U.S. Department of Energy
HelioCon
Heliostat Consortium for Concentrating Solar-Thermal Power

Heliostat Consortium
Annual Report: 2023

NREL Transforming ENERGY

Sandia National Laboratories

ASTRI

Heliostat Consortium Annual Report: 2023

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Acknowledgments

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The authors would like to thank our Board of Advisors, who provide valuable feedback and help prioritize opportunities and capabilities. The full list of advisors is available at https://heliocon.org/advisors.html.

We would also like to thank our advisors from the U.S. Department of Energy, Andru Prescod and David Haas, for their helpful review and invaluable support of HelioCon.

Preface

The Heliostat Consortium for Concentrating Solar-Thermal Power (HelioCon) began in 2021, funded by the U.S. Department of Energy's Solar Energy Technologies Office to advance U.S. heliostat technologies over the next five years. This report provides detailed information on progress the HelioCon team has made since its founding, including expanding the number of partnerships with industry, research, education, and other institutions; increasing our staff; providing information to a growing audience through our web presence; and participating in national and international conferences with industry leaders.

Guangdong Zhu, Ph.D.
HelioCon Executive Director

List of Acronyms

ADACS	Avian Detection and Collection System
ANU	Australian National University
CSP	concentrating solar-thermal power
DLR	German Aerospace Center
DOE	U.S. Department of Energy
ENEA	Italian National Agency for New Technologies, Energy and Sustainable Economic Development
IAB	integrated access and backhaul
IPH	industrial process heat
LCOH	levelized cost of heat
NIO	non-intrusive optical
NREL	National Renewable Energy Laboratory
NSTTF	National Solar Thermal Test Facility
R&D	research and development
RFP	request for proposals
ReTNA	Reflected Target Non-intrusive Assessment
RTE	resources, training, and education
SETO	Solar Energy Technologies Office
TEA	techno-economic analysis

Executive Summary

In 2021, the U.S. Department of Energy's (DOE) Solar Energy Technologies Office (SETO) funded the five-year formation of the Heliostat Consortium (HelioCon) to advance U.S. heliostat technologies by engaging subject matter experts and general stakeholders for direct project-level collaboration, external consulting, and mission-specific panels and workshops.

The Heliostat Consortium is led by the National Renewable Energy Laboratory (NREL), in partnership with Sandia National Laboratories and the Australian Solar Thermal Research Institute.

HelioCon serves as a hub to integrate all DOE-funded efforts that directly advance heliostat technologies and engage the international society on this topic. HelioCon objectives are to:

- Develop strategic core capabilities and infrastructure to support high-performance heliostat manufacturing, validation, and optimization and facilitate industry's ability to design, manufacture, install, and operate central receiver heliostat fields with higher technical and economic performance.
- Ensure that these capabilities are readily available to industry, meeting its needs.
- Fund research on new technologies with significant potential to improve heliostat field economic performance.
- Form U.S. centers of excellence focused on heliostat technology to restore U.S. leadership in heliostat research, development, and validation.
- Promote workforce development by encouraging student internships and postdoctoral positions and through the formation of a HelioCon early-career scientist group to promote networking and highlight existing training and educational programs in heliostat design, production, and operation.

Heliostats track the sun to reflect sunlight to a receiver, where it can be stored as heat for long-duration energy storage and converted into electricity. There can be more than 10,000 heliostats in a single concentrating solar-thermal power (CSP) plant, representing 30%–50% of the cost of system construction and a primary driver of operations and maintenance costs.

HelioCon emphasizes the significance of heliostats as a key component of CSP technologies. CSP with low-cost thermal energy storage can be used either to produce dispatchable electricity or provide high-temperature heat to difficult-to-decarbonize industries, such as cement, steel, and chemical production.

SETO is working to lower heliostat costs, with a target of $50 per square meter, to reach its goal of $0.05 per kilowatt-hour electricity or equivalent heat generation for next-generation CSP plants, which incorporate thermal energy storage.

Motivation and Objective

Heliostat-based CSP systems offer immense potential to provide low-cost, dispatchable renewable thermal and electrical energy to help achieve 100% decarbonized energy infrastructure in the United States. The HelioCon mission is threefold: (1) establish strategic core testing and modeling capabilities and infrastructure at national laboratories; (2) support heliostat technology development in relevant industries; and (3) serve as a central repository to integrate industry, academia, and other stakeholders for heliostat technology research, development, validation, and deployment.

Work That Has Been Done

In 2022, HelioCon released a multiyear heliostat roadmap,[1] which identifies research and deployment gaps in heliostat technologies as well as strategies to overcome them during the next five years. The report aims to remove commercial risks and improve economic competitiveness to attract investors to heliostat-based CSP systems.

The roadmap report contains six technical topics: metrology and standards; components and controls; advanced manufacturing; resources, training, and education (RTE); field deployment; and techno-economic analysis (TEA). HelioCon topic area leaders had numerous discussions with industry experts and stakeholders to understand the challenges in each area along with which research, development, and capability investments would have the greatest impact on the heliostat industry.

Guided by the roadmap study, researchers from core HelioCon member organizations developed, prioritized, and have been conducting research and development (R&D) tasks that intend to address the most critical gaps identified in the roadmap study report. Additionally, a request for proposals (RFP) resulted in awards of $3.5 million split between seven projects aimed at achieving DOE's goals for heliostat cost reduction, sustained multifaceted innovation, and improved solar field performance. The RFP was announced in 2022, with awardees selected in the spring of 2023 (more information in Section 1.2).

Members of the Heliostat Consortium continue to promote work being done in heliostat industry through website content, outreach, networking at conferences, a seminar series, and other methods.

Work That Is Planned

HelioCon founding (core) members will continue the R&D efforts identified as highest priority for HelioCon, which cover all topics, except advanced manufacturing. We believe that the relevant industrial developers are best suited for addressing the gaps under advanced manufacturing.

Awards to seven projects from the HelioCon RFP Round 1 will focus on lowering the cost of heliostats and heliostat technologies and creating new market opportunities for the heliostat industry. Projects range from design and manufacturing, automation, wireless controls, and education and outreach that will create course materials for students, graduate students, and people already working in the heliostat industry. Projects will be implemented over the next 1–3 years.

A key component of the projects will be strong collaboration and communication among the original HelioCon member organizations and the new members (6) from the RFP. Researchers

[1] Available at https://www.nrel.gov/docs/fy22osti/83041.pdf.

from NREL, Sandia National Laboratories, and the Australian Solar Thermal Research Institute will be working with the awardees and connecting them to valuable resources at the labs.

Anticipated Results

Major anticipated outcomes from the Heliostat Consortium's work include:

- A fully validated third-party performance assessment platform for an integrated heliostat and its components
- A series of modeling and testing guidelines and standards
- A publicly available, easily accessible suite of tools, models, and resources for the public
- An engaged and active heliostat community that advances heliostat technologies.

The consortium will utilize the developed capabilities and infrastructure to help reduce commercial risks and support the CSP industry to develop more competitive heliostat technologies in the future energy market.

Table of Contents

List of Figures

1 Impact

The HelioCon team includes researchers and administrative support from the National Renewable Energy Laboratory (NREL); researchers from Sandia National Laboratories and the Australian Solar Thermal Research Institute; a Board of Advisors that includes utilities, developers, plant owners, component suppliers, engineering/procurement/construction companies, academic researchers, and standards and international advisors; members that include consortium-funded project performers and cost-share providers; and non-consortium stakeholders that include subject matter experts from U.S. and international institutions.

Since launching in 2021, the consortium has quickly grown in membership, support, and awareness.

1.1 People

1.1.1 HelioCon Leadership

The Heliostat Consortium leadership team consists of the following people:

- **Guangdong Zhu, Ph.D**., HelioCon Executive Director. Zhu is the group manager and a senior researcher in the Thermal Energy Systems Group within the Energy Conversion and Storage Systems Center at NREL.

- **Margaret Gordon, Ph.D.**, HelioCon Co-Lead. Since 2021, Gordon has managed the Concentrating Solar Technologies group of 30+ members at Sandia and the National Solar Thermal Test Facility, which is the only large-scale high-flux testing facility in North America.

- **Mark Mehos, M.S.**, HelioCon Partnership Director. Mehos has been with NREL since 1986. He previously managed the Thermal Energy Systems Research and Development (R&D) group with an emphasis on concentrating solar power (CSP), thermal energy for grid storage, solar thermal derived fuels, and thermal systems optimization.

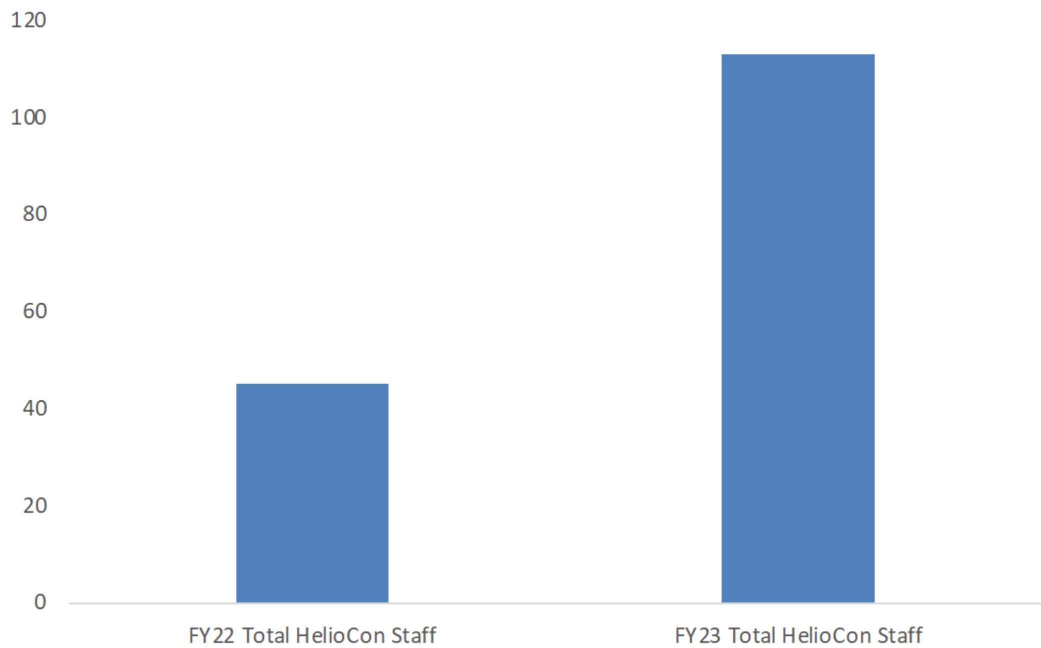
1.1.2 HelioCon Staff

The Heliostat Consortium's research and administrative staff has more than doubled in the past year. This growth has allowed HelioCon to quickly increase its research capacity, presence at conferences and events, and ability to reach new or potentially new partners. Specifically,

