently issued a patent for its R&D 100 Award-winning Isothermal Battery Calorimeters (IBCs). The multi-size IBCs were

developed by energy storage engineers at NREL's Transportation and Hydrogen Systems Center, with funding from the U.S. Department of Energy's Vehicle Technologies Office, and licensed by NETZSCH North America for commercialization. (http://www.nrel.gov/transportation/energystorage/news/2016/39758.html)

- NREL

16. Low Cost, High Temperature, High Ripple Current DC Bus Capacitors
    A. In September 2008, Electron Energy Corporation received a $750,000 Small Business Technology Transfer (STTR) grant from the U.S. Department of Energy and used the money, in a collaborative effort with University of Delaware, to develop a process that allows manufacturers to maximize the electrical resistivity of Neodymium Iron Boron and Samarium Cobalt sintered rare earth magnets without reducing their magnetic strength. (https://energy.gov/articles/grant-helps-make-us-rare-earth-magnets-more-common)
17. Simulation tools for Advanced Engine Combustion that enable High Efficiency, Clean Combustion
    A. FCA, Argonne National Laboratory, Bosch, Delphi, and Ohio State University designed, built, and tested a dual-fuel advanced combustion 2.4-liter engine with a number of extremely efficient features. (https://www.energy.gov/eere/success-stories/articles/eere-success-story-fca-and-partners-achieve-25-fuel-economy)
        - ANL
    B. A computer code developed by a trio of Lawrence Livermore National Laboratory (LLNL) researchers has significantly advanced predictive computer science for designing next-generation car and truck engines. (https://www.energy.gov/eere/success-stories/articles/eere-success-story-zero-order-reaction-kinetics-zero-rk-coding)
        - LLNL
18. Spatial resolved capillary inlet-mass spectrometry (SPACI-MS)
    A. Researchers at ORNL in collaboration with the Caterpillar Technical Center have developed a new modified cast austenitic stainless steel with significantly more high-temperature performance, durability and reliability than the common commercial grade of that stainless steel - and at the same cost per pound as cast stainless steel. (https://www.ornl.gov/news/materials-steel-21st-century)
        - ORNL
19. Superplastic Forming (SPF) Technology
    A. Auto makers seeking enhanced fuel efficiency by replacing heavier steel with lighter aluminum have been challenged by aluminum's low formability. By understanding the basic mechanisms underpinning superplastic deformation, an approach that leads to high formability, new aluminum alloys and advanced forming processes were developed and commercialized to allow the manufacture of complex shapes. (http://science.energy.gov/bes/highlights/2001/bes-2001-09-a/) (http://www.pnl.gov/science/highlights/highlight.asp?groupid=756&id=1033)
        - PNNL
20. Structural Magnesium Castings
    A. Development of Integrated Die Casting Process for Large Thin-Wall Magnesium Applications Enabling Production of Lightweight Magnesium Parts for Near-Term Automotive Applications

(https://energy.gov/sites/prod/files/2015/03/f20/development_of_integrated_die_casting_process_factsheet.pdf)

21. Aluminum Friction Stir Tailor Welded Blanks
    A. Researchers have demonstrated a new process for the expanded use of lightweight aluminum in cars and trucks at the speed, scale, quality and consistency required by the auto industry. In partnership with General Motors, Alcoa and TWB Company LLC, researchers from the Department of Energy's Pacific Northwest National Laboratory have transformed a joining technique called friction stir welding, or FSW. (http://www.pnnl.gov/news/release.aspx?id=4200)
        - PNNL
22. Infrared, In-line Weld Inspection
    A. APLAIR Manufacturing Systems, a small business in Tennessee, licensed the infrared weld inspecting technology from ORNL to improve and validate the technology. (https://www.energy.gov/eere/success-stories/articles/eere-success-story-promising-inspection-technique-vehicle-welding)
23. Aluminum Formability Extension
24. Autonomie Vehicle Energy Consumption Model
    A. Autonomie s a most powerful and robust system simulation tool for vehicle energy consumption and performance analysis. Developed in collaboration with General Motors, Autonomie is a MATLAB©-based software environment and framework for automotive control-system design, simulation, and analysis. (https://www.anl.gov/energy-systems/project/tool-vehicle-system-simulation-autonomie)
        - ANL
25. Advancing Plug-In Hybrid Technology and Flex Fuel Application on a Chrysler Mini-Van PHEV
    A. FCA US LLC viewed this DOE funding as a historic opportunity to begin the process of achieving required economies of scale on technologies for electric vehicles. The funding supported FCA US LLC's light-duty electric drive vehicle and charging infrastructure-testing activities and enabled FCA US LLC to utilize the funding on advancing Plug-in Hybrid Electric Vehicle (PHEV) technologies to future programs. FCA US LLC intended to develop the next generations of electric drive and energy batteries through a properly paced convergence of standards, technology, components, and common modules, as well as first-responder training and battery recycling. To support the development of a strong, commercially viable supplier base, FCA US LLC also used this opportunity to evaluate various designated component and sub-system suppliers. The original project proposal was submitted in December 2009 and selected in January 2010. The project ended in December 2014. (https://energy.gov/eere/vehicles/downloads/advancing-plug-hybrid-technology-and-flex-fuel-application-chrysler-mini-van)
26. Thermal Management System for Lithium Batteries
27. Heavy Duty Vehicle Add on Aerodynamic Technology
    A. Physicist Kambiz Salari at the Energy Department's Lawrence Livermore National Laboratory (LLNL) is applying his expertise in fluid dynamics, computer modeling and simulation to improve the fuel economy of heavy vehicles through aerodynamic improvements. The program is funded by the Department of Energy's Vehicle Technologies Office in the Office of Energy Efficiency and Renewable Energy. Salari and his LLNL team, NASA Ames, and

industry collaborators have already designed cost-effective aerodynamic add-on devices that help heavy vehicles on the road today achieve more than 15% fuel economy improvements. By partnering with multiple companies including Navistar, Freight Wing, ATDynamics, Kentucky Trailer, Wabash National, Frito-Lay, Spirit, Safeway, Michelin and Praxair, Salari and his team have significantly increased fleets' adoption of aerodynamic and other energy-efficiency devices developed by LLNL. (https://energy.gov/eere/success-stories/articles/eere-success-story-heavy-vehicle-fuel-efficiency-no-drag)

- LLNL

28. Cathode Catalysts and Supports for Fuel Cells
    A. The U.S. Department of Energy's (DOE's) efforts have advanced the state of the art of hydrogen and fuel cell technologies—making significant progress toward overcoming key challenges to widespread commercialization. See the Fuel Cell Technologies Office's accomplishments fact sheet. (https://energy.gov/eere/fuelcells/fuel-cell-technologies-office-accomplishments-and-progress) (https://energy.gov/eere/fuelcells/downloads/advanced-cathode-catalysts-and-supports-pem-fuel-cells-0)
        - ANL
29. GenDrive™ Fuel Cell Power System
    A. FedEx Freight Delivers on Clean Energy (https://energy.gov/articles/fedex-freight-delivers-clean-energy)
30. Hydrogen Generation from Electrolysis
31. TITAN™: High Pressure Hydrogen Storage Tank for Gaseous Truck Delivery
    A. Development of High Pressure Hydrogen Storage Tank for Storage and Gaseous Truck Delivery (https://www.hydrogen.energy.gov/pdfs/review15/pd021_baldwin_2015_o.pdf)
        - ANL
32. Orion™: Fuel Cell Technology for Hybrid Power Applications
    A. Nuvera Fuel Cells, in a new partnership with the U.S. Department of Energy's (DOE) Pacific Northwest National Laboratory (PNNL) and Thermo King, a manufacturer of transport temperature control systems for a variety of mobile applications and a brand of Ingersoll Rand, is using advanced fuel cell technology to power transport refrigeration units (TRUs) on tractor trailers used to deliver frozen foods and fresh produce to supermarkets. Using fuel cells in place of the more commonly used diesel generators will cut carbon emissions and reduce noise pollution. (http://www.nuvera.com/blog/nuvera-and-doe-national-laboratory-to-demonstrate-fuel-cell-power-for-refrigerated-trucks-in-grocery-distribution)
        - PNNL
33. Reduction in Fabrication Costs of Gas Diffusion Layers
34. Hydrogen Refueling Station Technology
    A. EERE supported the development of the world's first tri-generation station—a combined heat and power system that produces hydrogen in addition to heat and electricity—in Fountain Valley. The system runs on natural gas and biogas generated by the Orange County Sanitation District's wastewater treatment facility. Hydrogen produced by the fuel cell system is sent to a fueling station that is able to support 25 to 50 fuel cell electric vehicles. The fuel cell system also produces 250 kilowatts of electricity to power the wastewater treatment facility. The project was developed as a partnership between the Energy

    Department, California Air Resources Board, South Coast Air Quality Management District, the Orange County Sanitation District, Southern California Gas Company and private industry.The project is managed by Air Products and Chemicals, Inc., and additional partners include FuelCell Energy and the National Fuel Cell Research Center. (https://energy.gov/eere/success-stories/articles/eere-success-story-worlds-first-tri-generation-fuel-cell-and-hydrogen)

35. Electrolyzer Incorporating a Low-Cost Membrane
    A. Giner, Inc. (Giner) has developed PEM-based electrolyzer technology that operates at differential pressure for producing hydrogen at moderate to high pressure directly in the electrolyzer stack, while oxygen is evolved at nearatmospheric pressure. The goals of the project are to reduce the cost of the stack and system, improve electrolyzer efficiency, and to demonstrate electrolyzer operation at moderate pressure. (https://www.hydrogen.energy.gov/pdfs/progress13/ii_a_1_hamdan_2013.pdf)
36. Stackable Structural Reactor for Low-Cost Hydrogen Production
    A. https://energy.gov/sites/prod/files/2015/04/f22/fcto_2014_pathways_commercial_success.pdf pg. 200
37. Hydrogen Composite Tanks
    A. https://www.hydrogen.energy.gov/pdfs/progress15/iv_b_7_newhouse_2015.pdf
    B. https://www.hydrogen.energy.gov/pdfs/progress15/iv_d_7_haight_2015.pdf
        - ORNL
38. DetecTape™: Early Warning Visual Hydrogen Leak Detector
    A. DetecTape™, a color-changing, self-fusing silicone tape designed to detect hydrogen gas leaks in fuel cell, transmission, storage and generation facilities. Hydrogen equipment operators can use this new visual indicator to quickly identify precise leak locations and initiate maintenance protocols, expediting the restoration of equipment while maintaining a safe workplace. The chemochromic gas detector combines Element One's hydrogen reactive pigment with Midsun Specialty Products' UV-resistant, self-fusing silicone tape. Lab testing reports performed at the U.S. Department of Energy's National Renewable Energy Laboratory over the past 13 months are available upon request. Field trials are also underway with several prominent laboratories, facilities, and stations in the hydrogen community. (https://energy.gov/sites/prod/files/2016/03/f30/fcto_webinarslides_detectape_h2_leaks_031416.pdf)
        - NREL
39. Low-Cost PEM Fuel Cell Metal Bipolar Plates
    A. https://www.hydrogen.energy.gov/pdfs/review13/fc105_wang_2013_p.pdf
        - ORNL
40. Membranes and Membrane Electrode Assemblies for Dry, Hot Operating Conditions
    A. Polymer electrolyte membrane fuel cells (PEMFCs) represent a promising energy technology for transportation, stationary, and back-up power applications. While many breakthroughs have been made over the last few years in developing PEMFCs, technical and economic barriers for their commercialization still exist. Key areas where improvements are still needed are in expanding the temperature range and lowering the humidification

requirements of the stack, particularly for automotive fuel cell applications. (https://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pathways_2011.pdf)

41. Complex Coolant for Polymer Electrolyte Membrane Fuel Cells
    A. https://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pathways_2011.pdf
    B. https://energy.gov/sites/prod/files/2015/04/f22/fcto_2014_pathways_commercial_success.pdf
42. Novel Manufacturing Process for Fuel Cell Stacks
    A. https://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pathways_2011.pdf
    B. https://energy.gov/sites/prod/files/2015/04/f22/fcto_2014_pathways_commercial_success.pdf
43. Efficient and cost-effective dewatering of algal systems
    A. The Energy Department today announced up to $15 million for three projects aimed at reducing the production costs of algae-based biofuels and bioproducts through improvements in algal biomass yields. These projects will develop highly productive algal cultivation systems and couple those systems with effective, energy-efficient, and low-cost harvest and processing technologies. This funding will advance the research and development of advanced biofuel technologies to speed the commercialization of renewable, domestically produced, and affordable fossil-fuel replacements. (https://energy.gov/eere/articles/energy-department-announces-15-million-advance-algae-based-biofuels-and-bioproducts)
        - NREL, PNNL, SNL
44. Industrial cellulases and accessory enzymes for biomass and other applications
45. Sacccharomyces cerevisiae for biofuels production
46. Catalytic conversion of biomass to Benzene/Toluene/Xylene (BTX)
47. Integrated hydropyrolysis and hydroconversion (IH2) technology
48. Hydrotreatment technology for small scale biofuels production
49. Clostridium strains for alcohol production from substrate-containing gases
50. Multiple reactor systems and processes for continuous gas fermentation
51. Fermentation processes for producing isopropanol using recombinant microorganisms
52. Engineered Clostridium autoethanogenum strains and methods for simultaneous and independent ethanol and acetate generation
53. Wood molasses production process
54. Nanocellulose materials processes
55. Phenometrics climate simulation reactor
56. Drop-in replacement catalyst for a broad spectrum of vegetable and algal oil feedstocks.
57. Biomass Feedstock Harvesting and Handling Equipment
58.