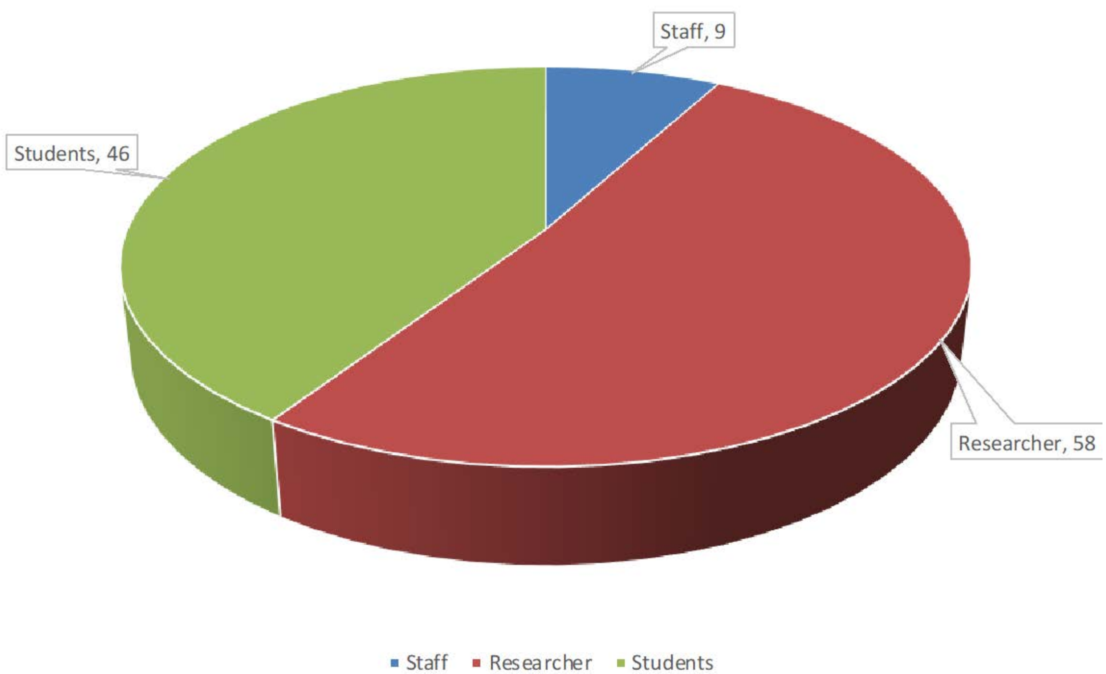
- HelioCon participating staff increased to **113** in FY23.

- HelioCon key staff increased to **37** in FY23, and researcher staff members dominate.

- HelioCon has directly engaged **46** graduate and undergraduate students (including 20 interns hired at national labs) in FY23. HelioCon recruited two undergraduate interns under DOE's [Science Undergraduate Laboratory Internships](https://science.osti.gov/wdts/suli) (SULI) program to support research activities under HelioCon. HelioCon also took this opportunity to expand its workforce for heliostat research and development and increase its diversity, equity, inclusion, and accessibility portfolio.



a) Trends of HelioCon staff growth in the past two years



b) HelioCon 2023 staffing distribution

Figure 1. HelioCon staffing summary

1.1.3 HelioCon Members

HelioCon members perform research, development, and deployment (RD&D) work directly supporting HelioCon's mission. RD&D activities are supported directly through HelioCon and/or by non-consortium-funded cost share. Members of HelioCon are given access to consortium research facilities and resources. Direct collaborations between consortium members are highly encouraged. Membership in the Heliostat Consortium has increased from 6 to 12 members since 2022.

Current members are:

- NREL (lead: Guangdong Zhu)
- Sandia National Laboratories (lead: Margaret Gordon)
- Australian Solar Thermal Research Institute (lead: Dominic Zaal)
    - Commonwealth Scientific and Industrial Research Organisation (lead: Mike Collins)
    - Australian National University (lead: Joseph Coventry)
    - University of Adelaide (lead: Matthew Emes)
    - Queensland University of Technology (lead: Michael Cholette)

- Request for Proposal (RFP) Awardees
    - Solar Dynamics – SunRing (PI: Kyle Kattke)
    - University of New Mexico (PI: Eirini Eleni Tsiropoulou)
    - Northeastern University (PI: Hameed Metghalchi)
    - Solar Dynamics – Wireless (PI: Rick Sommers)
    - University of Arizona (PI: J. Roger Angel)
    - Tietronix (PI: Michel Izygon)
    - Sarcos Robotics (PI: Eric Belski).

1.1.4 Board of Advisors

The Heliostat Consortium's Board of Advisors is made up of subject matter experts who represent utilities, developers, plant owners, component suppliers, engineering/procurement/construction companies, academia, standards, and international advisors. Through regular meetings and interactions with the leadership team, the Board of Advisors:

- Provide a knowledge base of existing industrial development and scientific progress.
- Assist with the early development and implementation of consortium roadmap and RFPs, subject to conflict-of-interest procedures.
- Promote collaborations through multiorganization projects.
- Provide feedback to ensure work performed under the consortium maintains industrial relevance.

1.2 Request for Proposals

The Heliostat Consortium used an RFP to engage a wide community to advance heliostat technologies. Round 1 of the RFP was issued in September of 2022, with $3.5 million total awarded to six awardees in June 2023. The focus of the seven awarded projects is to lower the cost of heliostats and heliostat technologies, improve technical performance and reliability, and create new market opportunities for the heliostat industry, with the goal of enabling widespread deployment of concentrating solar to decarbonize the electricity grid and energy systems.

The awardees were:

- Solar Dynamics – SunRing: Advanced Manufacturing and Field Deployment
- University of New Mexico HELIOCOMM: A Resilient Wireless Heliostats Communication System
- Northeastern University – An Educational Program on Concentrating Solar Power and Heliostats for Power Generation and Industrial Processes
- Solar Dynamics – Demonstration of a Heliostat Solar Field Wireless Control System
- University of Arizona – Actively Focused Lightweight Heliostats
- Tietronix – Digital Twin and Industry 4.0 in Support of Heliostat Technology Advancement
- Sarcos Robotics – Robotic-Assisted Facet Installation (RA-FI).

Heliostat Technology Advancement
REQUEST FOR PROPOSALS (RFP)

RFP RFX-2022-10161

Submit proposals adhering to the template with page limits to HelioConRFP@nrel.gov by: 4:00 pm MT, Tuesday, November 8, 2022. Additional information about the Heliostat Consortium can be found at: *https://www.heliocon.org*

RFP Issue Date:	09/20/2022
RFP Webinar	10/10/2022 4:00 p.m. MDT
Submission Deadline for Full Proposal:	All Topic Areas: 11/08/2022 4:00 p.m. MT
Expected Date for Selection Notifications:	December 2022
Expected Time Frame for Award Negotiations:	January 2023 – February 2023

READ THIS DOCUMENT CAREFULLY

This solicitation is being conducted under the procedures for competitive subcontracts established by the National Renewable Energy Laboratory (NREL).

NREL will award a subcontract based on the following.

BEST VALUE SELECTION

All Statement of Work (SOW) requirements being met with the best combination of:

* Technical factors (based on qualitative merit criteria), and
* Evaluated price (or cost).

IMPORTANT DATES

Issue Date: September 20, 2022

Solicitation Webinar: October 10, 2022, 4:00 p.m. MDT

Deadline for Questions: October 14, 2022, 4:00 p.m. MDT

Response Due Date: November 8, 2022, 4:00 p.m. MT

Award Selection Anticipated: December 2022

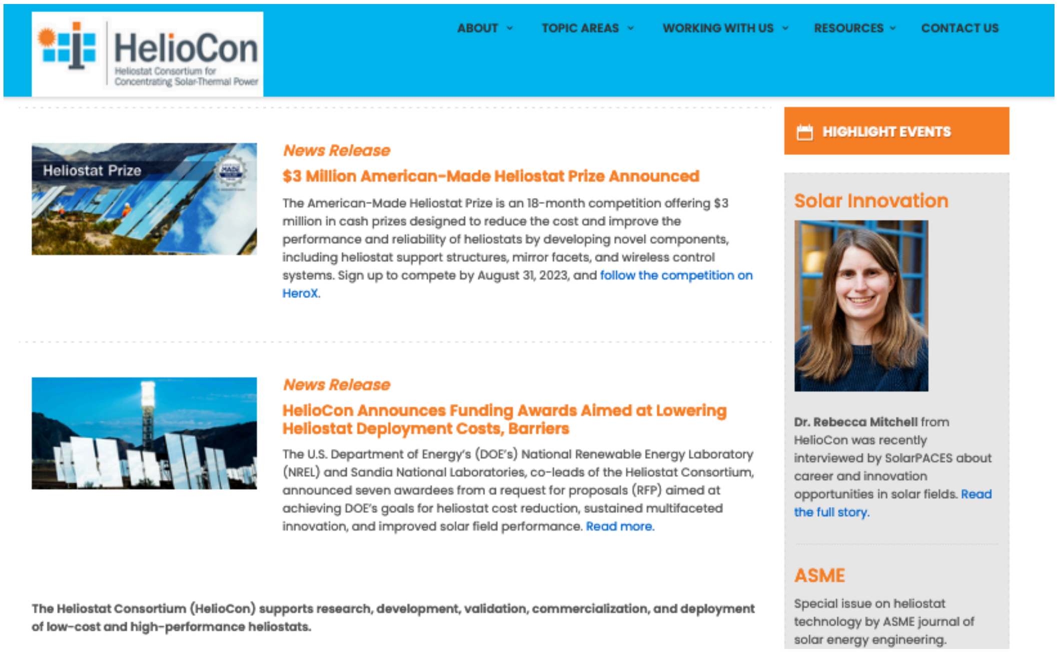
A webinar to address questions regarding the HelioCon RFP solicitation is scheduled for October 10 at 4:00 pm MDT. Interested parties can participate in the webinar by registering at:

HelioCon RFP

1.3 Outreach

The Heliostat Consortium relies on a variety of tactics to proliferate news and information about the heliostat (CSP in general) industry. In addition to launching a website with an expanding suite of resources, HelioCon members regularly speak at national and international conferences, and a virtual HelioCon seminar series has seen significant growth in viewership since it launched in 2021.

1.3.1 Website Visits



The Heliostat Consortium website, www.HelioCon.org, is intended to promote heliostat technology and its applications and share resources with the public and key stakeholders. Staff members regularly update the website with new content, share content on social media platforms and through U.S. Department of Energy (DOE) and NREL communications channels, and work to increase traffic and visits to the site.

HelioCon is intended to serve as a resource to interested persons/entities on heliostat technologies.

In FY 2023, the HelioCon website averaged:

- More than 200 unique visitors per month
- Approximately 2,000 total page views per month
- Visitors from more than 7 different countries each month.

1.3.2 Conferences

SPIE 2022 Workshop

Photo from Guangdong Zhu, NREL

In August 2022, HelioCon hosted a heliostat technology workshop at the 2022 SPIE Optics + Photonics annual program with over 3,000 participants. The featured heliostat workshop presented the current status, and future promise and challenges of heliostat technology and its application in energy decarbonization. It also introduced the newly formed HelioCon and encouraged the engagement of the SPIE community. Representatives from DOE, national labs, and one U.S. power plant hosted the workshop.

SolarPACES 2022

The Heliostat Consortium presented and exhibited during the 2022 SolarPACES Conference in Albuquerque, New Mexico. SolarPACES (Solar Power and Chemical Energy Systems) is an international cooperative network bringing together teams of national experts from around the world to focus on the development and marketing of CSP systems.

Sandia’s Concentrating Solar Power program provided tours of the National Solar Thermal Test Facility to conference attendees. HelioCon members had 12 presentations at the conference, on the following topics:

- NREL-led Heliostat Consortium for Research, Development, and Validation (HelioCon)
- Agile Deflectometry
- Gap Analysis of Heliostat Field Deployment Processes
- HelioCon RFP Information
- Heliostat Consortium: Heliostat Soiling
- Heliostat Consortium Roadmap: Advanced Manufacturing Gap Analysis
- Question-Based Gap Analysis of Heliostat Optical Metrology Methods
- Technical Gap Analysis of Heliostat Components and Controls
- Summary of an Initial Heliostat Supply Chain Analysis
- Equivalent Breakeven Installed Cost: A Tradeoff-Informed Measure for Technoeconomic Analysis of Candidate Heliostat Improvements
- Heliostat Consortium Gap Analysis on Wind Load for Achieving a Fully Competitive Heliostat Industry
- A Non-Intrusive Optical Method Measure Optical Errors of in-situ Heliostats in Utility-Scale Power Tower Plants: Detecting Uncertainties in Heliostat Geometry.

2023 HelioCon Annual Workshop

Photo from Guangdong Zhu, NREL

The Heliostat Consortium for Concentrating Solar-Thermal Power (HelioCon) hosted its annual workshop during the ASME-ES Conference July 10–12, 2023, in Washington D.C. During the summary session portion of the workshop, the HelioCon team provided technical work highlights, introduced recently awarded RFP projects, and led a discussion on progress made on gaps identified in the heliostat roadmap report as well as future goals. During technical sessions, researchers presented information about specific HelioCon topic areas and initiatives. The workshop had options for virtual and in-person attendance, with 45 people attending in person.

SPIE 2023 Conference - Advances in Solar Energy: Heliostat Systems Design, Implementation, and Operation

Photo from Guangdong Zhu, NREL

In August 2023, HelioCon hosted its first conference in the SPIE Optics + Photonics annual program—Advances in Solar Energy: Heliostat Systems Design, Implementation, and Operation. The solar energy conference attracted over 40 submissions and comprised six technical sessions and one featured panel over three days. The invited speakers came from DOE, NREL, and top-notch research institutes and universities.

The featured panel was on the international heliostat market, and the panelists included representatives from the DOE Solar Energy Technologies Office (SETO), NREL, BrightSource Energy, Heliogen, Cosin Solar, and the German Aerospace Center (DLR). The panelists from global leading developers of heliostat technology shared their product design philosophy, status, success story, and challenges.

1.3.3 HelioCon Seminar Series

Launched in December 2021, the HelioCon Seminar Series features researchers presenting on topics related to the heliostat field and industry. Presentations occur live, with recordings of the sessions available on the HelioCon website and emailed to recipients on the consortium's email list.

Since its launch, 17 researchers have shared their expertise. More than 20 HelioCon interns have also presented in special seminars in 2022 and 2023 to share projects that they worked on during their internships.

More than 500 people have attended the seminars live, and recordings have been viewed more than 2,000 times on YouTube.

1.3.4 Other Seminars

Additional seminars were given by HelioCon researchers one the following occasions:

- G. Zhu, "A Different Kind of Solar Power Is Arising," 2022 American Solar Energy Society conference, June 2022
- G. Zhu, "Introduction of Concentrating Solar Power Technologies and Their Applications," invited by the New Mexico chapter of the Association of Chinese-American Engineers and Scientists, July 2022
- G. Zhu, "Concentrating Solar Power Technologies: Current Status and Future Projection," University of California at San Diego, August 2022
- G. Zhu, "HelioCon: U.S. Heliostat Consortium to Advance Heliostat Technologies for Concentrating Solar Power," NREL Solar Program featured seminar, October 2022
- R. Mitchell, "Careers and Research Opportunities in Concentrating Solar Power," University of California Merced, April 2023
- G. Zhu, "A Bold Vision on Energy Decarbonization: From Concentrating Solar Power, Seasonal Storage, to Hybrid Energy Systems," University of California, Riverside, May 2023
- Virtual or in-person HelioCon introduction presentations were given in 2022 and 2023 to:
    - BrightSource Energy, Israel
    - AGC Glass, Belgium
    - IDMEA, Spain
    - CIEMAT, Spain
    - DLR, Germany
    - ENEA, Italy
    - Heliogen, USA
    - Vast Solar, Australia
    - Tekniker, Spain.

2 Research

Since its creation in 2021, the Heliostat Consortium is enabling strategic core testing and modeling capabilities and infrastructure at national labs, supporting heliostat technology development in relevant industries, and serving as a central repository to integrate industry, academia, and other stakeholders for heliostat technology research, development, validation, and deployment. Below are key research initiatives and future priorities for the consortium.

2.1 Major Research Activities

HelioCon members have contributed robust research to the heliostat field through a variety of technical reports, publications, patents, lab activities, and an RFP.

2.1.1 Roadmap Report

Released in 2022, the HelioCon Roadmap Report[2] is a multiyear heliostat roadmap that identifies research and deployment gaps in heliostat technologies as well as the strategies to overcome them during the next five years. The roadmap report contains six technical topics: metrology and standards; components and controls; advanced manufacturing; resources, training, and education (RTE); field deployment; and techno-economic analysis (TEA). The roadmap report is intended to serve as a central reference for the entire CSP community.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Roadmap to Advance Heliostat Technologies for Concentrating Solar-Thermal Power

Guangdong Zhu,[1] Chad Augustine,[1] Rebecca Mitchell,[1] Matthew Muller,[1] Parthiv Kurup,[1] Alexander Zolan,[1] Shashank Yellapantula,[1] Randy Brost,[2] Kenneth Armijo,[2] Jeremy Sment,[2] Rebecca Schaller,[2] Margaret Gordon,[2] Mike Collins,[3a] Joe Coventry,[3b] John Pye,[3b] Michael Cholette,[3c] Giovanni Picotti,[3c] Maziar Arjomandi,[3d] Matthew Emes,[3d] Daniel Potter,[3a] and Michael Rae[3a]

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Technical Report
NREL/TP-5700-83041
September 2022

2.1.2 Lab Activities

2.1.2.1 Metrology and Standards Activities

Necessary metrology techniques and standards are fundamental for any product design, prototyping, engineering, and improvement. The uniqueness of opto-mechanical metrology requires mutual validation between different technology on same measurement parameter. Thus, a gap on metrology would be satisfied only when:

- At least two viable metrology techniques for a given measurement parameter are available for the whole CSP industry.
- Any viable metrology technique is validated against a different trusted metrology technique or ground-truth article.

With respect to the heliostat technology, opto-mechanical characterization of heliostat performance would have a dominating impact to the performance of a commercial-scale heliostat-based system; however, this is extra-ordinarily difficult to accomplish at various stages such as product prototyping, mass-production control, and in-situ operation. For example, a degradation of 2 mrad in slope error or its equivalent may result in about 20% reduction of annual energy. Thus,

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[2] Available at https://www.nrel.gov/docs/fy22osti/83041.pdf.

- HelioCon intends to work with the international communities on conducting round-robin tests on various types of available metrology technologies on opto-mechanical errors.
- HelioCon plans to devote to the core opto-mechanical metrology development for in-door and in-situ environments.
- HelioCon calls for industry collaboration to develop the solar receiver flux real-time assurance tool which will be available to the whole industry. This tool would rely on available opto-mechanical metrology in fields.

Gaps in standards, such as site characterization, heliostat design, heliostat testing, heliostat field design, and heliostat field acceptance test protocol, unfortunately result in significant barriers for new players, an elongated design cycle, less confidence from potential investors, and potential difficult arbitration among involved parties for a given project. The gaps in standards can only be addressed through a collaborative effort from the international community. Here is a summary of top-ranked standards efforts:

- Heliostat terminology standard
- Heliostat design guideline
- Heliostat solar field design/simulation guideline
- Heliostat test guideline
- Heliostat solar field acceptance test guideline
- Site characterization guideline.

2.1.2.1.1 SOFAST Technology Project

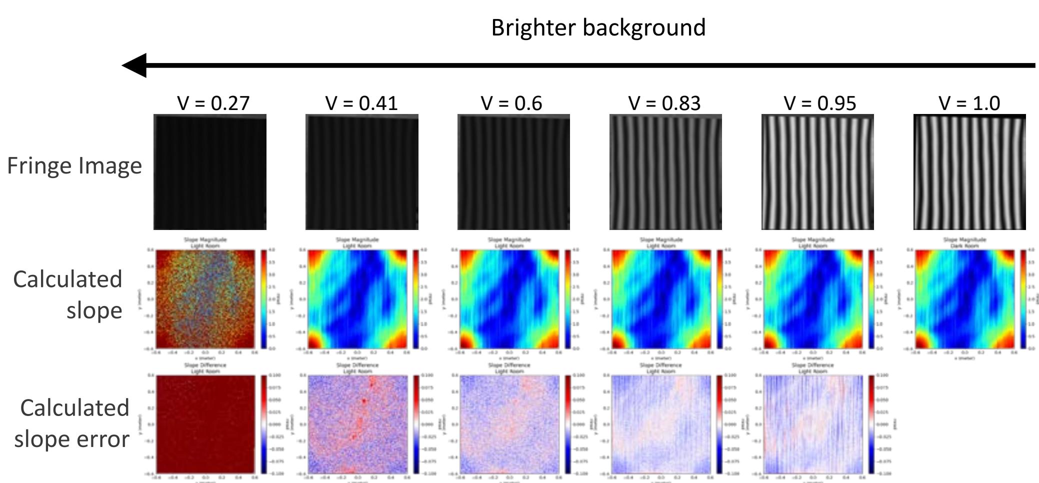


Figure 2. Examples of SOFAST sensitivity study on ambient light

Images from Randy Brost, Sandia

Description: SOFAST measures high-resolution slope maps at high speed. It aims to support prototype development, manufacturing process development, and high-volume manufacturing. SOFAST has been adopted by commercial entities, but improvements can be made to enhance its capabilities.

Project Lead: Randy Brost (Sandia)

Objectives:

- Advance SOFAST capabilities to meet industry requests.
- Release SOFAST version 2.0.

Approach:

- Adopt the principles of deflectometry.
- Increase ease of use, value, and impact.
- Improve code with python programming.
- Expand the envelope of use.

Status:

- Release SOFAST 2.0 to the public.
- In next year, to further improve SOFAST and release SOFAST under OpenCSP.

2.1.2.1.2 Non-Intrusive Optical Technology Project

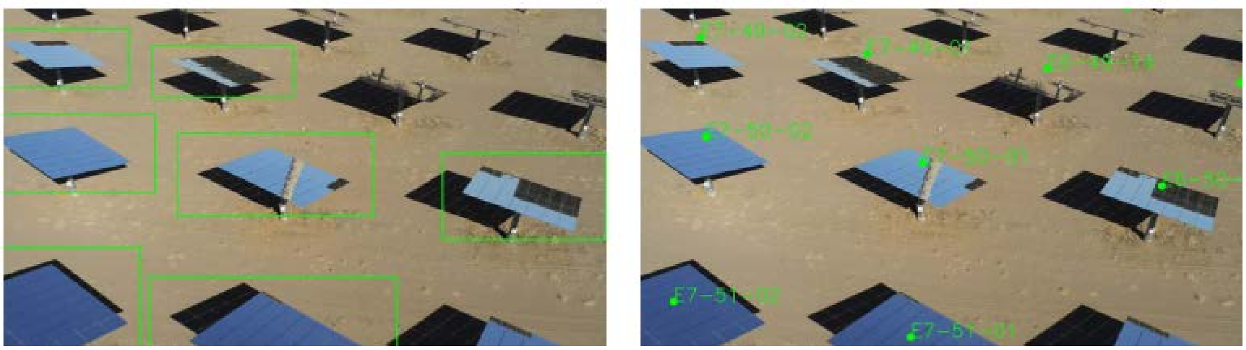


Figure 3. Examples of NIO automated image processing method adopting machine learning and advanced computer vision techniques

Images from Tucker Farrell, NREL

Description: The non-intrusive optical (NIO) approach is under development to measure mirror surface slope error, mirror facet canting error, and heliostat racking error based on reflection images using the natural target—the tower—in a heliostat field. The development of the NIO approach is expected to fill the critical gap for successful solar field operation and maintenance.