In the Building Technologies arena, EERE research has led to commercialized technologies including:

59. Building Energy Management Open Source Software
    A. BEMOSS is a Building Energy Management Open Source Software (BEMOSS) platform that is engineered to improve sensing and control of equipment in small- and medium-sized commercial buildings. BEMOSS will be able to optimize electricity usage to reduce energy

consumption and help implement demand response (DR). This opens up demand side ancillary services markets and creates opportunities for building owners, which in turn can help accelerate development of market-ready products like embedded Building Energy Management (BEM) systems and device controllers for HVAC, lighting and plug loads. BEMOSS aims to offer: scalability, robustness, plug and play, open protocol, interoperability, cost-effectiveness, as well as local and remote monitoring, allowing it to work with load control devices form different manufacturers that operate on different communication technologies and protocols. Currently, BEMOSS supports the following prevalent communication technologies: Ethernet (IEEE 802.3), Serial (RS-485), ZigBee (IEEE 802.15.4) and Wi-Fi (IEEE 802.11); and protocols: BACnet, Modbus, Web, OpenADR and SEP protocols. (https://energy.gov/eere/buildings/downloads/building-energy-management-open-source-software-development-bemoss)

60. Integrated Concentrating (IC) Solar Array: Energy-Efficient Facades for Green Buildings
61. Liquidarmor: Advanced Energy-Saving Flashing and Sealant for Buildings
    A. A liquid sealant developed by Dow Chemical, and evaluated at DOE's Oak Ridge National Laboratory, was recognized recently for its superior sealant qualities and performance. LIQUIDARMOR, marketed by Dow, won the 2016 Gold Edison Award for Building Construction & Lighting. The Edison Awards honor the best in innovation and excellence in the development of new products and services. (https://energy.gov/eere/success-stories/articles/eere-success-story-dow-partners-ornl-commercialize-advanced-energy)
        - ORNL
62. QwikSEER WattSaver: Energy Saving HVAC Control
    A. A result of this research produced the QwikSEER+WattSaver™, an electronic control board that operates in the cooling mode of a new or existing air conditioner or heat pump. By varying the airflow of the blower motor, this technology optimizes the airflow of the air conditioner, thus reducing the total energy consumption and improving humidity control and mold control.
63. Thermoelectric Materials for Waste Heat Recovery
    A. https://www1.eere.energy.gov/vehiclesandfuels/pdfs/thermoelectrics_app_2011/monday/meisner.pdf
        - ORNL
64. LED chips and packaging (61 product offerings)
    A. https://energy.gov/sites/prod/files/2016/09/f33/comm-products-factsheet_sept2016_0.pdf
65. LED power supplies (3 product offerings)
66. LED light engine (5 product offerings)
67. Lumiled LUXEON LEDs
68. Advansor: High-Efficiency, Low-Emission Refrigeration System
    A. https://energy.gov/eere/success-stories/articles/eere-success-story-new-advanced-refrigeration-technology-provides
        - ORNL
69. Solstice N40: A Low Global Warming Refrigerant
    A. Research supported by the Energy Department's Building Technologies Office that led to a major breakthrough in refrigeration systems' efficiency is now being carried by a major U.S.

refrigerant wholesaler. (https://energy.gov/eere/success-stories/articles/eere-success-story-new-refrigerant-boosts-energy-efficiency)

- ORNL

70. Wireless Remote Monitoring System for Residential Air Conditioners and Heat Pumps
71. Cree LEDs and Lighting Products
72. XQ series of LEDs; Philips Lumiled's LUXEON TX LED package
73. OpenStudio
    A. OpenStudio is DOE's open-source "operating system" for building energy modeling. Started in 2008 with an EnergyPlus geometry creation plug-in for the 3D drawing tool SketchUp, OpenStudio has grown into a robust, full-featured software development kit (SDK) that automates many of the functions associated with creating energy models, modifying existing energy models to create design alternatives, running energy simulations, and collating, analyzing, and visualizing results from energy modeling experiments.
        - NREL, ANL, LBNL, ORNL, PNNL
74. Trilogy 45 Q-Mode (QE) Ground-Source Integrated Heat Pump
    A. For more than 10,000 years, various cultures have turned to the stable temperature of the ground as a resource of comfort. When it comes to going green while keeping cozy, one of our best options could be going back to our roots. The Energy Department's Oak Ridge National Laboratory has partnered with ClimateMaster -- a leading manufacturer of geothermal and water-source heat pumps -- to develop an appliance that could provide space conditioning and all domestic hot water needs while consuming at least 50% less energy than conventional minimum efficiency equipment. (https://energy.gov/articles/technology-breakthrough-geothermal)
        - ORNL
75. Preserva® Advanced Sequential Dual Evaporator Cycle for Refrigerators
76. Everest Polyolesters: Next-Generation Refrigerant Lubricants
77. Coating product (15 product offerings)
78. Smart Energy Load Control Modules: CEA 2045 Compliant Wireless Controller for Water Heaters/ "Emerson Wireless Controller for Water Heaters"
79. Low-Cost R10/High SHGC Heat Mirror® Window Development
80. Energy Plus
    A. EnergyPlus™ is a whole building energy simulation program that engineers, architects, and researchers use to model both energy consumption—for heating, cooling, ventilation, lighting and plug and process loads—and water use in buildings. (https://energyplus.net/)
        - NREL, Various DOE National Labs
81. ThermaDeck: An Insulated and Ventilated Roof System
    A. https://www.ornl.gov/news/materials-over-top
        - ORNL
82. Predictive Control Harnesses Building Thermal Mass as High Performance Energy Storage
83. Phosphor manufacturing method (15 product offerings)
    A. https://energy.gov/sites/prod/files/2015/07/f24/comm-product-factsheet_jun2015.pdf
84. Metal organic chemical vapor deposition (MOCVD) tool (2 product offerings)
    A. With the help of DOE funding, Veeco is working on reducing epitaxy costs and increasing LED efficiency by developing a physical vapor deposition (PVD) tool for depositing aluminum

nitride buffer layers on LED substrates. (https://energy.gov/eere/ssl/veeco-develops-tool-reduce-epitaxy-costs-and-increase-led-brightness)

-

85. Lithography tool
    A. Ultratech modified an existing lithography tool used for semiconductor manufacturing to better meet the cost and performance targets of the high-brightness LED manufacturing industry. The goal was to make the equipment compatible with the wide range of substrate diameters and thicknesses prevalent in the industry while reducing the capital cost and the overall cost of ownership (COO). (https://energy.gov/eere/ssl/ultratech-develops-improved-lithography-tool-led-wafer-manufacturing)
    B. https://str.llnl.gov/str/Sween.html
        - LLNL, LBNL, SNL
86. Inspection tool
87. L Prize LED Lighting Competition
    A. The L Prize competition will substantially accelerate America's shift from inefficient, dated lighting products to innovative, high-performance products. Just as Thomas Edison transformed illumination over a century ago, the L Prize will drive innovation and set "reach" performance goals for the industry.
    Sponsored by the U.S. Department of Energy, the L Prize is the first government-sponsored technology competition designed to spur lighting manufacturers to develop high-quality, high-efficiency solid-state lighting products that set leading-edge performance benchmarks for industry (https://www.energy.gov/eere/success-stories/articles/eere-success-story-l-prize-competition-drives-led-lighting-innovation)
88. Veeco Instruments, Inc LED Manufacturing Equipment
    A. With the help of DOE funding, Veeco is working on reducing epitaxy costs and increasing LED efficiency by developing a physical vapor deposition (PVD) tool for depositing aluminum nitride buffer layers on LED substrates. (https://energy.gov/eere/ssl/veeco-develops-tool-reduce-epitaxy-costs-and-increase-led-brightness)
89. View Dynamic Glass: Low-Cost, High-Energy-Savings, Solid-State Dynamic Glass
    A. Residential and commercial buildings represent a prime opportunity to improve energy efficiency and sustainability worldwide. Currently, lighting and thermal management within buildings account for 20% of the United States' yearly energy consumption. The objective of this Small Business Innovation Research Phase 2 project is to develop a low-cost, near-infrared (NIR) selective, plasmonic smart insulating glass unit (IGU) that reduces building energy consumption by dynamically optimizing solar gain without affecting natural light.
        - LBNL
    B. https://energy.gov/articles/making-smart-windows-smarter
        - LBNL, NREL
90. OpenADR Client: Distributed Intelligent Automated Demand Response (DIADR) Building Management System
    A. The mission of the OpenADR Alliance is to foster the development, adoption, and compliance of the Open Automated Demand Response (OpenADR) standards through collaboration, education, training, testing and certification.
    (http://www.openadr.org/members)

- LBNL

91. Phosphor product (2 product offerings)
92. Efficient LED System-in-Module for General Lighting
93. LUXEON A and LUXEON S: Warm White Illumination-Grade LED
94. ATLAS: An Energy-Efficient Triple IG Window Manufacturing System
    - LBNL NREL
95. EnerLogic: Low-Emissivity, Energy-Control Retrofit Window Film
96. OptiQ: An Advanced Commercial Window Technology
    A. https://energy.gov/eere/buildings/about-emerging-technologies
97. Suntuitive: Sunlight-Responsive Thermochromic Window Systems
    A. https://energy.gov/eere/amo/suntuitive-sunlight-responsive-thermochromic-window-systems
98. NextAire Packaged Gas Heat Pump
    A. http://web.ornl.gov/info/ornlreview/v44_3_11/article05.shtml
        - ORNL
99. LED chip (5 product offerings)
100. WhiteOptics Reflector Coating for LED Fixtures
    A. https://energy.gov/eere/ssl/whiteoptics-low-cost-reflector-composite-boosts-led-fixture-efficiency
101. Lighting Power and Control Network for SSL Systems
102. Hybrid Solar Lighting
103. Echo: A Hybrid Solar Electric/Thermal System
104. Integrated, Solid-State LED Luminaire for General Lighting
105. Ballast/Drive Technology for Metal Halide or Solid-State Lighting Systems
106. GeoSpring Hybrid Water Heater
    A. https://energy.gov/articles/hot-new-advances-water-heating-technology
        - ORNL
107. Quiet Climate 2: Efficient Heat Pump for Classrooms
    A. https://eetd.lbl.gov/l2m2/classrooms.html
        - LBNL
108. Next-Generation Envelope Materials
    A. https://energy.gov/eere/buildings/listings/building-envelope-projects
        - ORNL, LBNL, NREL, ANL
109. Adapting Wireless Technology for Lighting Control
    A. http://newscenter.lbl.gov/2006/01/30/lighting-it-right-with-smart-dust/
        - LBL
110. SageGlass Electrochromic Windows
    A. http://www.nrel.gov/news/features/feature_detail.cfm/feature_id=1555
        - NREL
    B. https://www.sageglass.com/article/doe%E2%80%99s-national-renewable-energy-lab-incorporates-dynamic-glass-two-state-art-facilities
        - NREL
111. Wireless Infrastructure for Performance Monitoring, Diagnostics, and Control in Small Commercial Buildings

112. High-Efficiency LED Lamp for Solid-State Lighting
113. Vertex Residential Gas Condensing Gas Water Heater

The DOE EERE Wind Energy Technologies Office – has over three decades of demonstrated success in technology commercialization, and the impact of DOE's wind R&D extends to industries outside wind energy, among them automotive and aerospace. Examples from the DOE EERE Wind Office include:

114. Leading wind turbines and system components in today's market, such as GE Wind Energy's 1.5 MW wind turbine, Clipper Windpower's Liberty turbine, Southwest Windpower's Skystream turbine, Knight and Carver's STAR (Sweep Twist Adaptive Rotor) wind turbine blades, and TPI Composites blade fabrication techniques are all traceable to DOE-funded research.
115. Leading global producers, including Vestas Wind and Mitsubishi, have a large number of patents linked to DOE-funded patents.
116. Development of MW Class machines enabled cost-competitive utility-scale wind
    A. Development of Megawatt Class Machines (1986-2000): Fundamental R&D and testing was completed at the National Renewable Energy Laboratory (NREL) that opened the door for modern multi-megawatt wind turbines. This work was done in partnership with Enron/Zond which was later acquired by GE. The turbine concepts developed under this partnership was the flagbearer for the most installed turbine in the country today.
117. Airfoil and blade improvements allow larger rotors with increased energy capture
    A. Flatback Airfoils (2000 – SNL): Flatback airfoils provide improved structural performance of inboard blade sections while also improving the lift characteristics of thick airfoils as compared to those with a sharp trailing edge. Flatback airfoils have had a marked impact as they are now an industry standard with adoption from largest 3 turbine manufacturers in the world (Vestas, GE, and Siemens).
    B. Aeroelastic Tailoring in Blades (1990s – SNL): Aeroelastic tailoring in blades has allowed for turbines to get larger and has been adopted by the largest OEMs in the world. Aeroelastic tailoring in blades allows for passive load reductions in blades, as the blade bends due to high thrust loads, the angle of attack changes due to intentional coupling. The change in angle of attack reduces the lift on the airfoil, and thereby reduces the loading on the rotor.
    C. Carbon Fiber Design Technologies (2003 – SNL): Carbon fiber design technologies were developed in the national labs and now account for 70% of blades currently in production in the industry. This technology allows for dramatic weight reductions in blades, which in turn enables larger rotors, more energy capture and a lower cost of energy.
118. EERE Wind funding has also led to the development of Advanced Computational Tools Enable Industry Technology Innovation
    A. FAST Turbine and Controls Design Tool (2000s – NREL): FAST is an open source hydro-aero-elastic simulation tool for analysis wind turbine designs. FAST is used in all corners of the industry, including academia and offshore applications for the design of wind turbines. A key feature is coupled hydrodynamic and aeroelastic response to atmospheric turbulence and wave interaction for designing floating offshore wind platforms.
    B. Simulator for Wind Farm Applications (SOWFA) High Fidelity Modeling Analysis Tool (2011 – NREL): SOWFA is a high-fidelity modeling tool developed by DOE that is revolutionizing the way wind plants are analyzed by OEM's. The increased analytical accuracy provided by this

tool enables the wind industry to reduce the time and cost for technology innovation and results in increased energy capture at the wind plant level and reduced cost of wind energy.