Project Leads: Rebecca Mitchell and Tucker Farrell (NREL)

Objectives:

- Serve as an in-situ technology suitable for utility-scale heliostat fields.
- Measure slope error, canting error, and tracking error.

Approach:

- Use drone-driven camera.
- Adopt the principles of reflectometry with a far-field reflection target.
- Develop automated image-processing through computer vision and machine learning.

Status:

- The project is entering into its demonstration stage, with work completed at NSTFF and Crescent Dunes, and work planned at Cerro Dominador.
- In next year, carry out a rigorous validation with other metrology tools.

2.1.2.1.3 UFACET Technology Project

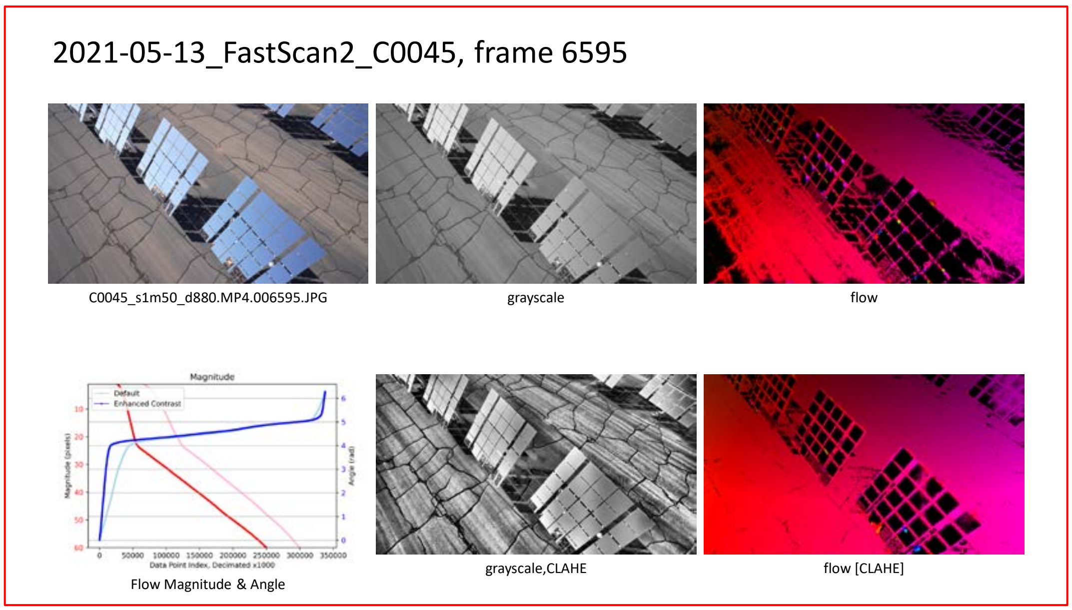


Figure 4. Illustration of UFACET fast scanning technique

Images from Ben Bean, Sandia

Description: The UFACET technique is under development to adopt drone-driven camera and near field target (such as neighboring heliostat) for in-situ measurements of slope error and canting error.

Project Lead: Randy Brost (Sandia)

Objectives:

- Serve as an in -situ technology suitable for utility-scale heliostat fields, particularly for fast calibration.

Approach:

- Use drone-driven camera.
- Adopt the principles of reflectometry with a near-field reflection target.
- Develop automated image-processing.

Status:

- Assembled combined rendering of UFACET analysis on single heliostat and full solar field.
- Completed new automated optical flow analysis to support synchronization and key frame generation.
- In next year, initiate development of advanced outdoor reflection-based technique using a phase-gate process.

2.1.2.1.4 OpenCSP Project

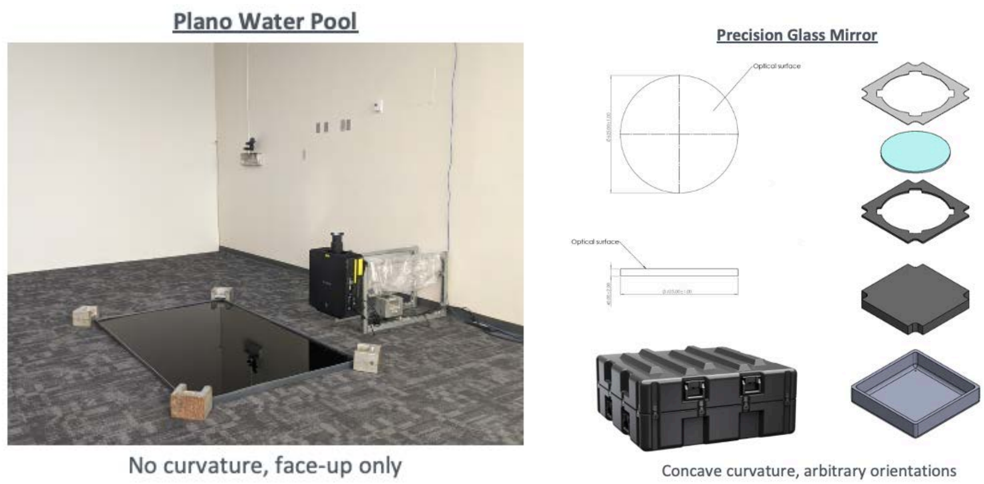


Figure 5. Examples of ground truth physical standards

Image from CSOL, Diagram from Randy Brost, Sandia

Description: OpenCSP is designed to resemble the success of OpenCV and PVLib and will be a community library of CSP foundation classes, algorithms, and applications. When successful, it would enable people to build new advanced CSP applications more quickly and enable new businesses to provide consulting services to help the CSP industry utilize and extend the code. It will reduce the barrier to startups and reduce operating costs for such businesses.

Project Lead: Randy Brost (Sandia)

Objectives:

- Establish a community library of CSP foundation classes, algorithms, and applications.

Approach:

- Develop coding standards.
- Establish foundation classes, core algorithms, and automated tests.
- Promote community collaboration to develop and, when ready, release new applications to the whole CSP community.

Status:

- Established foundation for OpenCSP diagnostics.
- In next year, release first version of OpenCSP and ground truth for wide use.

2.1.2.1.5 ReTNA Technology Project

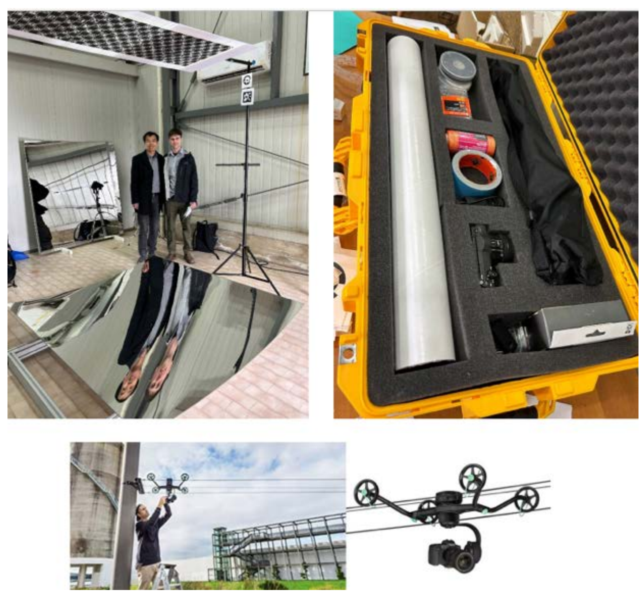


Figure 6. Illustration of ReTNA equipment and setup ease

Top Images from Devon Kesseli, NREL

Bottom Images from Amazon Product Posting

Description: The Reflected Target Non-intrusive Assessment (ReTNA) tool measures mirror surface slope and facet canting error with a manufactured setup. It is designed to adopt simple, low-cost equipment such as modular, lightweight printed targets and off-the-shelf cameras.

Project Lead: Devon Kesseli (NREL)

Objectives:

- Laboratory technology suitable for single heliostat prototype.
- Portable, efficient, and automatic.

- Measure slope error, canting error
    - Varying orientation
    - Varying load.

Approach:

- Deflectometry and photogrammetry
- Automated image-processing through computer vision and machine learning

Status:

- Completed concept-proof stage.
- Building a prototype at NREL.
- In next year, carry out a rigorous validation campaign and collaborate with industrial partners for further commercialization.

2.1.2.1.6 Third-Party Evaluation Platform

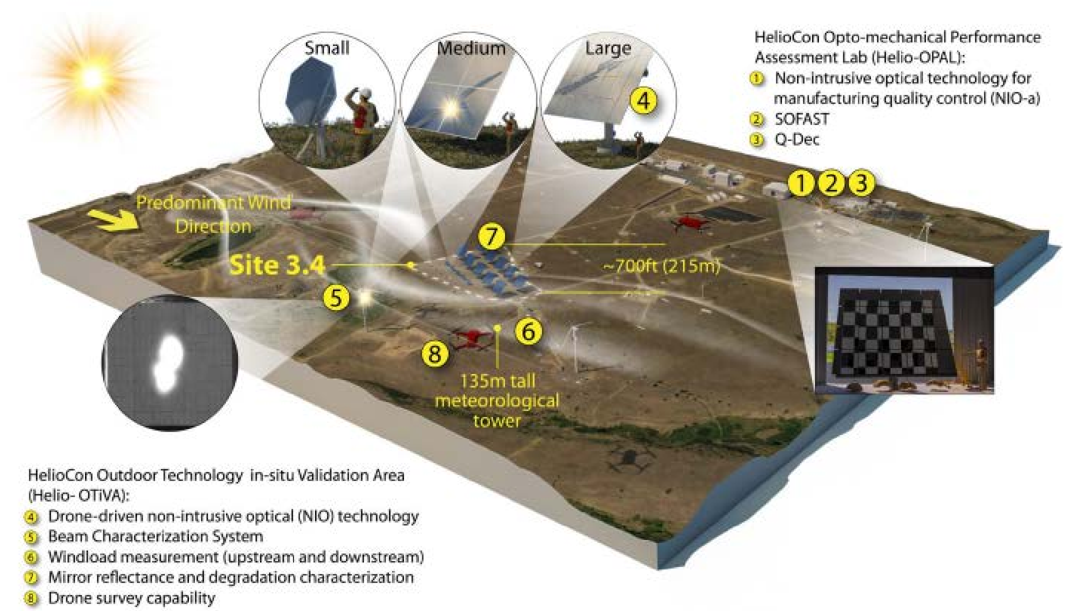


Figure 7. Artist-rendered plan of NREL's Third-Party Evaluation Platform

Image by Joshua Bauer, NREL

Description: HelioCon plans to deploy and validate the developed metrology techniques at NREL's Flatirons campus to support third-party evaluation of heliostat-related industrial products.