DOE EERE Solar Office funding has led to the development of numerous commercialized technologies, including:

119. Equipment
    A. Lamination and pulse simulator (Spire)
    B. Sinton instruments testing equipment
120. Materials
    A. Metallization pastes (Dupont Innovalight)
    B. Feedstock materials (Silicor)
        - Plasma Oxidation Technique developed by ORNL and RMX Technologies (https://www.energy.gov/eere/articles/eere-success-story-plasma-oxidation-carbon-fiber-precursor)
    C. Anti-soiling coatings (Enki Technology)
    D. Etching solutions (Allied Chemical, Sun Chemical)
    E. 1366 Technologies silicon wafers
121. Photovoltaic module technology
    A. SunPower/Cogenra modules
    B. Thin film modules (First Solar, SoloPower)
    C. Solar World modules
    D. Suniva modules
    E. Multijunction space solar cells (SolAero and Spectrolab)
122. Solar Packaging
    A. Encapsulant (STR)
    B. Sistine Solar customized module skin
123. Power Electronics
    A. Yaskawa-Solectria smart inverter
    B. SunPower Equinox microinverter
    C. Inverter control code (National Instruments)
    D. Inverter/converter technology and anti-islanding technology embedded in many of today’s commercial inverters and protection systems
124. Solar System Hardware
    A. Smash Solar mounting
    B. Zep Solar mounting
    C. Solaflect trackers
    D. ConnectDER meter collar for easier installation
125. Concentrating Solar Power
    A. Direct steam and molten salt power tower systems with storage (Brightsource, SolarReserve)
    B. Reflector films (3M, ReflecTec)
    C. Low-cost high pressure/high temperature heat exchangers (Brayton Energy)
    D. Wide-aperture parabolic trough solar collectors (SkyFuel, Abengoa)
    E. Atlas’s ultra-accelerated weather system

126. Solar Software
   A. Solar forecasting technology (Clean Power Research and IBM)
   B. Performance modeling and analytics (PVSyst, kWh Analytics, HOMER Energy, numerous others)
   C. Customer acquisition tools (Energy Sage, Faraday, SunNumber, Powerscout, Utility API, Genability)
   D. Automated photovoltaic system design (Folsom Labs, Aurora Solar, Solar Census)
   E. Interconnection tools (Qado Energy, Clean Power Research)
   F. Project development platforms (GeoCF, Sunvestment, Enact)
127. Solar Financial products
   A. Mosaic solar loan product
   B. Sungage Financial solar loan product
   C. Asset management (Ra Power Management, Sighten)

In Water Power Technologies, EERE research has resulted in hydropower products in the market including:

128. The sensor fish was developed by DOE and is an important tool for assessing biological effects of hydropower generating equipment. DOE funded demonstration projects, like Natel Energy, show the viability of small hydropower, and have opened up the door to other development projects.
129. The DOE funded wave energy converter simulation code is an open source code used by ocean energy industry for designing wave energy converters.

62. If DOE's topline budget in accounts other than the 050 account were required to be reduced 10% over the next four fiscal years (from the FY17 request and starting in FY18), does the Department have any recommendations as to where those reductions should be made?

Response: The Department will develop its FY18 budget request in accordance with Administration guidance which the Office of Management and Budget (OMB) is expected to issue after January 20, 2017.

63. How many fusion programs, both public and private, are currently being funded worldwide?

Response: There are 112 fusion programs being funded worldwide. Please see the attached document.

12/6/2016 ACT Question: How many fusion programs, both public and private, are currently being funded worldwide?" A: 112

[Blue indicates facilities where SC/FES provides some level of investment]

Experiment Name	Institution	Location	USA or International	Funding Source	Confinement Strategy	
ITER	International Collaboration (China, EU, India, Japan, Korea, Russia, USA)	Cadarache, France	International - USA membe	Gov	Magnetic	
DIII-D	General Atomics	San Diego, CA USA	USA	Gov	Magnetic	Private company funded by DOE
NSTX-U	Princeton Plasma Physics Lab	Princeton, NJ USA	USA	Gov	Magnetic	
Pegasus	University of Wisconsin-Madison	Madison, Wisconsin, USA	USA	Gov	Magnetic	
Conceptual - no construction known	Lockhead Martin - Skunk Works		USA	Private	Magnetic	
HSX	University of Wisconsin-Madison	Madison, Wisconsin, USA	USA	Gov	Magnetic	
HIDRA	University of Illinois	Illinois, USA	USA	Gov	Magnetic	
MST	University of Wisconsin-Madison	Madison, Wisconsin, USA	USA	Gov	Magnetic	
C-2U / C-3	Tri Alpha Energy	California, USA	USA	Private	Magnetic	
HBT-EP	Columbia, University	New York, New York, USA	USA	Gov	Magnetic	
LTX	Princeton Plasma Physics Lab	Princeton, NJ USA	USA	Gov	Magnetic	
MEDUSA	UW-Madison	Madison, WI USA	USA	Gov	Magnetic	
DIONISOS	Massachusetts Institute of Technology	Cambridge, MA, USA	USA	Gov	Magnetic	University programs may use some private funds to support their programs
HIT-SI		Washington	USA	Gov	Magnetic	
CTH	Auburn University	Alabama, USA	USA	Gov	Magnetic	
Large S Experiment	University of Washington	Seatle, WA USA	USA	Gov	Magnetic	
Helimac	University of Texas	Austin, TX	USA	Gov	Magnetic	
COBRA	Cornell University		USA	Gov	Inertial	
Matter Under Extreme Conditions station	LCLS at SLAC	Menlo Park, CA	USA	Gov	Inertial	
OMEGA	University of Rochester	Rochester, NY USA	USA	Gov	Inertial	
NIF	Lawrence Livermore National Lab	Livermore, CA USA	USA	Gov	Inertial	
ZaP	University of Washington	Washington, USA	USA	Gov	Inertial	
Trident	Los Alamos National Lab	Los Alamos, NM	USA	Gov	Inertial	
ZEBRA	University of Nevada	Nevada, USA	USA	Gov	Inertial	
NIKE	Naval Research Laboratories	USA	USA	Gov	Inertial	
Jupiter Laser Facility	Lawrence Livermore National Lab	Livermore, CA	USA	Gov	Inertial	
Z-machine	Sandia National Lab	NM, USA	USA	Gov	Inertial	
NDCX-II	Lawrence Berkeley National Lab	Berkeley, CA	USA	Gov	Inertial	
DPE	Sandia National Lab	Livermore, CA, USA	USA	Gov	Materials Test Stand	
PISCES-A/-B	University of California, San Diego	San Diego, CA, USA	USA	Gov	Materials Test Stand	
TPE	Idaho National Lab	Idaho Falls, ID, USA	USA	Gov	Materials Test Stand	
Proto-MPEX	Oak Ridge National Lab	Oak Ridge, TN, USA	USA	Gov	Materials Test Stand	
GOLEM	Czech Technical University	Prague, Czech Republic	International	Gov	Magnetic	
T-10	Kurchatov Institute	Moscow, Russia	International	Gov	Magnetic	
Alvand		Tehran, Iran	International	Gov	Magnetic	
Joint European Torus (JET)		Culham, United Kingdom	International	Gov	Magnetic	
JT-60SA		Naka, Ibaraki Prefecture, Japan	International	Gov	Magnetic	
Large Helical Device (LHD)	National Institute for Fusion Science	Toki, Gifu, Japan	Internatioanl	Gov	Magnetic	
Aditya	Institute for Plasma Research	Gujarat, India	International	Gov	Magnetic	
COMPASS		Prague, Czech Republic	International	Gov	Magnetic	
FTU		Frascati, Italy	International	Gov	Magnetic	
ISTTOK	Instituto de Plasmas e Fusão Nuclear	Lisbon, Portugal	International	Gov	Magnetic	
ASDEX Upgrade		Garching, Germany	International	Gov	Magnetic	
H-1NF	Australia National University		International	Gov	Magnetic	
TCV	EPFL	Switzerland	International	Gov	Magnetic	
TCABR	University of São Paulo	São Paulo, Brazil	International	Gov	Magnetic	

HT-7		Hefei, China	International	Gov	Magnetic
CSTN-IV	Nagoya University	Nagoya, Japan	International	Gov	Magnetic
MAST-U	Culham	Culham, United Kingdom	International	Gov	Magnetic
Globus-M	Ioffe Institute	Saint Petersburg, Russia	International	Gov	Magnetic
HL-2A		Chengdu, China	International	Gov	Magnetic
EAST		Hefei, China	International	Gov	Magnetic
KSTAR		Daejon, South Korea	International	Gov	Magnetic
SST-1		Gandhinagar, India	International	Gov	Magnetic
IR-T1	Islamic Azad University	Tehran, Iran	International	Gov	Magnetic
ST25	Tokamak Energy	Culham, Oxfordshire, UK	International	Private	Magnetic
WEST		Cadarache, France	International	Gov	Magnetic
Proto-Sphera	ENEA	Italy	International	Gov	Magnetic
TST-2	University of Tokyo	Tokyo, Japan	International	Gov	Magnetic
SUNIST	Tsinghua University	China	International	Gov	Magnetic
ETE	National Space Research Institute	Brazil	International	Gov	Magnetic
W7-X		Germany	International	Gov	Magnetic
RFX		Italy	International	Gov	Magnetic
Gas Dynamic Trap	Budker Institute of Nuclear Physics	Akademgorodok, Russia	International	Gov	Magnetic
TJ-II		Spain	International	Gov	Magnetic
FTP		Italy	International	Gov	Magnetic
Extrap-T2R		Sweden	International	Gov	Magnetic
IGNITOR (?)		Russia and Italy	International	Gov	Magnetic
NOVA-UNICAMP		Brazil	International	Gov	Magnetic
TCR-Br		Brazil	International	Gov	Magnetic
KTM		Russia	International	Gov	Magnetic
H1NF		Australia	International	Gov	Magnetic
Heliotron J		Japan	International	Gov	Magnetic
KTX		China	International	Gov	Magnetic
Gutta		Russia	International	Gov	Magnetic
CPD		Japan	International	Gov	Magnetic
LATE		Japan	International	Gov	Magnetic
GLAST		Islamabad, Pakistan	International	Gov	Magnetic
Uragan-3	Kharkiv Institute of Physics and Technology	Kharkiv, Ukraine	International	Gov	Magnetic
SCR-1	Instituto Tecnológico de Costa Rica	Cartago, Costa Rica	International	Gov	Magnetic
FT-2	IOFFE Institute	St. Petersburg, Russia	International	Gov	Magnetic
TUMAN-3	IOFFE Institute	St. Petersburg, Russia	International	Gov	Magnetic
EGYPTOR		Cairo, Egypt	International	Gov	Magnetic
LIBTOR (TM-4A)		Tajour, Libya	International	Gov	Magnetic
T-11M		Triniti, Russia	International	Gov	Magnetic
SINP		Kolkata, India	International	Gov	Magnetic
HYBTOK-II		Nagoya, Japan	International	Gov	Magnetic
Damavand		Tehran, Iran	International	Gov	Magnetic
J-TEXT	Wuhan University	Huazhong, China	International	Gov	Magnetic
QUEST		Japan	International	Gov	Magnetic
HIST		Japan	International	Gov	Magnetic
TPE-RX	National Institute of Advanced Industrial Science and Technology	Tsukuba, Japan	International	Gov	Magnetic
Qiangguang-1		China	International	Gov	Magnetic
VEST		Korea	International	Gov	Magnetic
ToriX		Paris, France	International	Gov	Magnetic
MTF	General Fusion		International	Private	Inertial
Laser Megajoule	The French Alternative Energies and Atomic Energy Commission (CEA)	Bordeaux, France	International	Gov	Inertial
FIREXI and II	ILE	Osaka, Japan	International	Gov	Inertial
Gekko XII	Institute for Laser Engineering	Osaka, Japan	International	Gov	Inertial

ISKRA-4	Lasers at the Russian Federal Nuclear Center VNIIEF	Russia	International	Gov	Inertial
ISKRA-5	Lasers at the Russian Federal Nuclear Center VNIIEF	Russia	International	Gov	Inertial
Vulcan	Central Laser Facility, Rutherford Appleton Laboratory	UK	International	Gov	Inertial
SG-III		China	International	Gov	Inertial
LULI2000	LULI laboratory at École Polytechnique	France	International	Gov	Inertial
LFEX		Japan	International	Gov	Inertial
MAGNUM-PSI/PILOT-PSI	Dutch Institute for Fundamental Energy Research	Eindhoven, Netherlands	International	Gov	Materials Test Stand
PSI-2/JULE-PSI/JUDITH	Forschungszentrum Juelich	Juelich, Germany	International	Gov	Materials Test Stand
ITER Divertor Test Facility	Efremov Institute	St. Petersburg, Russia	International	Gov	Materials Test Stand
GLADIS	IPP Garching	Munchen, Germany	International	Gov	Materials Test Stand
NAGDIS-II	Nagoya Univ.	Nagoya, Japan	International	Gov	Materials Test Stand
CDPS	Tohoku Univ.	Sendai, Japan	International	Gov	Materials Test Stand
MAGPIE	Australian National Univ.	Canberra, Australia	International	Gov	Materials Test Stand

64. What mechanisms exist to help the national laboratories commercialize their scientific and technological prowess?

Response: The following is a list of partnering mechanisms* that are used by the DOE laboratories to engage with industry and others for numerous purposes:

Cooperative Research and Development Agreements (CRADA)
Strategic Partnership Project (SPP)
Agreements for Commercializing Technology (ACT)
Technical Assistance Agreement
Proprietary and Non-proprietary User Agreements
Technology License Agreement
Material Transfer Agreement
Small Business Technology Transfer (STTR)

*Not all technology transfer mechanisms are available at each of the laboratories. In some cases they might not be legally authorized at all labs (i.e. ACT) while in others the resources may not be available to offer all the mechanisms (i.e. User facilities)

The *Guide to Partnering with DOE's National Laboratories* provides an overview of the various mechanisms available for partnering with the national labs. Excerpts from this Guide are provided below. More information on the above mechanisms is available in the Guide available online (https://www.inl.gov/wp-content/uploads/2016/05/Revised-Guide-Partnering-with-National-Labs-Final.pdf).

Cooperative Research and Development Agreements (CRADA)

A CRADA is an Agreement between one or more laboratories and one or more non-federal entities (CRADA Participants) that permits the transfer of laboratories' technologies, processes, R&D capabilities, or technical know-how to the private sector and allows for the option to negotiate up to an exclusive license in a field of use for any laboratory inventions that result from the work performed under the CRADA (subject inventions) as well as protection for up to five years of commercially valuable information generated through the work under the CRADA.

Strategic Partnership Project (SPP)

Strategic Partnership Projects (SPP) enable industry, non-profit institutions, and other non-federal entities to engage the laboratory to perform a defined scope of work or tasks on a full-cost recovery basis.

Agreements for Commercializing Technology (ACT)

Agreements for Commercializing Technology (ACT) is a pilot program which functionally enables Laboratory Contractors to act in a private capacity and conduct privately-sponsored research at the Contractor's risk for third parties. Under this mechanism, DOE allows the laboratory contractor to enter into agreements on a commercial basis as a private entity, and assume the risk of any terms of the agreement.

Technical Assistance Agreement

Many Labs offer a Technology Assistance Program, which leverages the expertise of laboratory scientists and engineers to help members of the small business community solve important challenges.

Proprietary and Non-Proprietary User Agreements

Specialized, standard agreements are available to expedite user access to DOE Designated User Facilities^. Each national laboratory has state of the art facilities that are open to industrial and academic users for conducting research. It is possible to perform proprietary or non-proprietary research at the Designated User Facilities. For proprietary research that is not intended for publication, access to facilities is available on a full cost recovery basis.

^Listings of these facilities can be found at http://energy.gov/node/210241.

Technology License Agreement

The DOE laboratories also engage with business via license to commercialize laboratory-developed technology. A *Licensing Guide and Sample License* is also available online (http://energy.gov/sites/prod/files/2015/01/f19/LicensingGuideFINAL.pdf).

Material Transfer Agreement

A Material Transfer Agreement (MTA) protects tangible research products provided either to or by the Laboratory. This is an agreement that the products provided by one party to another will be protected from further transmittal. The agreement normally requires return or destruction of materials and products at the end of the agreement.

Small Business Technology Transfer (STTR)

Small Business Technology Transfer (STTR) is similar to Small Business Innovation Research (SBIR) except it additionally requires that the small business concern collaborate with a U.S. nonprofit research institute (RI) through the STTR-funded project. A DOE National Lab may, and frequently serves as an RI on STTR awards. Both are statutory programs in which federal agencies set aside a small fraction of their funding for competitions among small business only.

MajorTechnology Transfer Mechanisms at DOE Laboratories at a Glance

Agreement	Use	Funding	Subject Inventions	Generated Data	U.S. Competitiveness	Cost	Highlights
Cooperative Research and Development Agreement (CRADA)	Collaborative research between DOE Labs and public and/or private entities for the mutual benefit of the parties	Private and/or Federal funds	Lab and Participant may elect their own inventions and Participant has right to negotiate exclusive license to Lab inventions	Protected for up to 5 years	Products embodying IP resulting from CRADA shall be manufactured substantially in the U.S.	Lab and Participant may share costs or Participant pays 100% funds-in	✓ Collaborative research ✓ 5 year data protection ✓ Designed for multi-party collaborative research
Strategic Partnership Project (SPP)	Work for businesses and other non-federal entities using highly specialized or unique DOE facilities, services or technical expertise	Private funds	Sponsor may elect title to Subject Inventions[1]	Protected as Sponsor's proprietary data w/limited exceptions[1,2,3]	U.S. Preference: Sponsor agrees not to grant any party exclusive right to use or sell products embodying Subject Inventions in the U.S. unless products are manufactured substantially in the U.S.	Sponsor pays full cost recovery	✓ Sponsor typically retains right to elect title to subject inventions ✓ Generated data treated as proprietary
		Federal funds (e.g. grantee)	Lab may elect title to Subject Inventions of the Lab	Unlimited Gov. rights	U.S. Preference (see above)	Sponsor pays full cost recovery	✓ Access to unique facilities and expertise using
Agreements for Commercializing Technology (ACT)	Work for businesses and other non-federal entities using highly specialized or unique DOE facilities, services or technical expertise	Private funds	Initial title to the designated IP Lead. (ACT Participant or Lab Contractor)	Protected as proprietary data w/limited exceptions[1,2,3]	U.S. Preference (see above)	Participant pays full cost recovery <u>plus</u> additional negotiated compensation to the Contractor	✓Flexible terms for IP, indemnity, adv. payment ✓Optional performance guarantee ✓ Negotiable IP terms ✓ Option for limited Gov. R&D
Proprietary User Agreement	User may access designated facilities to conduct its own proprietary research	Private funds	User may elect title to its Subject Inventions	User may protect as proprietary	n/a	User pays approved user rate	✓Generated data treated as proprietary ✓Merit based access to unique facilities
Non-Proprietary User Agreement	Non-proprietary research at designated facilities	n/a	Lab and User may elect their own Subject Inventions	Unlimited Gov. Rights	U.S. Preference (see above)	Each party covers own cost	✓Merit based access to unique facilities

[1] Certain exceptions or restrictions may apply (e.g. foreign SPP Sponsors may be granted the right to elect title to inventions and receive proprietary data protection but only after the approval of DOE field patent counsel and concurrence from the cognizant DOE program office).[2] Proprietary data protection may not be available at all facilities. [3] If the limited Gov. R&D license is utilized, data protection will be limited to 5 years.

Source: Guide to Partnering with DOE's National Laboratories, Technology Transfer Working Group 2016

65. Which activities does the Department describe as commercialization programs or programs with the specific purpose of developing a technology for market deployment?

Response: In general at DOE, we are developing tools, conducting foundational research and advancing technologies to facilitate market adoption and enable more diverse and affordable options for the private sector to develop and commercialize.

A list of examples is attached as Appendix D of Baseline and Process Evaluation of Small Business Vouchers Pilot: Appendix D - National Laboratory Initiatives and Technology Commercialization Initiatives Having Some Indirect Lab Involvement http://energy.gov/eere/analysis/downloads/baseline-and-process-evaluation-small-business-vouchers-pilot

Appendix D National Laboratory Initiatives and Technology Commercialization Initiatives Having Some Indirect Lab Involvement

In addition to the SBV pilot – the subject of this evaluation study – there are other national lab initiatives. Also, there are a number of technology commercialization initiatives that indirectly involve the labs.

D.1 LAB INITIATIVES

D.1.1 DOE's Lab-Corp Pilot (2015 to Present)

Lab-Corps is a U.S. Department of Energy (DOE)-funded pilot intended to accelerate the commercialization of clean energy technologies from DOE national laboratories (labs). Office of Energy Efficiency and Renewable Energy's (EERE's) Technology-to-Market program provided $2.3 million (fiscal year 2015) to launch the Lab-Corps pilot, and received FY 2016 and FY 2017 funding to continue operations. Lab-Corps trains selected lab scientists and engineers in techniques to accelerate technology commercialization. Training occurs in a group setting with extensive individual coaching and feedback provided by experienced entrepreneurs.

D.1.2 Lab-Embedded Entrepreneurship Program (2014 to Present)

Lab-Embedded Entrepreneurship Program (LEEP) provides an institutional home for researchers to build their research into products and train to be entrepreneurs. LEEP is funded by EERE's Advanced Manufacturing Office, and co-managed with EERE's Technology-to-Market Program. LEEP takes top entrepreneurial scientists and engineers and embeds them within the U.S. national laboratories to perform applied research and development (R&D) with the express goal of launching a clean energy business. In addition to technological access and support, LEEP trains innovators to develop entrepreneurial acumen and skills, while introducing them to the ecosystem partners needed to facilitate commercial and investment opportunities. This dual focus on R&D and entrepreneurial development provides innovators with the platform they need to take their ideas from the lab and onto the commercialization pathway.

D.1.3 Agreement for Commercializing Technology (2011 to 2017)

The Agreement for Commercializing Technology (ACT) was created in response to feedback received in a Notice of Inquiry Concerning Technology Transfer at DOE National Laboratories. Initially launched as a three-year pilot program in December 2011, the ACT allows lab contractors to negotiate and enter agreements directly with the private sector sponsors using terms and conditions that are more consistent with industry practices. These privately sponsored research agreements are performed at the contractor's risk. Under ACT, the contractor may charge those parties additional compensation beyond the direct costs of the work at the lab. Some of the benefits that the contractors offered under an ACT include waiver of Advanced Payment requirements, fixed price contracting, performance guarantees, IP flexibility, and the option for a government research license for subjects' inventions instead of the broader a government use license.

D.1.4 Technology Commercialization Fund (2005 to Present)

The Technology Commercialization Fund (TCF) is a nearly $20 million funding opportunity that leverages the R&D funding in the applied energy programs to mature promising energy technologies with the potential for high impact. It uses 0.9 percent of the funding for the Department's applied energy research, development, demonstration, and commercial application budget for each fiscal year from the Office of Electricity, EERE, Office of Fossil Energy, and Office of Nuclear Energy. These funds are matched with funds from private partners to promote promising energy technologies for commercial purposes. The goal of the TCF is two-fold. First, it is designed to increase the number of energy technologies developed at DOE's national labs that graduate to commercial development and achieve commercial impact. Second, the TCF will enhance the Department's technology transitions system with a forward-looking and competitive approach to lab-industry partnerships. TCF enhance DOE's technology transitions efforts by providing national lab technologies funds for maturation, empowering a broader set of potential industry partners to engage with the national laboratories, and focused industry engagement to identify high-quality partners. EERE is the largest contributor to this program.

D.1.5 Entrepreneur-in-Residence (2007 to 2008)

EERE began its Entrepreneur in Residence (EIR) initiative in 2007 to support clean energy technology commercialization and to address long-standing concerns that national lab inventions were not being sufficiently transferred into the marketplace. After conducting a competitive solicitation, EERE selected venture capital-sponsored entrepreneurs and placed them at key national laboratories. EERE's goal was to accelerate lab technology transfer by enabling start-up entrepreneurs to work directly with the laboratories, thereby bridging the gap between leading scientific and business talent.

D.1.6 Historical Technology Maturation Programs

For more information about the history of DOE technology maturations programs see "Department of Energy Technology Maturation Programs", IDA Science and Technology Policy Institute, May 2013 available at *https://www.ida.org/idamedia/Corporate/Files/Publications/STPIPubs/ida-p-5013.ashx.*

D.2 COMMERCIALIZATION INITIATIVES INDIRECTLY INVOLVING LABS

D.2.1 Build4Scale Manufacturing Training for Cleantech Entrepreneurs (2016 to Present)

The Energy Department's Build4Scale Manufacturing Training for Cleantech Entrepreneurs is a joint effort between the Clean Energy Manufacturing Initiative (CEMI) and the Office of Energy Efficiency and Renewable Energy's (EERE's) Technology-to-Market Office that provides entrepreneurs with the tools they need to identify and address manufacturing challenges early in the process. Understanding how to navigate these challenges saves time and capital, making cleantech startups more attractive to industry partners and investors.

D.2.2 DOE's clean technology university prize competition (Cleantech Up) (2015 to Present)

DOE's Cleantech University Prize (Cleantech UP) aims to inspire and equip the next generation of clean energy entrepreneurs and innovators by providing them with competitive funding for business development and commercialization training and other educational opportunities.

Launched in 2015, Cleantech UP builds on its precursor, the DOE National Clean Energy Business Plan Competition. Eight institutions will host annual Cleantech UP Collegiate Competitions, where students receive entrepreneurial support and compete for cash prizes and services to further support the commercialization of their clean energy technologies. The Collegiate Competitions will establish team development and training that will aid students in developing the skills to move clean energy technologies from the discovery phase to the marketplace. Winners of the Collegiate Competitions will be eligible to compete in the Cleantech UP National Competition. In 2016, the National Competition included a $50,000 voucher at a National Laboratory.

D.2.3 DOE's National Incubator Initiative for Clean Energy (2014 to Present)

The National Incubator Initiative for Clean Energy (NIICE) enables U.S. companies with new clean energy technologies and business models to enter the marketplace or reach commercial readiness faster than before through technical services and connections to industry. NIICE has established a national network of more than 19 different incubators and supporting organizations. Known as the Incubatenergy Network, its members are working together to share best practices and build connections to support entrepreneurs that are driving innovation in clean energy sectors across the nation. Incubatenergy is led by the Electric Power Research Institute in partnership with the National Renewable Energy Laboratory. The initiative also funded several regional incubators that have attracted leading industry partners to help companies scale up, develop markets, and deploy energy innovations at an expedited rate.

D.2.4 DOE National Clean Energy Business Plan Competition (2011 - 2015)

DOE's National Clean Energy Business Plan Competition built regional networks of student-focused business creation contests across the country, with six regional organizations receiving a total of $ 2 million over three years to host competitions, including $100,000 each in annual prize money for the first-place teams. The regional competitions shared common objectives that included creating a new generation of entrepreneurs to address the nation's energy challenges. The regional winners competed each year for the Grand Prize in a final nationwide Competition. Sponsors of the National Competition included the National Renewable Energy Laboratory.

D.2.5 America's Next Top Energy Innovator (2011 - 2013)

To increase engagement with small businesses, the America's Next Top Energy Innovator Program was launched in May 2011. The program made it easier for start-ups to evaluate inventions and technologies developed at the DOE's national laboratories by lowering the cost of an option agreement for up to three patents for $1,000. An option agreement is a precursor to a license agreement and allows companies time to evaluate the technology and to assemble resources required to commercialize the technology. The option duration was set at 12 months, with the potential for a three to six-month extension. Participating start-ups were invited to enter the America's Next Top Energy Innovator Competition. Each participant in the competition uploaded a short video onto the DOE website, and a public voting competition was held to select the most innovative company. The site received one-half million unique hits. Experts conducted a separate review of the companies and scored them based on their potential economic and societal contributions. The winners of the competition were featured at the 2012 Advanced Research Projects Agency-Energy (ARPA-E) Energy Innovation Summit and had the opportunity to meet the Secretary of Energy.

D.2.6 Energy Innovation Portal (2010 to Present)

The Energy Innovation Portal is a one-stop resource to locate energy-related technologies developed with EERE funding and available for licensing from national laboratories and participating research institutions. Developed and managed by the National Renewable Energy Laboratory (NREL), the Portal was created to simplify access and increase private sector licensing of energy efficiency and renewable energy technologies at DOE laboratories. The Portal contains over 16,000 DOE-created patents and patent applications, providing streamlined searching and browsing of patents, patent applications, and marketing summaries for clean energy technologies. The Portal also allows interested parties to directly contact the licensing representative from each lab and improves opportunities for "cross-laboratory" intellectual property bundling.

D.2.7 Small Business Innovation Research and Small Business Technology Transfer (1983 to Present)

The Small Business Innovation Research (SBIR) program is a highly competitive program that encourages domestic small businesses to engage in federal research and/or research and development (R/R&D) that has the potential for commercialization. The Small Business Technology Transfer (STTR) program, like SBIR, expands funding opportunities in the federal innovation R&D arena. Unlike SBIR, it requires small businesses to formally collaborate with a research institution. STRR’s role is to bridge the gap between the performance of basic science and commercialization of resulting innovations.

In fiscal year 2013, the SBIR/STTR Programs Office within the Office of Science initiated an effort to utilize the SBIR and STTR programs to assist with technology transfer. This initiative, called the SBIR Technology Transfer Opportunity Pilot, was motivated by the opportunity to combine the commercialization objectives of the SBIR and STTR programs with the technology transfer goals of the Department. Participation in the SBIR Technology Transfer Opportunity Pilot is voluntary and covered by an MOU between DOE and the participating research institution.

66. What independent evaluation panels does the lab have to assess the scientific value of its work? Who sits on these panels? How often do they hold sessions? Do they publish reports?