Project Lead: Rebecca Mitchell (NREL)

Objectives:

- Make available third-party heliostat performance assessment capabilities to serve CSP industry.
  - Evaluation of heliostat designs under indoor and outdoor conditions
  - Validation of newly developed metrology technologies by others.

Approach:

- Develop/acquire, install, and calibrate most-advanced metrology technologies within HelioCon.
- Demonstrate the test capability with a case study.
- Call for test services on commercial heliostat designs.

Status:

- Developing new techniques and planning space needs at NREL's Flatirons campus.
- In next year, perform a scoping study to understand the total platform cost and a priority list of metrology tools to acquire.

2.1.2.2 Components and Controls Activities

Heliostats comprise static and dynamic components required to operate within a highly controlled manner to provide accurate solar flux pointing during CSP operation. The general composition includes a reflective area, control system, and mounting and tracking mechanism. A reflective area is typically made up of one or more mirrors (also known as facets). Efforts have required optimization of the component designs to lower costs of customized components such as the drive system, which can account for up to a third of total cost. Larger reflective surfaces and their respective supporting structures are exposed to higher wind loads and can have increased optical losses and mechanical stress levels. Therefore, there has been interest to utilize smaller facet heliostats to optimize size with respect to receiver geometry, alternative materials and components are being considered to reduce heliostat weight, while improving rigidity and control, and reducing costs. Additionally, resilient control of the heliostat is required for adjustment of heliostat structure so it can accurately track sun position to reflect concentrated sunlight toward a receiver. Wireless and closed-loop controls have become increasingly attractive for new installations as they offer potential cost savings and enhanced performance. Heliostat durability and reliability are not well characterized but are of key importance to ensure high performance and safe operation over the designed lifetime. Component degradation—particularly for drives, mirrors, and electronics—is also not well documented in literature but is critical for predicting long-term system performance and planning, as well as financing system O&M. Some of the components and controls primary gaps that have been identified include:

- Lower-cost mirror designs with comparable performance to existing glass mirrors are needed.
- Composites or other advanced structures (e.g., torque tubes, pedestals, foundation) are necessary for hitting cost targets and reducing dynamic component costs (i.e., drives).

- Closed-loop control must be more broadly applied to achieve higher receiver performance and flux control, and automatic alignment/calibration processes.
- Wireless systems approaches must be broadly introduced to capitalize on lower plant cost, while wireless risks and technical issues must be avoided. Standardized requirements and testing capabilities are needed.

2.1.2.2.1 Composite Heliostat Design Evaluation Project

Description: The project intends to assess composite materials and designs to reduce mirror and structural costs, while improving performance/reliability; design optimization and TEA.

Project Leads: Matt Muller, Daniel Tsvankin (NREL)

Objectives:

- Evaluate potential of composite materials for heliostat mirror facets and structure for meeting the DOE cost target goal: $50/m^2.

Approach:

- Perform initial design optimization to reduce heliostat cost.
- Carry out TEA and cost comparison between composites and state-of-the-art materials/design.

Status:

- Initial results discourage use of unidirectional composites as they do not currently provide cost gains when considered to achieve the same stiffness as the baseline steel design. Structural facets (sandwiched composites) or alternatively-designed heliostats optimized for composite material properties provide opportunity for further consideration.
- In next year, a composite structural facet prototype is to be built and evaluated.

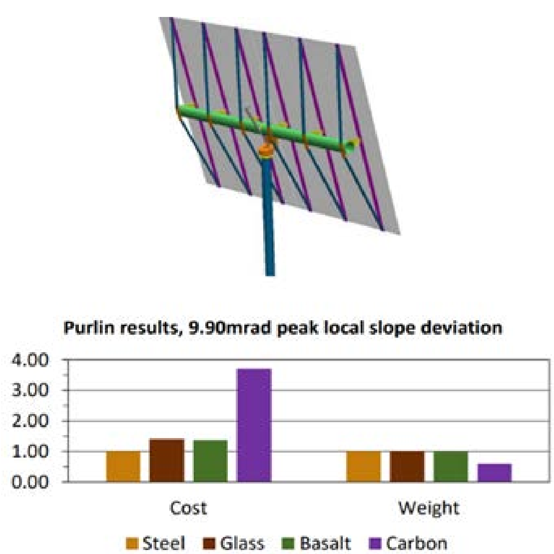


Figure 8. Illustration of heliostat composite design and initial cost analysis

2.1.2.2.2 Heliostat Field Closed-Loop Control System Testbed Development

Description: A heliostat field closed-loop control system testbed is needed to perform failure mode effects analysis on components and control to determine acceleration/reliability factors. HelioCon intends to develop such a test bed based on the existing infrastructure at Sandia's National Solar Thermal Test Facility (NSTTF).

Project Lead: Ken Armijo (Sandia)

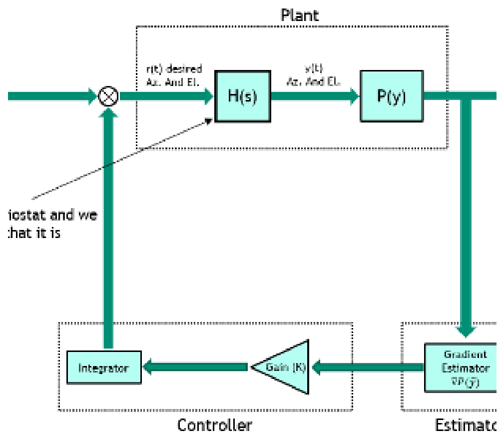


Figure 9. Illustration of new communication infrastructure

Objectives:

- Develop a closed-loop control system testbed to assess the durability of heliostat components and closed-loop controls and ensure their qualities under realistic operational conditions in future commercial projects.

Approach:

- Upgrade Sandia's NSTTF heliostat field with respect to both software and hardware.
- Develop new control software able to accommodate real-time heliostat aiming and closed-loop feedback algorithm.
- Develop new communication infrastructure for wireless communication test.

Status:

- The testbed is in the design stage.
- Software architectures utilized to determine optimal pointing of each heliostat, accounting for unique metrology considerations.

2.1.2.2.3 Heliostat Design Qualification Standard Development

Description: In this effort, we will review existing designs, literature, and data; interview stakeholders on needs and priorities; develop standardized requirements and testing capabilities; identify environmental phenomena to exercise accelerated wear and complete initial outlines for and IEC design qualification standard.

Project Lead: Matt Muller, Daniel Tsvankin (NREL)

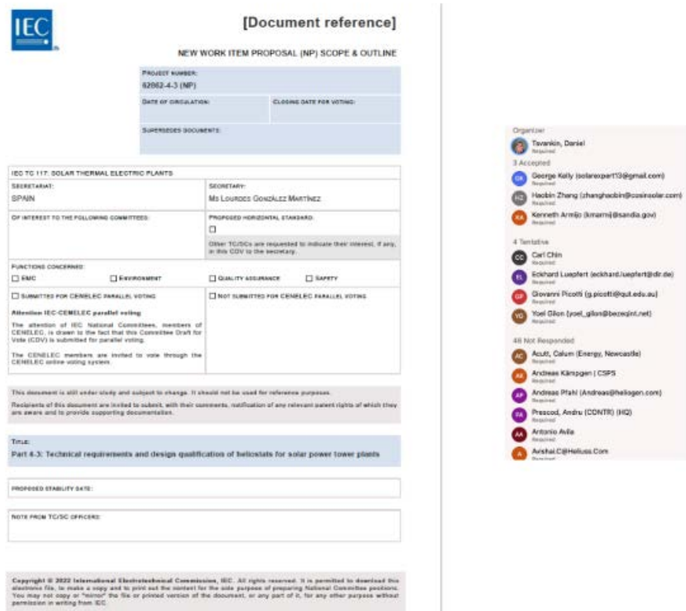


Figure 10. IEC standard proposal was submitted, and an international workgroup was formed

Objectives:

- Develop a standard on technical requirements and design qualification of heliostats for solar power tower plants.

Approach:

- NREL is co-leading the standard development with Cosin Solar, with an international IEC TC117 working group including experts from multiple countries.

Status:

- A New Proposal (NP) was submitted to the International Electrotechnical Committee (IEC) for a design qualification standard for heliostats and achieved the necessary five country support and voting approval.

- A working group was formed and has been meeting regularly to discuss key components of the standard.

- In next year, the working group led by NREL will develop a first draft design qualification standard through an international collaborative effort.

2.1.2.3 Field Deployment Activities

Heliostats field deployment costs are greatly affected by the location and the supply chain. Cost reductions can come from learning rates, heliostat design features that facilitate ease of installation, and process improvements. Learning rates are optimal when there is steady policy, and cost pressure, and when multiple deployments happen within a single institution.

Historically, time gaps between deployments have caused suppliers and technology developers to lose institutional knowledge.

The field deployment subtask may be able to help by improving the barriers to successful project deployment. There is a gap in understanding of overall costs for small modular systems since commercial deployments have historically reduced levelized cost of energy by maximizing the capacity of a single receiver and power block. Stabilizing the supply chain may be aided by reducing investor risk by optimizing systems in the $200-300 million range, reducing utility risk by improvements in power performance predictions, and increasing the variety of types of projects that CSP is eligible for by developing modular systems of approximately 10 MW. There is a gap in understanding barriers to site selection. Permitting risk can be mitigated by eliminating wildlife impacts and identifying environmental benefits, and by engaging early with communities and allowing shared leadership on deployment matters such as site selection and jobs, preserving institutional knowledge on deployment/manufacturing/assembly processes. Solar layouts are typically optimized for a few times of the year. There is a gap in understanding of multiple or unbounded design points. Flexible field layout algorithms that are sized to operate in a larger variety of solar conditions and therefore deployable in more regions, can be developed. Heliostat design for ease of deployment cannot reduce optical quality. Wireless communications and photovoltaic power with batteries on each heliostat have been shown to have great benefits in reducing trenching/wiring costs as well as enabling smart calibration features. There is a gap in understanding the potential reductions in pedestal mass due to inner field wind load reductions. There is also a gap in understanding of wind loads on the inner field and whether full field forced stow during wind events is necessary. There is a potential to use load sensors instead of anemometers to determine stow. Cost reductions related to deployment processes may be possible. There is a gap in the knowledge of how much field deployment processes cost within the full plant or collector budget. It may be less costly and less impactful to the habitat to leave the field in its natural state to the greatest extent possible. Manual cleaning may be less costly than mechanized washing. There is a gap in understanding how natural vegetation may reduce soiling and erosion within a field. Windload is identified as a cross-cut separate sub-topic under field deployment and further elaborated here.

2.1.2.3.1 High-Fidelity Performance Model Project

Description: Utilize existing performance characterization tools to develop model fits that approximate the past performance of existing plants for which performance data is available. To achieve this, we will integrate a set of tools including SAM, SolarTHERM, LORE, SolarPILOT, and SolTrace.