Response: The DOE laboratories each have independent boards and/or advisory panels that serve to advise the laboratory contractor on a range of areas from scientific vision and laboratory operations to evaluating the quality and impact of the science and technology R&D that the laboratories conduct. The members of those groups are selected by the laboratory contractor and experienced, subject-matter experts from academia, industry and other stakeholders in the fields being reviewed. The frequency of meetings varies by group. The groups do not publish reports as a matter of course, but they do provide findings to laboratory management.

Separately, the Department assesses the scientific and technical value of the laboratories' work at several stages. Ongoing work at the DOE laboratories is regularly evaluated through program peer reviews in which the sponsoring DOE program office convenes groups of independent experts in the relevant field(s) to assess the laboratory work based on established review criteria. In addition, any new work at a DOE laboratory is generally selected based on merit-based peer review of an initial proposal that is submitted to DOE and thus is evaluated for it scientific and technical merit from the very beginning. The outcome of these reviews is not public information.

67. Can you provide a list of cooperative research and development grants (CRADAs) for the past five years? Please provide funding amounts, sources, and outcomes?

Response: The below chart provides information on the total active CRADAs for FY 2010 through FY 2014 and well as total funds provided by CRADA partners in FY 2014. DOE began collecting the funding data in FY 2014 and does not have earlier funding information.

DOE laboratories are required to submit final reports on individual CRADAs to the Office of Science and Technology Information (OSTI), which is managed by the Office of Science. Attached is a spreadsheet that lists the final reports published within the last five years on individual CRADAs. The reports are available on-line at: https://www.osti.gov/scitech/search/semantic:CRADA%20Reports/filter-results:F Please note that OSTI has not yet received all final reports.

Total number of Active CRADAs:

	FY2010	FY2011	FY2012	FY2013	FY2014
Total Active CRADAs	697	720	742	742	702
Total Partner Funds-In	Not collected	Not collected	Not collected	Not collected	$64.3M

ng int+A1	OSTI ID	Report Number	Other ID Numbers	Publication Date	Title	Date Submitted to OSTI
INL	1037317	INL/CRADA-04-05		11/2/2011	Solvent and Membrane Project – Phase II Development Efforts for Phosphazene Battery Solvents	3/28/2012
INL	1029598	INL/CRADA-06-17		11/8/2011	INL Acoustic Imaging Camera Inspection of Fasteners	10/23/2013
PNNL	1031437	PNNL-20998	35404; VT0401000	12/13/2011	Final Report of a CRADA Between Pacific Northwest National Laboratory and the General Motors Company (CRADA No. PNNL/271): "Degradation Mechanisms of Urea Selective Catalytic Reduction Technology"	12/15/2011
NREL	1033029	NREL/TP-7A10-53587		1/1/2012	Platform Li-Ion Battery Risk Assessment Tool: Cooperative Research and Development Final Report, CRADA Number CRD-10-407	1/12/2012
NREL	1033030	NREL/TP-7A10-53586		1/1/2012	Examination of Na-Doped Mo Sputtering for CIGS Devices: Cooperative Research and Development Final Report, CRADA Number CRD-10-375	1/12/2012
NREL	1038335	NREL/TP-5400-53836		3/1/2012	Thermal Characterization and Analysis of A123 Systems Battery Cells, Modules and Packs: Cooperative Research and Development Final Report, CRADA Number CRD-07-243	4/12/2012
ORNL	1036188	ORNL/TM-2011/544	VT0604000; CEVT008	3/1/2012	DOE Project 18545, AOP Task 2.0B, CRADA with Reaction Design	3/13/2012
SNL	1035847	SAND2012-1709P		3/1/2012	Hybrid Band effects program (Lockheed Martin shared vision CRADA)	3/6/2012
NREL	1039802	NREL/TP-5100-53837		4/1/2012	Overcoming the Recalcitrance of Cellulosic Biomass by Value Prior to Pulping: Cooperative Research and Development Final Report, CRADA Number CRD-07-221	5/10/2012
NREL	1043746	NREL/TP-7A10-53846		4/1/2012	Development of Thin Film Silicon Solar Cell Using Inkjet Printed Silicon and Other Inkjet Processes: Cooperative Research and Development Final Report, CRADA Number CRD-07-260	6/21/2012
NREL	1039824	NREL/TP-5200-53848		4/1/2012	Carbon Nanosheets and Nanostructured Electrodes in Organic Photovoltaic Devices: Cooperative Research and Development Final Report, CRADA Number CRD-08-321	5/10/2012
NREL	1039823	NREL/TP-7A10-53842		4/1/2012	Development and Demonstration of Energy Savings Perform Contracting Methodologies for Hydroelectric Facilities: Cooperative Research and Development Final Report, CRADA Number CRD-08-309	5/10/2012
NREL	1039821	NREL/TP-5200-53588		4/1/2012	Development of ZnTe:Cu Contacts for CdTe Solar Cells: Cooperative Research and Development Final Report, CRADA Number CRD-08-320	5/10/2012
NREL	1039801	NREL/TP-5200-53835		4/1/2012	Metallization for Self Aligned Technology: Cooperative Research and Development Final Report, CRADA Number CRD-08-295	5/10/2012
NREL	1039799	NREL/TP-5000-53456		4/1/2012	Dynamometer Testing of a NW2200 Drivetrain: Cooperative Research and Development Final Report, CRADA Number CRD-10-394	5/10/2012
NREL	1039789	NREL/TP-7A10-53455		4/1/2012	Algae Biofuels Collaborative Project: Cooperative Research and Development Final Report, CRADA Number CRD-10-371	5/10/2012
NREL	1039788	NREL/TP-5500-53841		4/1/2012	GridAgents DER Testing: Cooperative Research and Development Final Report, CRADA Number CRD-08-265	5/10/2012

ng int+A1	OSTI ID	Report Number	Other ID Numbers	Publication Date	Title	Date Submitted to OSTI
NREL	1039787	NREL/TP-5200-53844		4/1/2012	Development of CdS/CdTe Tin Film Devices for St. Gobain Coated Glass: Cooperative Research and Development Final Report, CRADA Number CRD-08-317	5/10/2012
TJNAF	1108689	JLAB-ACC-12-1503; DOE/OR/23177-2931	Reference Metals Company Inc. CRADA 2004-S002-Mod 2.	4/1/2012	Thermal conductivity of large-grain niobium and its effect on trapped vortices in the temperature range 1.8?5 K	12/4/2013
NREL	1040941	NREL/TP-5000-53838		5/1/2012	Wind Turbine Blade Test Definition of the DeWind DW90 Rotor Blade: Cooperative Research and Development Final Report, CRADA Number CRD-09-326	5/24/2012
NREL	1040936	NREL/TP-5000-53574		5/1/2012	Cooperation Reliability Testing of the Clipper Windpower Liberty 2.5 MW Turbine: Cooperative Research and Development Final Report, CRADA Number CRD-07-210	5/24/2012
NREL	1047339	NREL/TP-5200-53590		5/1/2012	Inverted Metamorphic Cell Development: Cooperative Research and Development Final Report, CRADA Number CRD-05-156	8/2/2012
NREL	1040946	NREL/TP-5000-53843		5/1/2012	NREL Wind Turbine Blade Structural Testing of the Modular Wind Energy MW45 Blade: Cooperative Research and Development Final Report, CRADA Number CRD-09-354	5/24/2012
NREL	1046313	NREL/TP-7A10-53849		6/1/2012	Assessment of U S. Energy Wave Resources: Cooperative Research and Development Final Report, CRADA Number CRD-09-328	7/19/2012
NREL	1046280	NREL/TP-7A10-55172		6/1/2012	Microalgal Production of Jet Fuel: Cooperative Research and Development Final Report, CRADA Number CRD-07-208	7/19/2012
NREL	1051900	NREL/TP-7A10-55341		7/1/2012	Low Cost High Efficiency InP-Based Solar Cells: Cooperative Research and Development Final Report, CRADA Number CRD-09-344	9/27/2012
NREL	1045732	NREL/TP-7A10-53591		7/1/2012	High Performance Photovoltaic Solar Cells: Cooperative Research and Development Final Report, CRADA Number CRD-05-169	7/12/2012
NREL	1051916	NREL/TP-7A10-54461		7/1/2012	Application of Vacancy Injection Gettering to Improve Efficiency of Solar Cells Produced by Millinet Solar: Cooperative Research and Development Final Report, CRADA Number CRD-10-417	9/27/2012
NREL	1045721	NREL/TP-7A10-53589		7/1/2012	Platform Li-Ion Battery Risk Assessment Tool: Cooperative Research and Development Final Report, CRADA Number CRD-01-406	7/12/2012
NREL	1047329	NREL/TP-7A10-55051		7/1/2012	Pyrolysis Oil Stabilization: Hot-Gas Filtration; Cooperative Research and Development Final Report, CRADA Number CRD-09-333	8/2/2012
ANL	1050814	ANL/ES/C0900101		8/27/2012	Accelerated deployment of nanostructured hydrotreating catalysts. Final CRADA Report.	9/13/2012
NREL	1051944	NREL/TP-7A10-55340		9/1/2012	Solar Resources Measurements in Houston, TX -- Equipment Only: Cooperative Research and Development Final Report, CRADA Number CRD-06-204	9/27/2012
NREL	1051899	NREL/TP-7A10-55870		9/1/2012	SunEdison Photovoltaic Grid Integration Evaluation: Cooperative Research and Development Final Report, CRADA Number CRD-08-302	9/27/2012

ng int+A1	OSTI ID	Report Number	Other ID Numbers	Publication Date	Title	Date Submitted to OSTI
NREL	1051892	NREL/TP-7A10-55171		9/1/2012	Isolation, Preliminary Characterization and Preliminary Assessment of Scale-Up Potential of Photosynthetic Microalgae for the Production of Both Biofuels and Bio-Active Molecules in the U S. and Canada: Cooperative Research and Development Final Report, CRADA Number CRD-10-372	9/27/2012
NREL	1051909	NREL/TP-7A10-53850		9/1/2012	Testing and Evaluation of Photoelectrochemical Membranes: Cooperative Research and Development Final Report, CRADA Number CRD-08-313	9/27/2012
NREL	1051924	NREL/TP-7A10-55835		9/1/2012	Exploration of Novel Materials for Development of Next Generation OPV Devices: Cooperative Research and Development Final Report, CRADA Number CRD-10-398	9/27/2012
NREL	1051896	NREL/TP-7A10-55869		9/1/2012	New Approaches for Passivation of Crystalline and Amorphous Silicon: Cooperative Research and Development Final Report, CRADA Number CRD-09-351	9/27/2012
NREL	1056748	NREL/TP-7A10-56613		11/1/2012	Development of a High Volume Capable Process to Manufacture High Performance Photovoltaic Cells: Cooperative Research and Development Final Report, CRADA Number CRD-08-322	12/6/2012
NREL	1056729	NREL/TP-7A10-55834		11/1/2012	Optical Materials, Adhesive and Encapsulant, III-V, and Optical Characterization Evaluation: Cooperative Research and Development Final Report, CRADA Number CRD-07-216	12/6/2012
TJNAF	1060917	2011S003		12/12/2012	CRADA Final Report, 2011S003, Faraday Technologies	1/30/2013
ORNL	1059845	ORNL/TM-2012/613		12/15/2012	CRADA Final Report for NFE-08-01826: Development and application of processing and processcontrol for nano-composite materials for lithium ion batteries	1/15/2013
TJNAF	1059035	CRADA 2009S001		12/18/2012	CRADA 2009S001: Investigation of the Supercondcuting RF Properties of Large Grain Ingot Niobium	1/2/2013
FNAL	1333134	FERMILAB--CRADA-FRA-2013-0001	1498701	1/1/2013	Integration and Commissioning of a Prototype Federated Cloud for Scientific Workflows	11/22/2016
NREL	1062481	NREL/TP-7A10-57110		1/1/2013	Development of Novel RTP-like Processing for Solar Cell Fabrication using UV-Rich Light Sources: Cooperative Research and Development Final Report, CRADA No. CRD-11-442	2/7/2013
NREL	1062460	NREL/TP-7A10-55050		1/1/2013	Inks for Ink Jet Printed Contacts for High Performance Silicon Solar Cells: Cooperative Research and Development Final Report, CRADA No. CRD-06-199	2/7/2013
NREL	1063021	NREL/TP-7A10-56614		1/1/2013	Organic Based Nanocomposite Solar Cells: Cooperative Research and Development Final Report, CRADA Number CRD-04-145	2/14/2013
NREL	1062467	NREL/TP-7A10-57185		1/1/2013	Evaluation of Ion Damage in Solar Cells: Cooperative Research and Development Final Report, CRADA Number CRD-07-00234	2/7/2013
NREL	1062473	NREL/TP-7A10-57109		1/1/2013	Equipment Only - Solar Resources Measurements at the University of Texas at Austin, TX: Cooperative Research and Development Final Report, CRADA Number CRD-07-222	2/7/2013