Project Lead: Alexander Zolan (NREL)

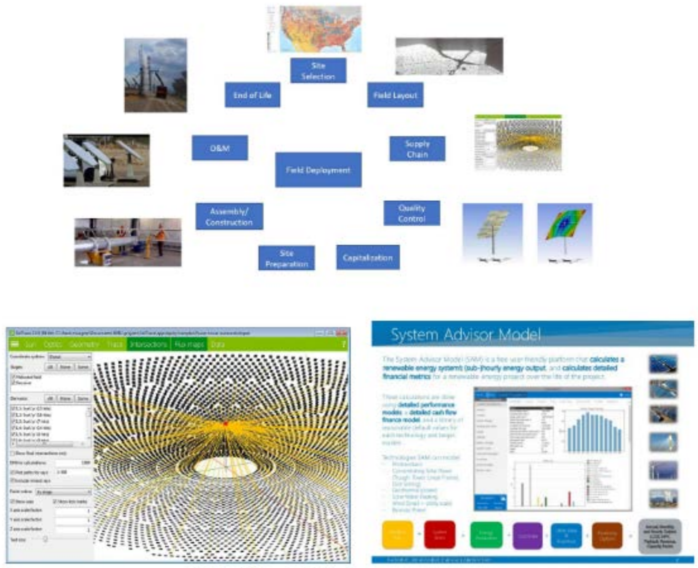


Figure 11. Illustration of field deployment process and example of high-fidelity performance prediction model

Objectives:

- High-fidelity performance model to fill the gap between project developers and investors.

Approach:

- Define required site-specific data.
- Define required heliostat and heliostat field data.
- Define performance output metrics with associated uncertainties.
- Integrate a suite of modeling tools with necessary improvement.

Status:

- Identifying key sources of uncertainty in performance models
- In next year, identify key parameters and time-series models to minimize the performance prediction uncertainty.

2.1.2.3.2 Analysis of Heliostat O&M at Ivanpah

Description: We will develop a survey of O&M budgeting and staffing for solar field maintenance using the Ivanpah power plant as a case study. This consists of an interview with high-level questions on operating policies and staffing levels, followed by a form in which more details can be obtained, such as costs and more detailed scheduling. A detailed soiling analysis campaign is also planned.

Project Lead: Alexander Zolan (NREL)

Figure 12. Illustration of solar field at Ivanpah power plant

Photo from Alexander Zolan

Objectives:

- Obtain field measurements at an operating facility to observe soiling conditions.
- Compare performance of measurement devices and analyze mirror cleaning activities.

Approach:

- Obtained >500 measurements across ~120 heliostats in solar field of Unit 1.
- Developed separate models of soiling and cleaning optimization using (a) field-collected data, and (b) historical measurements shared by Ivanpah.

Status:

- Results confirmed that Ivanpah's cleaning frequency is appropriate, but it may be worth considering adjusting the cleaning schedule seasonally.
- Report on lessons learned for planning field measurement campaigns under development.
- Final report including analysis completed.

2.1.2.4 Impacts of Heliostat Shading on Desert Habitats, and a Proposed Methodology for Coexistent Field Deployment and Operations With Desert Flora and Fauna

Description: Environmental remediations such as translocation of desert tortoises within very large field areas can be costly and have mixed outcomes particularly for animals that are not adapted to moving large distances. The beneficial impacts of shading from heliostats on wildlife will be quantified in terms of vegetation and animal counts and a methodology for safely deploying and operating heliostat fields in the presence of wildlife will be developed. Cost analysis will be performed to assess the financial implications of a less invasive methodology versus a highly mechanized methodology that would assume translocation.

Project Leads: Jeremy Sment (Sandia), Alexander Zolan (NREL)

Photo from Jack Goldfarb

Objectives:

- Quantify the effects of heliostats on habitats and survivability of tortoises.
- Determine a methodology for field deployment and O&M that conforms to U.S. Fish and Wildlife Service goals and regulations with coexistence of protected species and heliostats.
- Demonstrate automated detection techniques using unmanned aerial vehicle as part of methodology.

Approach:

- Measure temperature, moisture, and vegetation in quadrats at an existing plant and approved future plant sites to determine the impacts of heliostat shading on habitat.
- Work with Ivanpah biologists for historic observations on the 2013 plant deployment and leverage existing data on the health and tracking of desert tortoises near Ivanpah.
- Consulting with U.S. Fish and Wildlife Service to refine study approach, advise permitting requirements, and co-develop a methodology to satisfy the ESA and industry viability.
- Resi Solutions, an environmental services group, conducts tortoise surveys with unmanned aerial vehicles and will help to inform the best practices approach to minimize the cost of identifying tortoises.

Status:

- Project scoping study initiated with biologist collaboration.
- Identified contacts at U.S. Fish and Wildlife Service and Ivanpah Solar Energy Project.

2.1.2.5 Techno-Economic Analysis

TEA makes use of models and analysis to quantitatively assess the benefits of heliostat design, manufacturing, and operation concepts for HelioCon. One of the main objectives of TEA is to relate the cost and performance of heliostats and heliostat components to the overall system performance. To do this, we developed three baseline cases to use for technoeconomic analysis in the consortium. We limit the scope of our study to the heliostat field, receiver, and tower performance based on the thermal energy collected by the heat transfer fluid compared to its installed and operating costs, using the levelized cost of heat (LCOH) as the key metric in our analysis. The three baseline cases we developed are: (i) a large, commercial-scale electricity plant with a 100-MWe power cycle; (ii) a smaller, modular electricity plant with a 20-MWe power cycle and a 100-MWt receiver; and (iii) a small, modular plant used for industrial process heat (IPH) with a 30-MWt receiver. We performed a parametric study on each case to determine the impact of key parameters on LCOH using SAM and SolarPILOT. Results show that LCOH is most sensitive to optical error and installation costs followed by the heliostat reflectance and O&M costs. The baseline LCOH ranges from 1.8 to 2.8 cents/kWh of heat for the three cases and the parametric analyses consistently span about 0.5 cents/kWh of heat, regardless of the size of the plant.

As with other topics, a gap analysis was performed for TEA. Most of the identified gaps are related to developing models or data. The need for a linkage between model inputs and actual components is considered the most important gap. Specifically, a concerted effort is needed to better understand field O&M and the trade-offs between O&M costs and system performance. We also require a better model of high-temperature IPH applications. The TEA topic assists other topics in their gap ranking by estimating the potential impact of their gaps on LCOH if they are solved (or remain unaddressed). This ranking is performed by first interpreting the impact of addressing the gap on various cost or performance measures for a given CSP plant, and implementing those changes in an instance of SAM. While the impacts are rough estimates, this TEA-informed ranking can still be useful to estimate which gaps have the highest impact on the projected cost and productivity of future plant installations.

2.1.2.5.1 Heliostat Field Optimization for Power Tower Solar Industrial Process Heat Applications

Description: Develop base cases for modular (~20 MWt) high-temperature (500+°C) process heat power tower systems at three different process heat temperatures and demonstrate how the levelized cost of heat changes as a function of both process temperature and tower and receiver cost.

Project Lead: Chad Augustine (NREL)

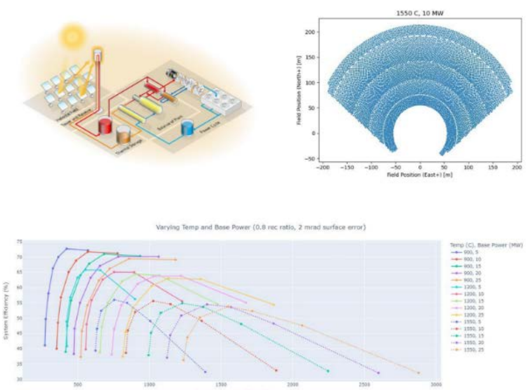


Figure 13. Example of sensitivity study using the process heat model

Objectives:

- Develop heliostat field, tower, and receiver model for IPH applications.
- Determine practical and commercial operating limits for IPH applications (temperature, project size, impact of receiver media, etc.).
- Develop field layout "best practices" for IPH applications.

Approach:

- Develop cost correlations for tower and receiver for IPH.
- Optimize base case field layouts based on cost correlations.

Status:

- Improving models required for TEA analysis.
- Carrying out initial sensitivity analysis.
- In next year, plan to develop a system analysis framework to derive optimum size of heliostats as a reference to the industry.

2.1.2.6 Resources, Training, and Education

Description: The RTE topic is a dedicated effort from HelioCon to support the heliostat community. It encompasses resources, practices, and programs to ensure that newcomers to the heliostat development business have an adequate knowledge base and training to conduct R&D efforts; outsiders to the field are provided with resources and opportunities to help them join the workforce; and the workforce community is a productive, healthy, and fulfilling environment for all workers. To fulfill the most pressing identified gaps:

- Programs and practices will be implemented to support diversity, equity, and inclusion within the heliostat workforce and to drive the industry toward energy solutions that benefit underserved communities.
- Efforts will be made to create more opportunities for heliostat research and education in universities to support a workforce pipeline.
- Informational and training resources will be created to market heliostats to the public and to support onboarding of new employees.
- A web-based resource database will be created to make RTE resources accessible to the public.

2.1.2.6.1 HelioCon Database

Description: HelioCon intends to develop and update a resource database to reflect the most current industry developments and increase the public accessibility of industry knowledge, and data is a crucial step toward supporting the growth of the industry.

Project Lead: Rebecca Mitchell (NREL)

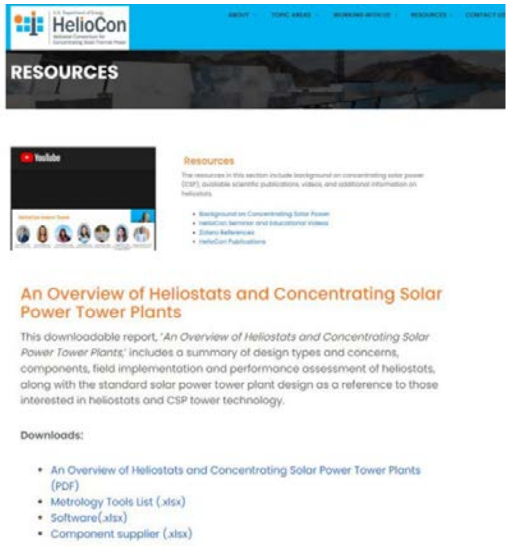


Figure 14. Snapshot of HelioCon web-based database

Objectives:

- Establish a publicly accessible web-based resource database containing fundamental and expert knowledge

Approach:

- HelioCon will gather available resources and knowledge into a web database:
    - Industry knowledge: stakeholder contacts, O&M/manufacturing/design practices
    - Resource library: references, trainings, and software tools
    - Resources/guidance for promoting diversity, equity, and inclusion.

Status:

- Completed 1) reference library, 2) education and training resources, 3) lists of heliostat component suppliers and developers, metrology tools, and software tools, and 4) existing power tower plant database.
- In next year, work on 1) available standards and guidelines, 2) other specialized library/database, and 3) best practices/lessons learned.

2.1.2.7 International Collaboration Projects

HelioCon has made efforts on formal international collaboration to tackle the challenges faced by the heliostat community.

2.1.2.7.1 Raytrace Model Round-Robin Test

Description: In this project, three different software packages for Monte Carlo ray-tracing of central tower CSP systems were first compared in a multi-stage cross-validation process. The first three packages are (1) SolTrace, an open-source code from NREL, (2) Solstice, an open-source code originally by CNRS-PROMES and Méso-Star with additions by Australian National

University (ANU), and (3) TieSOL, a commercial code developed by Tietronix. The comparison aims to improve accuracy and reliability of the above tools and provide benchmark cases for checking future tools.

Project Leads: Rebecca Mitchell (NREL), Ye Wang (ANU), Michel Izygon (Tietronix), John Pye (ANU)

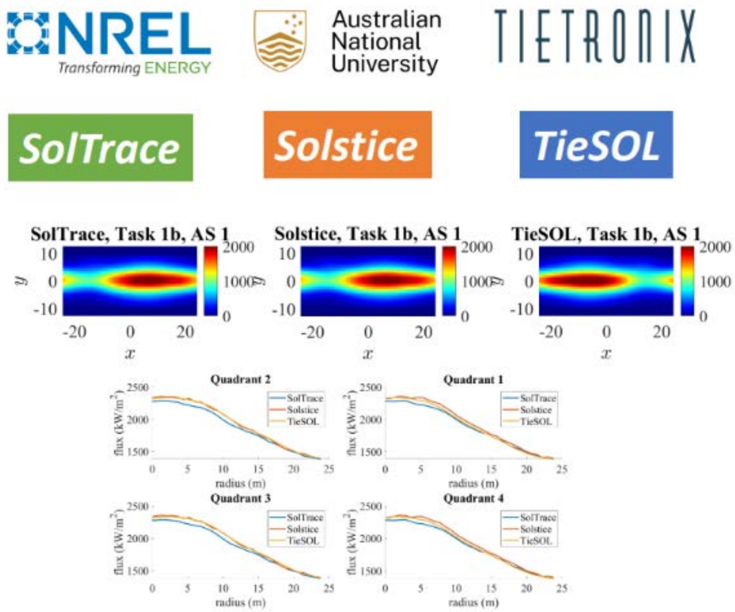


Figure 15. Illustration of comparison results between three raytrace models

Objectives:

- Examine/improve (if necessary) accuracy of raytrace models available in the market.

Approach:

- Perform case studies to validate three raytrace models through round-robin test.
- Validate other SolTrace models per request.

Status:

- Near completion of round-robin test of three raytrace models.
- Publish the final comparison results as a reference to the public.
- In next year, offer validation for the other raytrace models.

2.1.2.7.2 Laboratory Slope Error Metrology Round-Robin Test

Description: An international team including ENEA, DLR, Fraunhofer Solar, Sandia National Laboratories and NREL has been formed to perform a round-robin test on the metrology tools developed by individual entities to validate each other.

Project Leads from HelioCon: Devon Kesseli (NREL), Randy Brost (Sandia), Braden Smith (Sandia)

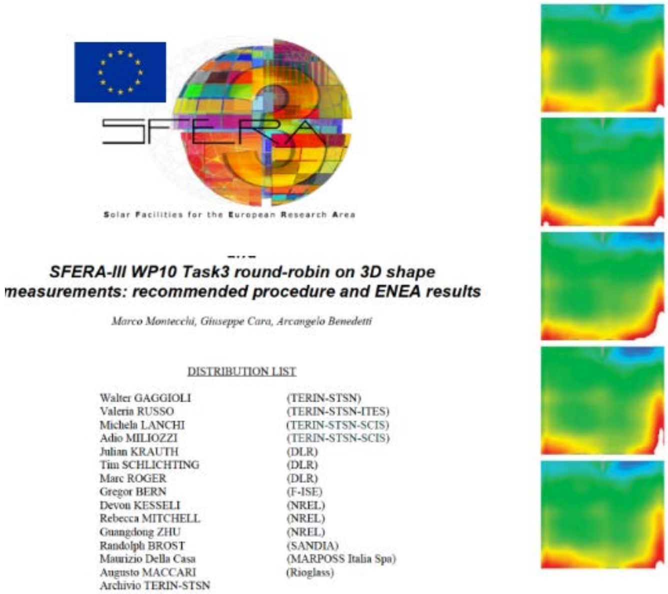


Figure 16. Participating parties in the slope error measurement round-robin test

Objectives:

Examine/improve (if necessary) accuracy of laboratory slope error metrology available in the market.

Approach:

- Perform round robin test within five institutes: ENEA, DLR, Fraunhofer, Sandia, NREL.
- Collaborate with international community with support from European Union programs.

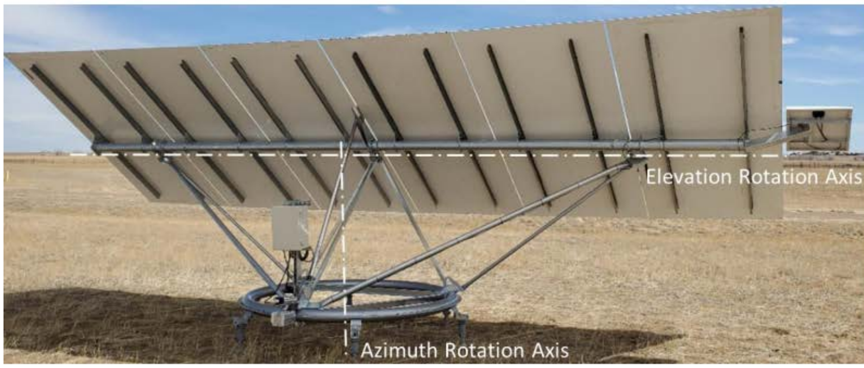
Status:

- Collecting and measuring mirror facets shipped from European partners.
- In next year, publish the round-robin test results.

2.1.3 Request for Proposals Projects

Seven projects were selected in 2023 to collectively receive $3.5 million in funding to advance heliostat technologies. These projects will address the critical gaps identified by industry members, stakeholders, and suppliers in the HelioCon Roadmap report and provide high-impact results that are strategic in time, that use or enhance lab capabilities, and that establish a basis for future years. Funded projects will be completed in 1-3 years.

2.1.3.1 SunRing: Advanced Manufacturing and Field Deployment



Baseline SunRing	
Reflective area	27 m^2
Dimensions	8.46 x 3.21 m
Aspect ratio	2.6
Stow height	1.98 m
Mirror shape	Canted, flat
Foundation	3 x screw piles
Power	PV + battery
Control	Wireless

Figure 17. SunRing heliostat prototype developed by Solar Dynamics

Principal Investigator: Kyle Kattke

This project by Solar Dynamics LLC and partners will develop processes to maximize cost-competitiveness, performance, and reliability of Solar Dynamics' existing SunRing heliostat design. The project will implement off-site preassembly and kitting for the heliostat subassemblies, conceptually develop and prototype an automated manufacturing cell that is transportable and re-deployable for future projects, develop a comprehensive installation and commissioning schedule, and compile a holistic cost model of the SunRing to develop a business case and aid in site and design decision-making.

Overall goals:

- Move large portion of SunRing assembly off-site.
- Redesign mirror array and realize predicted optical performance.
- Reduce uncertainty in field works (construction → commissioning).
- Create holistic cost model (capital costs – lifetime O&M) in today's dollars.

2.1.3.2 HELIOCOMM: A Resilient Wireless Heliostats Communication System

Principal Investigator: Eirini Eleni Tsiropoulou

This components and controls project by the University of New Mexico team will model a resilient wireless communication system based on the principles of integrated access and backhaul (IAB) technology, entropy-based routing, dynamic spectrum management, and interference mitigation. These technical advances will enable an industry pathway to low-cost, wirelessly controlled heliostat fields through photovoltaic-powered controls and communications with reduced energy usage, as well as safety and resilience through faster (milliseconds) communication and reduced risk of communication breakdowns or losses.

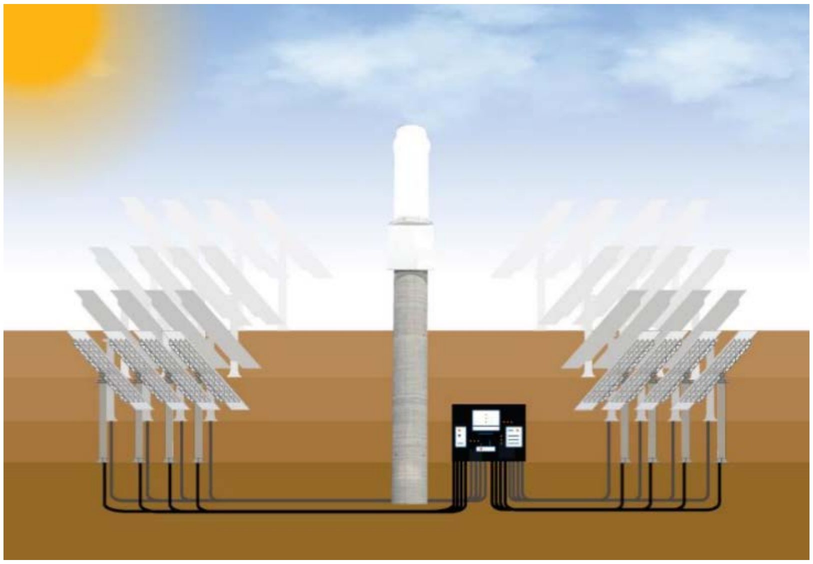


Figure 18. Artist-rendered architecture of wireless communication by the UNM team

Major goals and objectives:

- Design of IAB-based network and optimization of energy efficiency and latency.
- Testing of IEEE 802.11ax and the IEEE 802.15.4 under the IAB-based network.
- Dynamic clustering-based network reconfiguration.
- Design an entropy-based routing.
- Perform dynamic spectrum management in the access and wireless backhaul.
- Implement intra- and inter-cluster interference mitigation.
- Perform modeling and simulation.
- Perform emulation-based experiments.
- Partial HELIOCOMM validation at Sandia National Laboratories (NSTTF).

2.1.3.3 Demonstration of a Heliostat Solar Field Wireless Control System

Principal Investigator: Rick Sommers

Solar Dynamics LLC, with partners Remcom and Vanteon Corporation, will carry out a project aimed at demonstrating the reliable operation of a wireless heliostat solar field control system using commercially available products and developing analytical tools to de-risk the large-scale deployment of the wireless technology to solar fields with tens of thousands of heliostats. In parallel, a wireless radio frequency computer simulation of the demonstration system will be developed. The overall project goal is to prove that wireless technology is fully capable of replacing traditional wired networks with minimal compromises.

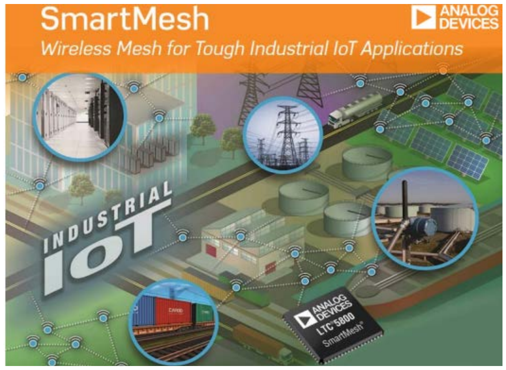


Figure 19. Artist-rendered heliostat field wireless control concept by Solar Dynamics

Objectives: De-risk the adoption of wireless communication systems used to control heliostats in CSP power plants.

- Develop CSP solar field wireless system analytical tools.
- Predict wireless performance of reference CSP power plant solar field using a 'tuned' wireless computer RF propagation model.
- Reduce the installation cost of heliostat solar fields.
- Detailed Bill of Materials for reference CSP power plan.

2.1.3.4 An Educational Program on Concentrating Solar Power and Heliostats for Power Generation and Industrial Process

Principal Investigator: Hameed Metghalchi

This project by Northeastern University will develop an educational program focused on CSP and heliostats for power generation and industrial processes. It will be developed during the two-year project and then become part of the Northeastern curriculum for undergraduate and graduate engineering students.