ng int+A1	OSTI ID	Report Number	Other ID Numbers	Publication Date	Title	Date Submitted to OSTI
INL	1061275	INL/CRADA-10-06		1/2/2013	Development and Optimization of Modular Hybrid Plasma Reactor	1/31/2013
AMES	1233429	CRADA--2008-01		1/22/2013	Nanoparticle Technology for Biorefinery of Non-Food Source Feedstocks	12/30/2015
NREL	1067915	NREL/TP-7A10-53847		2/1/2013	Evaluation of Solar Grade Silicon Produced by the Institute of Physics and Technology: Cooperative Research and Development Final Report, CRADA Number CRD-07-211	3/7/2013
NREL	1064543	NREL/TP-7A10-56615		2/1/2013	Scale-Up of CdTe Photovoltaic Device Processes for Commercial Application: Cooperative Research and Development Final Report, CRADA Number CRD-06-196	2/28/2013
PNNL	1064573	PNNL-22120	35404; VT0401000	2/14/2013	Final Report of a CRADA Between Pacific Northwest National Laboratory and the Ford Motor Company (CRADA No. PNNL/265): “Deactivation Mechanisms of Base Metal/Zeolite Urea Selective Catalytic Reduction Materials, and Development of Zeolite-Based Hydrocarbon Adsorber Materials”	2/28/2013
NREL	1073526	NREL/TP-5200-57655		3/1/2013	Development of Commercial Technology for Thin Film Silicon Solar Cells on Glass: Cooperative Research and Development Final Report, CRADA Number CRD-07-209	4/11/2013
NREL	1071976	None		3/1/2013	Development of YBCO Superconductor for Electric Systems: Cooperative Research and Development Final Report, CRADA Number CRD-04-150	3/28/2013
NREL	1076638	NREL/TP-7A10-57817		4/1/2013	Evaluate Si Layers: Cooperative Research and Development Final Report, CRADA Number CRD-07-255	4/25/2013
NREL	1078066	NREL/TP-7A10-58234		4/1/2013	Evaluation of Lifetime of High Efficiency Organic Photovoltaic Devices: Cooperative Research and Development Final Report, CRADA Number CRD-10-379	5/3/2013
NREL	1078058	NREL/TP-7A10-57656		4/1/2013	Catalysis for Mixed Alcohol Synthesis from Biomass Derived Syngas: Cooperative Research and Development Final Report, CRADA Number CRD-08-292	5/3/2013
NREL	1076665	NREL/TP-7A10-57653		4/1/2013	Mobile Building Energy Audit and Modeling Tools: Cooperative Research and Development Final Report, CRADA Number CRD-11-00441	4/25/2013
NREL	1076648	NREL/TP-7A10-57818		4/1/2013	Cooperative Research Between NREL and Ampulse on III-V PV: Cooperative Research and Development Final Report, CRADA Number CRD-12-464	4/25/2013
NREL	1076647	NREL/TP-7A10-55342		4/1/2013	Blade Testing Equipment Development and Commercialization: Cooperative Research and Development Final Report, CRADA Number CRD-09-346	4/25/2013
NREL	1079098	NREL/TP-7A10-53839		4/1/2013	Nanomaterial Composites for Next Generation Water Filters: Cooperative Research and Development Final Report, CRADA Number CRD-06-197	5/9/2013
NREL	1076645	NREL/TP-7A10-57796		4/1/2013	Metallic Inks for Solar Cells: Cooperative Research and Development Final Report, CRADA Number CRD-10-370	4/25/2013
NREL	1076644	NREL/TP-7A10-57183		4/1/2013	Boulder Wind Power Advanced Gearless Drivetrain: Cooperative Research and Development Final Report, CRADA Number CRD-12-00463	4/25/2013

ng int+A1	OSTI ID	Report Number	Other ID Numbers	Publication Date	Title	Date Submitted to OSTI
NREL	1076643	NREL/TP-7A10-53592		4/1/2013	Technical Support to SBIR Phase II Project: Improved Conversion of Cellulose Waste to Ethanol Using a Dual Bioreactor System: Cooperative Research and Development Final Report, CRADA Number CRD-08-310	4/25/2013
NREL	1076621	NREL/TP-7A10-57652		4/1/2013	FFP/NREL Collaboration on Hydrokinetic River Turbine Testing: Cooperative Research and Development Final Report, CRADA Number CRD-12-00473	4/25/2013
TJNAF	1329398	CRADA JSA 2012S004		4/22/2013	Closeout of CRADA JSA 2012S004: Chapter 5, Integrated Control System, of the document of the ESS Conceptual Design Report, publicly available at https://europeanspallationsource.se/accelerator-documents	10/20/2016
AMES	1127164	AL-C-2009-02		5/1/2013	CRADA (AL-C-2009-02) Final Report: Phase I. Lanthanum-based Start Materials for Hydride Batteries	4/9/2014
NREL	1081371	NREL/TP-7A10-58030		5/1/2013	Infrastructure, Components and System Level Testing and Analysis of Electric Vehicles: Cooperative Research and Development Final Report, CRADA Number CRD-09-353	5/30/2013
NREL	1087801	None		6/1/2013	Integrated Biorefinery Project: Cooperative Research and Development Final Report, CRADA Number CRD-10-390	7/18/2013
NREL	1087785	NREL/TP-7A10-58095		6/1/2013	Frito-Lay North America/NREL CRADA: Cooperative Research and Development Final Report, CRADA Number CRD-06-176	7/18/2013
NREL	1087775	None		6/1/2013	Application of Robust Design and Advanced Computer Aided Engineering Technologies: Cooperative Research and Development Final Report, CRADA Number CRD-04-143	7/18/2013
NREL	1084163	NREL/TP-7A10-58455		6/1/2013	Development of Inorganic Precursors for Manufacturing of Photovoltaic Devices: Cooperative Research and Development Final Report, CRADA Number CRD-08-308	6/20/2013
NREL	1083359	NREL/TP-7A10-58461		6/1/2013	Super-Resolution Optical Imaging of Biomass Chemical-Spatial Structure: Cooperative Research and Development Final Report, CRADA Number CRD-10-410	6/13/2013
NREL	1083368	NREL/TP-7A10-58458		6/1/2013	DEDALOS NREL: Cooperative Research and Development Final Report, CRADA Number CRD-07-237	6/13/2013
NREL	1087799	NREL/TP-7A10-58459		6/1/2013	Performance of MicroLink Cells Developed Under Navy STTR: Cooperative Research and Development Final Report, CRADA Number CRD-11-426	7/18/2013
NREL	1087773	NREL/TP-7A10-58025		6/1/2013	Biodiesel Emissions Testing with a Modern Diesel Engine - Equipment Only: Cooperative Research and Development Final Report, CRADA Number CRD-10-399	7/18/2013
NREL	1087790	NREL/TP-7A10-58460		7/1/2013	Defining the Interactions of Cellobiohydrolase with Substrate through Structure Function Studies: Cooperative Research and Development Final Report, CRADA Number CRD-10-409	7/18/2013

ng int+A1	OSTI ID	Report Number	Other ID Numbers	Publication Date	Title	Date Submitted to OSTI
NREL	1087782	NREL/TP-7A10-58457		7/1/2013	Identification of Catalysts and Materials for a High-Energy Density Biochemical Fuel Cell: Cooperative Research and Development Final Report, CRADA Number CRD-09-345	7/18/2013
NREL	1087797	NREL/TP-7A10-58027		7/1/2013	Solar Technology Validation Project - Hualapai Valley Solar (Met Station): Cooperative Research and Development Final Report, CRADA Number CRD-09-367-02	7/18/2013
NREL	1090965	NREL/TP-7A10-57184		8/1/2013	Solar Thermal Conversion of Biomass to Synthesis Gas: Cooperative Research and Development Final Report, CRADA Number CRD-09-00335	8/22/2013
NREL	1090971	NREL/TP-7A10-58749		8/1/2013	Solar Technology Validation Project - Iberdrola Renewables, Inc.: Cooperative Research and Development Final Report, CRADA Number CRD-08-298-3	8/22/2013
NREL	1090970	NREL/TP-7A10-58026		8/1/2013	Solar Technology Validation Project - Utah State Energy Program (Met Station): Cooperative Research and Development Final Report, CRADA Number CRD-09-367-09	8/22/2013
NREL	1090967	NREL/TP-7A10-59025		8/1/2013	Thin Film Materials and Processing Techniques for a Next Generation Photovoltaic Device: Cooperative Research and Development Final Report, CRADA Number CRD-12-470	8/22/2013
NREL	1090962	NREL/TP-7A10-58472		8/1/2013	Solar Technology Validation Project - Amonix, Inc.: Cooperative Research and Development Final Report, CRADA Number CRD-09-367-13	8/22/2013
NREL	1090961	NREL/TP-7A10-58750		8/1/2013	Solar Technology Validation Project - RES Americas: Cooperative Research and Development Final Report, CRADA Number CRD-09-367-11	8/22/2013
NREL	1090958	NREL/TP-7A10-58081		8/1/2013	Solar Technology Validation Project - Southwest Solar (Met Station): Cooperative Research and Development Final Report, CRADA Number CRD-09-367-08	8/22/2013
NREL	1090957	NREL/TP-7A10-58028		8/1/2013	Solar Technology Validation Project - Solargen (Met Station): Cooperative Research and Development Final Report, CRADA Number CRD-09-367-06	8/22/2013
NREL	1090956	NREL/TP-7A10-58752		8/1/2013	Solar Technology Validation Project - Loyola Marymount University: Cooperative Research and Development Final Report, CRADA Number CRD-09-367-03	8/22/2013
NREL	1090953	NREL/TP-7A10-58453		8/1/2013	Development of Advanced CdTe Solar Cells Based on High Temperature Corning Glass Substrates: Cooperative Research and Development Final Report, CRADA Number CRD-10-373	8/22/2013
NREL	1090952	NREL/TP-7A10-58751		8/1/2013	Solar Technology Validation Project - Tri-State G&T: Cooperative Research and Development Final Report, CRADA Number CRD-09-367-12	8/22/2013
NREL	1090161	NREL/TP-7A10-58527		8/1/2013	Equipment Loan: Cooperative Research and Development Final Report, CRADA Number CRD-07-250	8/15/2013
NREL	1090963	NREL/TP-7A10-58743		8/1/2013	Solar Technology Validation Project - USS Data, LLC: Cooperative Research and Development Final Report, CRADA Number CRD-09-367-04	8/22/2013
AMES	1233432	CRADA--2009-02		8/20/2013	Phase I. Lanthanum-based Start Materials for Hydride Batteries	12/30/2015

ng int+A1	OSTI ID	Report Number	Other ID Numbers	Publication Date	Title	Date Submitted to OSTI
NREL	1260894	NREL/TP--7A10-58973		9/1/2013	Electric Vehicle Grid Interaction Exploration: Cooperative Research and Development Final Report, CRADA Number CRD-11-431	7/8/2016
NREL	1260913	NREL/TP--7A10-59231		10/1/2013	Super-Resolution Optical Imaging of Biomass Chemical Spatial Structure: Cooperative Research and Development Final Report, CRADA Number CRD-10-411	7/8/2016
NREL	1260904	NREL/TP--7A10-59054		10/1/2013	Solar Resource Measurements in Sacramento, California: Cooperative Research and Development Final Report, CRADA Number CRD-06-205	7/8/2016
NREL	1107473	NREL/TP-5400-60477		10/1/2013	Improved Battery Pack Thermal Management to Reduce Cost and Increase Energy Density: Cooperative Research and Development Final Report, CRADA Number CRD-12-499	11/21/2013
NREL	1260320	NREL/TP--7A10-57654		10/1/2013	Radiometer Evaluation - Equipment Only: Cooperative Research and Development Final Report, CRADA Number CRD-10-00382	7/6/2016
NREL	1260887	NREL/TP--7A10-59230		10/1/2013	Electric Drive Dynamic Thermal System Model for Advanced Vehicle Propulsion Technologies: Cooperative Research and Development Final Report, CRADA Number CRD-09-360	7/8/2016
ORNL	1129561	NFE-10-02991	CRADA Number NFE-10-02991	10/1/2013	CRADA Final Report for CRADA Number NFE-10-02991 "Development and Commercialization of Alternative Carbon Precursors and Conversion Technologies"	4/29/2014
INL	1095623	INL/CRADA-08-05		10/3/2013	Aspen Code Development Collaboration	10/11/2013
NREL	1111201	NREL/TP-5200-60636		11/1/2013	Solar Resource Measurements in El Paso, Texas (Equipment CRADA Only): Cooperative Research and Development Final Report, CRADA Number CRD-08-273	12/19/2013
NREL	1111200	NREL/TP-5100-60552		11/1/2013	Pilot Scale Integrated Biorefinery for Producing Ethanol from Hybrid Algae: Cooperative Research and Development Final Report, CRADA Number CRD-10-389	12/19/2013
NREL	1260891	NREL/TP--7A10-58889		12/1/2013	Test of a 250 kVA Battery-Inverter System Micro-Grid: Cooperative Research and Development Final Report, CRADA Number CRD-11-460	7/8/2016
CHO	1111777	DOE-RIS-86146-1 FINAL REPORT	CRADA 0665	12/30/2013	Graphical Environment Tools for Application to Gamma-Ray Energy Tracking Arrays	4/17/2014
NREL	1122307	NREL/TP-5200-60531		1/1/2014	Solar Resource Measurements in 1400 JR Lynch Street, Jackson, Mississippi: Cooperative Research and Development Final Report, CRADA Number CRD-07-254	3/6/2014
NREL	1123224	NREL/TP-5500-60921		1/1/2014	Acciona Solar Technology Performance Evaluation: Cooperative Research and Development Final Report, CRADA Number CRD-10-384	3/13/2014
NREL	1121524	NREL/TP-5200-60425		1/1/2014	Solar Resource Measurements in Humboldt State University, Arcata, California: Cooperative Research and Development Final Report, CRADA Number CRD-08-262	2/27/2014
NREL	1123205	NREL/TP-5000-61078		1/1/2014	Vindicator Lidar Assessment for Wind Turbine Feed-Forward Control Applications: Cooperative Research and Development Final Report, CRADA Number CRD-09-352	3/13/2014

ng int+A1	OSTI ID	Report Number	Other ID Numbers	Publication Date	Title	Date Submitted to OSTI
NREL	1124012	NREL/TP-5200-61158		1/1/2014	Material and Device Analysis for Efficiency Improvement in Epitaxial Crystalline Solar Cells: Cooperative Research and Development Final Report, CRADA Number CRD-11-433	3/20/2014
NREL	1122308	NREL/TP-5200-60511		1/1/2014	Solar Resource Measurements in Cocoa, Florida (FSEC) - Equipment Loaned to NREL: Cooperative Research and Development Final Report, CRADA Number CRD-08-318	3/6/2014
NREL	1121525	NREL/TP-5200-60426		1/1/2014	Solar Resources Measurements in Elizabeth City, North Carolina - Equipment Only: Cooperative Research and Development Final Report, CRADA Number CRD-07-217	2/27/2014
NREL	1121487	NREL/TP-7A10-58029		1/1/2014	Commercialization of High-Temperature Solar Selective Coating: Cooperative Research and Development Final Report, CRADA Number CRD-08-300	2/27/2014
SRS	1121430	SRNL-STI--2013-00515		2/24/2014	CRADA Final Report For CRADA NO. CR-12-006 [Operation and Testing of an SO{sub 2}-depolarized Electrolyzer (SDE) for the Purpose of Hydrogen and Sulfuric Acid Production]	2/27/2014
NREL	1132182	NREL/TP-5100-62023		5/1/2014	Cost Effective Bioethanol via Acid Pretreatment of Corn Stover, Saccharification, and Conversion via a Novel Fermentation Organism: Cooperative Research and Development Final Report, CRADA Number: CRD-12-485	5/22/2014
NREL	1132185	NREL/TP-5500-62020		5/1/2014	Advanced Load Identification and Management for Buildings: Cooperative Research and Development Final Report, CRADA Number: CRD-11-422	5/22/2014
ORNL	1131520	ORNL/TM-2014/131	CRADA/NFE-11-03652	5/1/2014	Cryptographic Key Management and Critical Risk Assessment	5/20/2014
ORNL	1132557	NFE-11-03562	PTS ID#49031	5/28/2014	Centralized Cryptographic Key Management and Critical Risk Assessment - CRADA Final Report For CRADA Number NFE-11-03562	5/28/2014
NREL	1134500	NREL/TP-5J00-62185		6/1/2014	Development of Black Silicon Antireflection Control and Passivation Technology for Commercial Application: Cooperative Research and Development Final Report, CRADA Number CRD-12-475	6/19/2014
NREL	1134501	NREL/TP-5900-62186		6/1/2014	Noncomposite Counterelectrode Development: Cooperative Research and Development Final Report, CRADA Number CRD-06-203	6/19/2014
NREL	1134502	NREL/TP-5100-62189		6/1/2014	MBMS Monitoring of ClearFuels/Rentech PDU: Cooperative Research and Development Final Report, CRADA Number CRD-10-386	6/19/2014
NREL	1134499	NREL/TP-5100-62115		6/1/2014	Liquid-Liquid Separation Process: Cooperative Research and Development Final Report, CRADA Number CRD-09-362	6/19/2014
NREL	1134141	NREL/TP-5F00-62174		6/1/2014	Investigations into Performance and Lifetime Enhancements of OPV Devices: Cooperative Research and Development Final Report, CRADA Number CRD-08-263	6/16/2014
NREL	1134142	NREL/TP-2700-62148		6/1/2014	Novel Biological Conversion of Hydrogen and Carbon Dioxide Directly into Biodiesel: Cooperative Research and Development Final Report, CRADA Number: CRD-10-408	6/16/2014

ng int+A1	OSTI ID	Report Number	Other ID Numbers	Publication Date	Title	Date Submitted to OSTI
NREL	1144821	NREL/TP-5D00-62410		7/1/2014	Solar Resource Measurements in Canyon, Texas - Equipment Only Loan: Cooperative Research and Development Final Report, CRADA Number CRD-07-233	7/24/2014
ORNL	1149413	ORNL/TM-2014/250	KC0307010; ERKCC61; CRADA NFE-11-03456	7/1/2014	Neutron Scattering Studies of Liquid on or Confined in Nano- and Mesoporous Carbons, Including Carbide-Derived Carbons	8/12/2014
NREL	1150170	NREL/TP-5000-62509		8/1/2014	NaREC Offshore and Drivetrain Test Facility Collaboration: Cooperative Research and Development Final Report, CRADA Number CRD-04-140	8/21/2014
NREL	1150172	NREL/TP-5900-62488		8/1/2014	New N-Type Polymers for Organic Photovoltaics: Cooperative Research and Development Final Report, CRADA Number CRD-06-177	8/21/2014
NREL	1150173	NREL/TP-5500-62436		8/1/2014	Optical and Durability Evaluation for Silvered Polymeric Mirrors and Reflectors: Cooperative Research and Development Final Report, CRADA Number, CRD-08-316	8/21/2014
NREL	1150171	NREL/TP-5400-62487		8/1/2014	Connectivity Enhanced Energy Management and Control for EREVs: Cooperative Research and Development Final Report, CRADA Number CRD-11-457	8/21/2014
NREL	1150185	NREL/TP-5200-62571		8/1/2014	Development of New Absorber Materials to Achieve Organic Photovoltaic Commercial Modules with 15% Efficiency and 20 Years Lifetime: Cooperative Research and Development Final Report, CRADA Number CRD-12-498	8/21/2014
AMES	1233431	CRADA--2009-01		8/5/2014	Development of Low Cost Gas Atomization of Precursor Powders for Simplified ODS Alloy Production	12/30/2015
FNAL	1333131	FERMILAB--CRADA-FRA-2013-0002	1498837	8/10/2014	Testing Omega P's 650 KW, 1 3 GHZ Low-Voltage Multi-Beam Klystron for the Project X Pulsed LINAC	11/22/2016
NREL	1159379	NREL/TP-2700-62883		9/1/2014	Spectroscopic Studies of Photosynthetic Systems and Their Application in Photovoltaic Devices - Equipment Only: Cooperative Research and Development Final Report, CRADA Number CRD-06-175	10/10/2014
NREL	1159332	NREL/TP-5J00-62881		9/1/2014	Quantification Testing SPI Simulator 5600SLP: Cooperative Research and Development Final Report, CRADA Number CRD-12-482	10/10/2014
NREL	1156968	NREL/TP-5500-62766		9/1/2014	Concentrating Solar Power Hybrid System Study: Cooperative Research and Development Final Report, CRADA Number CRD-13-506	9/18/2014
NREL	1156967	NREL/TP-5100-62603		9/1/2014	Imperium/Lanzatech Syngas Fermentation Project - Biomass Gasification and Syngas Conditioning for Fermentation Evaluation: Cooperative Research and Development Final Report, CRADA Number CRD-12-474	9/18/2014
INIS	22283863			11/1/2014	Prokaryotic community composition involved production of nitrogen in sediments of Mejillones Bay; Composicion de la comunidad procariota involucrada en la produccion de nitrogeno en sedimentos de la bahia Mejillones	12/10/2014

ng int+A1	OSTI ID	Report Number	Other ID Numbers	Publication Date	Title	Date Submitted to OSTI
NREL	1165239	NREL/TP-5000-63283		11/1/2014	CENER/NREL Collaboration in Testing Facility and Code Development: Cooperative Research and Development Final Report, CRADA Number CRD-06-207	12/11/2014
NREL	1165237	NREL/TP-5100-63268		11/1/2014	Renewable Energy Institute International (REII): Cooperative Research and Development Final Report, CRADA Number CRD-10-387	12/11/2014
NREL	1165238	NREL/TP-5K00-63284		11/1/2014	Exploration of Novel Reaction Pathway for Formation of Copper Indium Gallium Diselenide: Cooperative Research and Development Final Report, CRADA Number CRD-03-121	12/11/2014
FNAL	1333133	FERMILAB--CRADA-FRA-2014-0002	1498807	11/5/2014	Enabling On-Demand Scientific Workflows on a Federated Cloud	11/22/2016
ORNL	1164260	NFE-08-01671; ORNL/TM-2014/632	CRADA/NFE-08-01671	11/28/2014	CRADA Final Report for CRADA Number NFE-08-01671 Materials for Advanced Turbocharger Designs	11/24/2014
NREL	1169215	NREL/TP--5000-63411		1/1/2015	Wind Energy R&D Collaboration between NIRE and NREL: Cooperative Research and Development Final Report, CRADA Number CRD-11-437	2/5/2015
NREL	1170351	NREL/TP--5D00-63510		2/1/2015	Inverter Load Rejection Over-Voltage Testing: SolarCity CRADA Task 1a Final Report	2/19/2015
NREL	1172273	NREL/TP-2700-63771		2/1/2015	Determining the Crystal Structure of the aa-CoA Synthase Npht7: Cooperative Research and Development Final Report, CRADA Number CRD-13-533	3/12/2015
NREL	1172283	NREL/TP-5500-63768		2/1/2015	Simulation and Field Evaluation Support for ESTCP Dynamic Windows: Cooperative Research and Development Final Report, CRADA Number CRD-12-492	3/12/2015
NREL	1170345	NREL/TP--5000-63650		2/1/2015	SWAY/NREL Collaboration on Offshore Wind System Testing and Analysis: Cooperative Research and Development Final Report, CRADA Number CRD-11-459	2/19/2015
NREL	1172932	NREL/TP-5D00-63769		2/1/2015	Improved Rotating Shadowband Radiometer Measurement Performance: Cooperative Research and Development Final Report, CRADA Number CRD-08-294	3/19/2015
NREL	1172275	NREL/TP-5000-63752		2/1/2015	Improved Tools for Wind Resource Assessment with Remote Sensing Sodar Device: Cooperative Research and Development Final Report, CRADA Number: CRD-09-363	3/12/2015
NREL	1172280	NREL/TP-6A20-63753		2/1/2015	Biomass Resource Demand Characterization Study: Cooperative Research and Development Final Report, CRADA Number CRD-11-436	3/12/2015
NREL	1176737	NREL/TP-5J00-63859		3/1/2015	Flexible CIGS Test and Evaluation: Cooperative Research and Development Final Report, CRADA Number CRD-08-293	3/26/2015
NREL	1176753	NREL/TP-5J00-63725		3/1/2015	Cooperative Research between NREL and Solar Junction Corp: Cooperative Research and Development Final Report, CRADA Number CRD-08-306	3/26/2015
NREL	1176752	NREL/TP-5K00-63817		3/1/2015	Buried Anode Device Development: Cooperative Research and Development Final Report, CRADA Number CRD-11-451	3/26/2015

ng int+A1	OSTI ID	Report Number	Other ID Numbers	Publication Date	Title	Date Submitted to OSTI
NREL	1215181	NREL/TP--7A40-63933		3/1/2015	Winnebago Resource Study. Cooperative Research and Development Final Report, CRADA Number CRD-09-329	9/18/2015
NREL	1215241	NREL/TP--5D00-64170		5/7/2015	Solar Resource Measurements at FPL Energy - Equipment Only. Cooperative Research and Development Final Report, CRADA Number CRD-08-283	9/18/2015
NREL	1215275	NREL/TP--5000-64279		5/7/2015	WindFloat Feasibility Study Support. Cooperative Research and Development Final Report, CRADA Number CRD-11-419	9/18/2015
NREL	1215285	NREL/TP--5J00-64299		5/11/2015	AIST-NREL Concentrator Photovoltaic (CPV) Demonstration. Cooperative Research and Development Final Report, CRADA Number CRD-10-402	9/18/2015
NREL	1215284	NREL/TP--5000-64298		5/12/2015	Cooperation on Lidar for Improved Wind Turbine Performance. Cooperative Research and Development Final Report, CRADA Number CRD-13-521	9/18/2015
NREL	1215311	NREL/TP--5J00-64419		6/1/2015	Optimization of Lattice Mismatched Heteroepitaxial Layers -- Equipment Only. Cooperative Research and Development Final Report, CRADA Number CRD-09-331	9/18/2015
NREL	1215344	NREL/TP--5K00-64646		7/9/2015	Commercialization Plan Support for Development of Low Cost Vacuum Insulating Glazing: Cooperative Research and Development Final Report, CRADA Number CRD-11-449	9/18/2015
NREL	1215346	NREL/TP--5000-64658		7/9/2015	Wind Farm Monitoring at Storm Lake I Wind Power Project -- Equipment Only: Cooperative Research and Development Final Report, CRADA Number CRD-10-369	9/18/2015
NREL	1215339	NREL/TP--5D00-64556		7/9/2015	Southern California Edison Grid Integration Evaluation: Cooperative Research and Development Final Report, CRADA Number CRD-10-376	9/18/2015
FNAL	1333132	FERMILAB--CRADA-FRA-2011-0001	1498818	7/15/2015	Design and Construction of Detector and Data Acquisition Elements for Proton Computed Tomography	11/22/2016
NREL	1215365	NREL/TP--5500-64771		7/28/2015	Equipment Loan for Concentrated PV Cavity Converter (PVCC) Research: Cooperative Research and Development Final Report, CRADA Number CRD-08-285	9/18/2015
NREL	1215337	NREL/TP--5100-64553		8/4/2015	Base-Catalyzed Depolymerization of Lignin with Heterogeneous Catalysts: Cooperative Research and Development Final Report, CRADA Number CRD-13-513	9/18/2015
NREL	1215351	NREL/TP--5J00-64701		8/4/2015	Improving Translation Models for Predicting the Energy Yield of Photovoltaic Power Systems. Cooperative Research and Development Final Report, CRADA Number CRD-13-526	9/18/2015
NREL	1215357	NREL/TP--5100-64727		8/4/2015	Cellulosic Biomass Sugars to Advantage Jet Fuel: Catalytic Conversion of Corn Stover to Energy Dense, Low Freeze Point Paraffins and Naphthenes: Cooperative Research and Development Final Report, CRADA Number CRD-12-462	9/18/2015

ng int+A1	OSTI ID	Report Number	Other ID Numbers	Publication Date	Title	Date Submitted to OSTI
ORNL	1237602	ORNL/TM--2015/391	ED2701000; CEED492	9/23/2015	CRADA final report: Technical assessment of roll-to-roll operation of lamination process, thermal treatment, and alternative carbon fiber precursors for low-cost, high-efficiency manufacturing of flow battery stacks and other energy devices	2/11/2016
ORNL	1222570	ORNL/TM--2015/525	BT0301000; BT0400000; CEBT002; CRADA/NFE-11-03561	9/30/2015	Advanced variable speed air source integrated heat pump (AS-IHP) development - CRADA final report	10/6/2015
NREL	1225966	NREL/TP--5000-65094		10/1/2015	Economic and Performance Analysis of Gear Box Failures. Cooperative Research and Development Final Report, CRADA Number CRD-07-236	11/16/2015
NREL	1225964	NREL/TP--5400-65093		10/1/2015	Evaluation of Hydrogen Sensors: Cooperative Research and Development Final Report, CRADA Number CRD-14-547	11/16/2015
NREL	1225965	NREL/TP--5500-65117		10/1/2015	Development of Abrasion-Resistant Coating for Solar Reflective Films. Cooperative Research and Development Final Report, CRADA Number CRD-07-247	11/16/2015
ORNL	1235001	ORNL/TM--2015/594	VT1301000; CEVT015	10/1/2015	Cummins MD & HD Accessory Hybridization CRADA - Annual Report FY15	1/19/2016
ANL	1326789	ANL/ES--C1200101	121641	10/9/2015	Particulate Emissions Control using Advanced Filter Systems: Final Report for Argonne National Laboratory, Corning Inc. and Hyundai Motor Company CRADA Project	9/28/2016
FNAL	1333843	FERMILAB-CRADA-FRA-2015-0001	1500915	10/31/2015	Data Intensive Scientific Workflows on a Federated Cloud	11/30/2016
FNAL	1333843	FERMILAB-CRADA--FRA-2015-0001	1500915	10/31/2015	Data Intensive Scientific Workflows on a Federated Cloud: CRADA Final Report	11/30/2016
NREL	1227112	NREL/TP--5000-65422		11/12/2015	NREL/University of Delaware Offshore Wind R&D Collaboration: Cooperative Research and Development Final Report, CRADA Number CRD-10-393	11/30/2015
NREL	1233144	NREL/TP--5000-65499		12/1/2015	Mobile Ocean Test Berth Support: Cooperative Research and Development Final Report, CRADA Number CRD-10-413	12/22/2015
NREL	1233147	NREL/TP--5100-65537		12/1/2015	Xylo-Oligosaccharide Process Development, Composition, and Techno-Economic Analysis. Cooperative Research and Development Final Report, CRADA Number CRD-12-483	12/22/2015
NREL	1233281	NREL/TP--5J00-65535		12/1/2015	Robust Technique for Measuring and Simulating Silicon Wafer Quality Characteristics that Enable the Prediction of Solar Cell Electrical Performance of MEMC Silicon Wafer. Cooperative Research and Development Final Report, CRADA Number CRD-11-438	12/23/2015
ANL	1334289	ANL/XSD-C0900201	131986	1/1/2016	Development of a laser Doppler displacement encoder system with ultra-low-noise-level for linear displacement measurement with subnanometer resolution - Final CRADA Report	12/5/2016
ANL	1334289	ANL/XSD-C0900201	131986	1/1/2016	Development of a laser Doppler displacement encoder system with ultra-low-noise-level for linear displacement measurement with subnanometer resolution - Final CRADA Report	12/5/2016
ANL	1334081	ANL/MCS-C1100401	131946	1/1/2016	Building-Wide, Adaptive Energy Management Systems for High-Performance Buildings - Final CRADA Report	12/2/2016
ANL	1331383	ANL/ES--C0900501	131644	1/1/2016	Engine Benchmarking - Final CRADA Report	11/9/2016

ng int+A1	OSTI ID	Report Number	Other ID Numbers	Publication Date	Title	Date Submitted to OSTI
ANL	1329392	ANL/NE--C1201400	130865	1/1/2016	Immobilization of Organic Radioactive and Non-Radioactive Liquid Waste in a Composite Matrix - Final CRADA Report	10/20/2016
ANL	1330783	ANL/GSS--C0700501	131243	1/1/2016	Solidification Technologies for Radioactive and Chemical Liquid Waste Treatment - Final CRADA Report	11/3/2016
NREL	1245128	NREL/TP--5400-66171		1/21/2016	Battery Pack Life Estimation through Cell Degradation Data and Pack Thermal Modeling for BAS+ Li-Ion Batteries. Cooperative Research and Development Final Report, CRADA Number CRD-12-489	4/4/2016
NREL	1245123	NREL/TP--5500-65964		1/29/2016	BEopt-CA (Ex) -- A Tool for Optimal Integration of EE/DR/ES+PV in Existing California Homes. Cooperative Research and Development Final Report, CRADA Number CRD-11-429	4/4/2016
NREL	1245131	NREL/TP--5400-66158		1/29/2016	Biodiesel Performance with Modern Engines. Cooperative Research and Development Final Report, CRADA Number CRD-05-153	4/4/2016
NREL	1240079	NREL/TP--5500-65919		2/17/2016	Portfolio-Scale Optimization of Customer Energy Efficiency Incentive and Marketing: Cooperative Research and Development Final Report, CRADA Number CRD-13-535	3/3/2016
NREL	1239886	NREL/TP--5500-65648		2/17/2016	Development of an Ultra-Low-Cost Solar Water Heater: Cooperative Research and Development Final Report, CRADA Number CRD-12-487	3/2/2016
NREL	1239884	NREL/TP--5D00-65843		2/17/2016	ERCOT-FESTIV Modeling: Cooperative Research and Development Final Report, CRADA Number CRD-15-584	3/2/2016
NREL	1245119	NREL/TP--5000-66155		2/23/2016	Array Effects in Large Wind Farms. Cooperative Research and Development Final Report, CRADA Number CRD-09-343	4/4/2016
NREL	1245118	NREL/TP--5K00-66170		3/8/2016	Solar Technology Test, Evaluation, and Data Collection: Cooperative Research and Development Final Report, CRADA Number CRD-08-279	4/4/2016
NREL	1247126	NREL/TP--5100-66226		3/27/2016	Conversion of Indigenous Agricultural Waste Feedstocks to Fuel Ethanol. Cooperative Research and Development Final Report, CRADA Number CRD-13-504	4/13/2016
NREL	1245133	NREL/TP--5400-66027		3/28/2016	Hydrogen Compressor Reliability Investigation and Improvement. Cooperative Research and Development Final Report, CRADA Number CRD-13-514	4/4/2016
ORNL	1247953	ORNL/TM--2016/144; CRADA/NFE--14-05142	ED2701000; CEED492	3/30/2016	Additive Manufacturing of Advanced High Temperature Masking Fixtures for EBPVD TBC Coating	4/19/2016
ORNL	1245362	ORNL/TM--2016/104	BT0302000; CEBT002; CRADA/NFE-07-01054	4/1/2016	High Efficiency Water Heating Technology Development Final Report. Part I, Lab/Field Performance Evaluation and Accelerated Life Testing of a Hybrid Electric Heat Pump Water Heater (HPWH)	4/5/2016
ORNL	1246778	ORNL/TM--2016/88	ED2802000; CEED492; CRADA/NFE-15-05496	4/1/2016	Adsorption Properties of Lignin-derived Activated Carbon Fibers (LACF)	4/12/2016

ng int+A1	OSTI ID	Report Number	Other ID Numbers	Publication Date	Title	Date Submitted to OSTI
NREL	1247124	NREL/TP--5100-66239		4/6/2016	Development of Kinetics and Mathematical Models for High-Pressure Gasification of Lignite-Switchgrass Blends: Cooperative Research and Development Final Report, CRADA Number CRD-11-447	4/13/2016
NREL	1255201	NREL/TP--5400-66501		5/1/2016	Development and Demonstration of Grid Integration System for PEVs, ESS, and RE: Cooperative Research and Development Final Report, CRADA Number CRD-13-515	6/2/2016
NREL	1255203	NREL/TP--5K00-66500		5/1/2016	Collaborative Research and Development by EpiSolar and NREL of Processes and Materials for Flexible CdS/CdTe Superstrate Devices: Cooperative Research and Development Final Report, CRADA Number CRD-14-550	6/2/2016
NREL	1255202	NREL/TP--5K00-66289		5/1/2016	Flexible CdTe Solar Cells and Modules: Cooperative Research and Development Final Report, CRADA Number CRD-14-548	6/2/2016
NREL	1255200	NREL/TP--5D00-66412		5/1/2016	NREL and DONG Energy Collaboration for Grid Simulator Controls and Testing: Cooperative Research and Development Final Report, CRADA Number CRD-13-527	6/2/2016
NREL	1257330	NREL/TP--4A00-66433		6/1/2016	Collaboration on OPT Design for Generating Electrical Power from Ocean Waves. Cooperative Research and Development Final Report, CRADA Number CRD-14-542	6/16/2016
ORNL	1263875	ORNL/TM--2016/296		6/20/2016	Oak Ridge National Laboratory Wireless Charging of Electric Vehicles - CRADA Report	7/19/2016
ORNL	1287037	ORNL/TM--2016/331	ED2802000; CEED492	7/18/2016	CRADA/NFE-15-05761 Report: Additive Manufacturing of Isotropic NdFeB Bonded Permanent Magnets	8/9/2016
ANL	1326956	ANL/NST--C1400701	130610	7/22/2016	NCD Diamond Semiconductor System for Advanced Power Electronics Systems Integration : CRADA report	9/29/2016
NREL	1296612	NREL/TP--5100-66938		8/1/2016	Catalytic Conditioning and Conversion of Bio-Syngas: Cooperative Research and Development Final Report, CRADA Number CRD-10-418	8/17/2016
NREL	1296605	NREL/TP--5400-66742		8/1/2016	Liquid Organic Battery Development: Cooperative Research and Development Final Report, CRADA Number CRD-14-540	8/17/2016
NREL	1296610	NREL/TP--5400-66936		8/1/2016	Predictive Battery Management System for Commercial Hybrid Vehicles: Cooperative Research and Development Final Report, CRADA Number CRD-13-520	8/17/2016
NREL	1326561	NREL/TP--5K00-66886		9/1/2016	Development of Optimal CZTS Device Structure: Cooperative Research and Development Final Report, CRADA Number CRD-12-476	9/27/2016
NREL	1326564	NREL/TP--5900-67167		9/1/2016	Development of Electrodeposited CIGS Solar Cells: Cooperative Research and Development Final Report, CRADA Number CRD-09-357	9/27/2016
ORNL	1329774	ORNL/TM--2016/603		9/29/2016	CRADA/NFE-15-05779 Report: Fabrication of Large Area Printable Composite Magnets	10/25/2016
NREL	1330944	NREL/TP--5400-67271		10/1/2016	Reliability Evaluation of Next Generation Inverter: Cooperative Research and Development Final Report, CRADA Number CRD-12-478	11/4/2016

ng int+A1	OSTI ID	Report Number	Other ID Numbers	Publication Date	Title	Date Submitted to OSTI
NREL	1330948	NREL/TP--2C00-67326		10/1/2016	University of Colorado - Center for Research and Education in Wind (CREW): Cooperative Research and Development Final Report, CRADA Number CRD-11-446	11/4/2016
ANL	1329712	ANL/CSE--C1100801	131136	10/18/2016	New Materials for Electric Drive Vehicles - Final CRADA Report	10/24/2016
ANL	1334081	ANL/MCS--C1100401	131946	10/27/2016	Building-Wide, Adaptive Energy Management Systems for High-Performance Buildings: Final CRADA Report	12/2/2016
LLNL	1332470	LLNL-TR--707403		10/28/2016	Atrial Model Development and Prototype Simulations: CRADA Final Report on Tasks 3 and 4	11/17/2016
ANL	1331818	ANL/ES--C1000101	131502	11/1/2016	Experimental Investigation of Coolant Boiling in a Half-Heated Circular Tube - Final CRADA Report	11/11/2016
ANL	1332930	ANL/ES--C1000301	131832	11/16/2016	Cooperation in Green Car Technology R&D - Final CRADA report	11/21/2016

Points to note about the data in the spreadsheet:

- Labs' practices for title and numbering of CRADA reports may vary The items listed on the spreadsheet were identified based on: CRADA in the Report title, CRADA as part of Report # or other identifying number, and/or flagged as Protected CRADA information (and therefore not included)
- OSTI is only able to identify CRADA reports submitted to OSTI which include this criteria
- This listing should not be considered a comprehensive listing of signed CRADAs as there may be other CRADAs in place across the complex for which final CRADA reports have not been submitted to OSTI

68. Can you provide a list of licensing agreements and royalty proceeds for the last five years?

Response: The below chart provides information on the total active licenses by DOE National Laboratories for FY 2010 through FY 2014 as well as the total royalty income earned. DOE does not collect licensing-agreement-level data.

Total number of Income-Bearing Licenses:

	FY2010	FY2011	FY2012	FY2013	FY2014
Total Active Licenses	3489	3510	3340	3709	4215
Total Royalty Income Earned	$25,220,000	$27,107,000	$28,735,000	$27,670,000	$23,321,000

69. Can you provide a list of the top twenty salaried employees of the lab, with total remuneration and the portion funded by DOE?

Response: The Department does not collect information on the top twenty salaried employees of the laboratories. While the Department has information on the amount it reimburses the top five compensated laboratory employees that information is not publicly available.

Information on some DOE contractor executive compensation is available on-line in reports filed under the Security Exchange Act or the Internal Revenue Code. For laboratory personnel that are State employees, employee compensation information may be available on the State's website.

70. Can you provide a list of all peer-reviewed publications by lab staff for the past three years?

Response: A list of the peer-reviewed publications in the DOE Office of Science and Technology Information (OSTI) database for 2013, 2014, 2015, and 2016 to date will be provided electronically due to its large size. The list includes most of the peer-reviewed publications authored by DOE laboratory contractor staff (from worked performed from both DOE and non-DOE funding sources). The requirement for laboratories to submit their peer-reviewed papers to OSTI is relatively recent and as a result we expect the list may not be complete as laboratories are still reaching full compliance on reporting.

The file includes has a summary count of peer-reviewed publications and the list of publications by year, including DOE lab, DOI number (if obtained), publisher, journal, title, and author(s).

71. Can you provide a list of current professional society memberships of lab staff?

Response: DOE does not collect information on the involvement of the DOE laboratory contractor staff in professional societies. Some DOE laboratories may maintain that information about their employees; however, the information is not publically available.

It is typical that lab employees belong to groups including, but not limited to:

- American Association of Mechanical Engineers (ASME)
- American Chemical Society (ACS)
- American Institute of Chemical Engineers (AIChE)
- American National Standards Institute (ANSI)
- American Physical Society (APS)
- American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE)
- Institute of Electrical and Electronics Engineers (IEEE)
- Intelligent Transportation Society of America
- Materials Research Society (MRS)
- Project Management Institute (PMI)
- Society for Industrial Microbiology and Biotechnology
- Society of Automotive Engineers (SAE)

72. Can you provide a list of all non-peer-reviewed publications by lab staff for the past three years?

Response: The laboratories are required to submit technical reports from projects performed at DOE laboratories sponsored by DOE/NNSA to the DOE Office of Science and Technology Information (OSTI). They are also required to submit information on work published in the peer-reviewed archival literature (information provided for Question 70). DOE does not require reporting by laboratory staff to DOE on other types of publications and does not systematically track other types of non-peer reviewed publications.

Due to the large size, the file will be provided electronically and includes a summary count of technical reports as well as the list of those publications by year (2013-2016), including DOE lab, report title, date, and author(s).

73. Can you provide a list of all websites maintained by or contributed to by laboratory staff during work hours for the past three years?

Response: DOE does not collect information about all of the websites maintained by or contributed to by DOE laboratory contract staff. Each laboratory has a public facing .gov website (links can be found at https://energy.gov/offices). To get a full inventory of lab-supported or lab-affiliated websites, we would have to conduct and extensive data call, which would take some time to complete.

74. Can you provide a list of all other positions currently held by lab staff, paid and unpaid, including faculties, boards, and consultancies?

Response: Regarding M&O contractor run laboratories, DOE collects very limited information on the involvement of DOE laboratory contractor staff in other professional activities such as faculty positions, boards, or consulting activities. Laboratory staff participation in such activities is managed by the laboratory contractor in accordance with limitations and requirements set forth in their contracts and the DOE Acquisition Regulation (DEAR) at 48 CFR 970.0371, Conduct of employees of DOE management and operating contractors. The laboratory contractors are responsible for ensuring that such activities do not present an apparent conflict of interest or interfere with the performance of the contractor employee's laboratory duties. DOE M&O laboratory contractors are required to secure contractor employee disclosures of certain, limited outside employment in accordance with DEAR 970.0371-8, Employee disclosure concerning other employment services. Contractors are required to provide these disclosures to the cognizant DOE Contracting Officer.