Northeastern University College of Engineering

The project will include:

- Possible involvement of freshmen in minor research in CSP
- Re-establishment of co-op with NREL and Sandia, New Mexico
- Involvement of under-represented minority students from Louise Stokes Alliances for Minority Participation (LSAMP) group for summer research
- Involvement of undergraduate students in capstone senior design projects relevant to heliostats

- Possible involvement of upper-class students in CSP research
- Development of a four credits senior/first year graduate course
- Development of five short courses for industry
- Possible supervising eight-credit MS theses, as well as four-credit graduate projects
- Presentation in ASME and ASEE meeting
- Publications in ASME Open Journal of Engineering

2.1.3.5 Twisting Heliostats With Closed-Loop Tracking

Principal Investigator: J. Roger Angel

This project will design, manufacture, and test a new type of heliostat and study its application for high-concentration CSP. The University of Arizona will integrate a DOE Small Innovative Projects in Solar type reflector with a high-accuracy mount and tracking camera to demonstrate an accurately focused and centered image of the solar disc. This will be maintained automatically throughout the day by mechanically coupled twisting of the reflector. Even when using perfectly focused facets, distortions of the reflected image on the receiver are introduced due to the non-normal incidence between the heliostat and the receiver. The dynamic focusing of the mirror facet can result in a reflected image that approaches the theoretical limit, potentially leading to higher operating temperatures for CSP and industrial process heat applications.

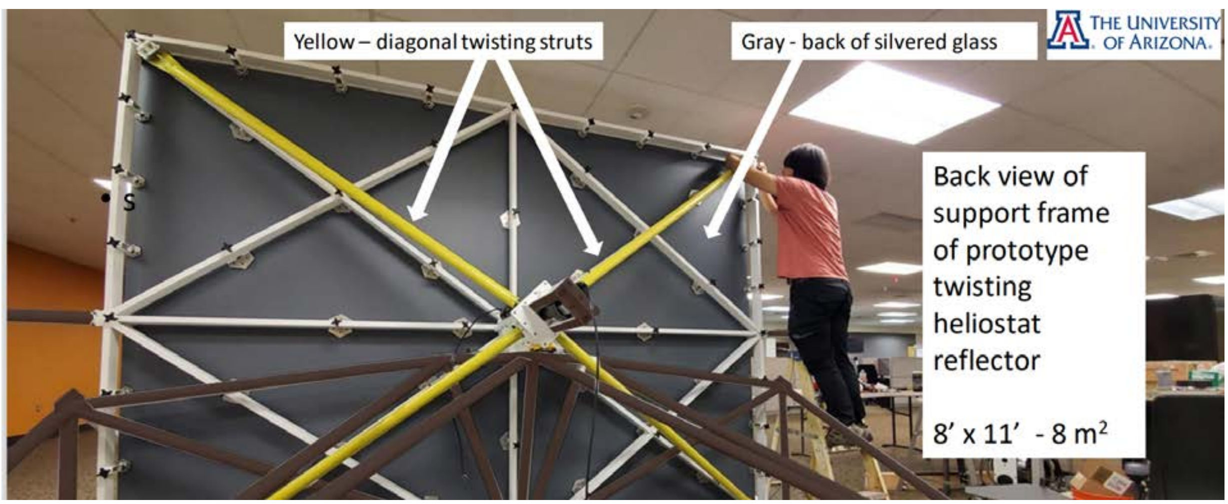


Figure 20. Prototype of high-performance twisting heliostat

2.1.3.6 Digital Twin and Industry 4.0 in Support of Heliostat Technology Advancement

Principal Investigator: Michel Izygon

The Tietronix project aims to leverage technologies from the Fourth Industrial Revolution (Industry 4.0) to enhance the CSP industry and achieve the cost reduction experienced by other industries that have already adopted such advancements. This project will use a model-based systems engineering approach to improve the design, analysis, and verification of heliostats and overall solar fields. The project will also use digital twin technology during the heliostat manufacturing process, conducting thorough testing before achieving full functionality. This approach ensures quality and enables optimization of solar field operations by providing comprehensive insights into heliostat performance. The project will demonstrate the potential of machine learning algorithms, virtual-reality training, and augmented-reality techniques in reducing operational costs and enhancing overall performance.

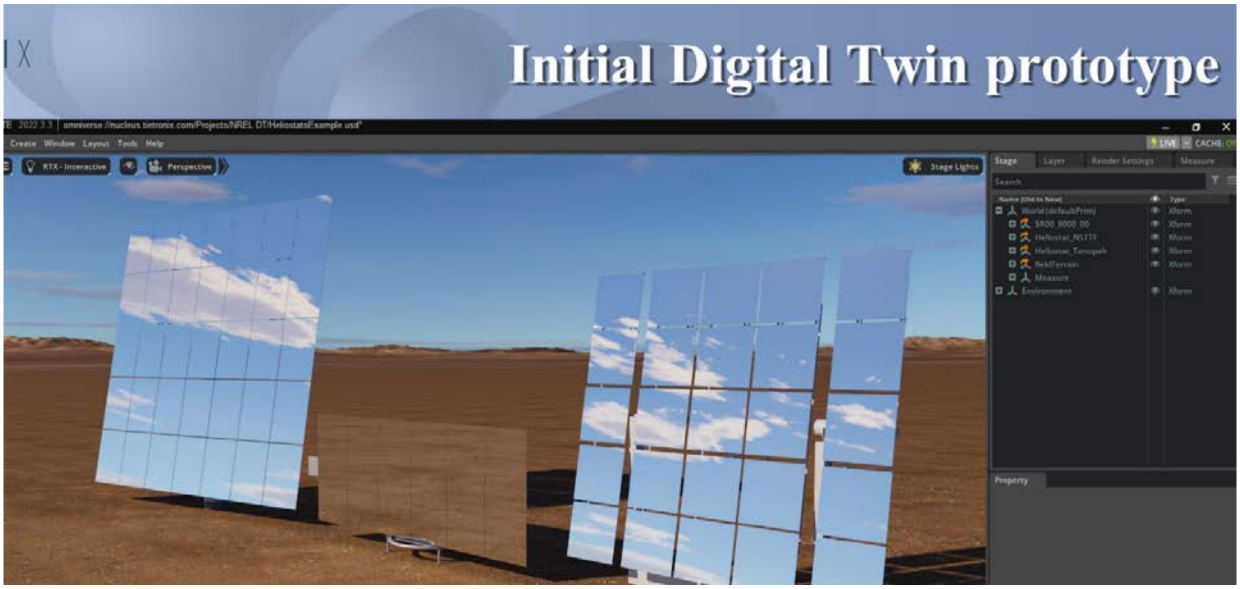


Figure 21. Illustration of initial digital twin prototype

Figure from Michel Izygon, Tietronix

2.1.3.7 Robotic-Assisted Facet Installation (RA-FI)

SARCOS

Principal Investigator: Eric Belski

Sarcos Technology and Robotics Corp., in collaboration with Heliogen, will investigate the feasibility of a novel mobile robotic system capable of supporting the installation of mirror facets onto a heliostat. The primary goal of this proposed effort is to refine the understanding of the challenges related to mirror facet installation to analytically determine the feasibility to address this task robotically from the vantage point of both technical and business considerations.

2.1.4 Research Activities at Australian Solar Thermal Research Institute

Australian Solar Thermal Research Institute (ASTRI) has been a core member of HelioCon and participating with their dedicated resources on additional top-priority research and development efforts. ASTRI members include:

- Commonwealth Scientific and Industrial Research Organisation (CSIRO)
- University of Adelaide (UoA)
- Queensland University of Technology (QUT)
- Australian National University (ANU)

2.1.4.1 Standardization of Slope Error Data Reporting

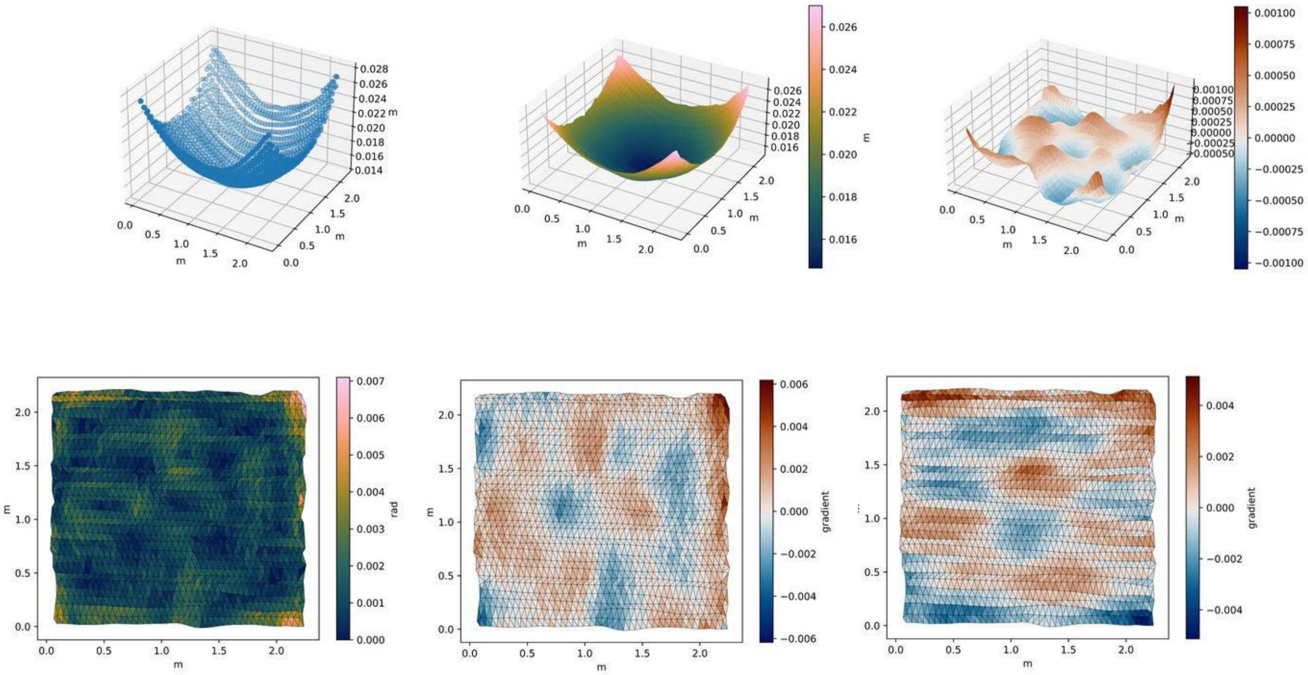


Figure 22. Example representation of slope error data

Image by CSIRO

Description: This project aims to address the challenges in interpreting the slope error data with inconsistent format across the whole community and resulting into unnecessary barriers in effective communication on heliostat performance assessment within the community.

CSIRO
Australia's National Science Agency

Project lead: Mike Collins (CSIRO)

Objective:

- Standardize methods for slope error data processing and reporting

Approach:

- Develop software tools for data processing and reporting
- Test against shared data sets
- Release library as open source

Status:

- Software tools developed and tested on CSIRO point cloud surface data.
- In next year, will develop a standard process to report slope error data proposed to metrology task group.

2.1.4.2 Heliostat Wind Load Field Measurements

Figure 23. Experimental setup and instrumentation for heliostat wind load measurements at the University of Adelaide Atmospheric Boundary Layer Research Facility (ABLRF) and wind tunnel

Image by University of Adelaide

Description: This project intends to increase the understanding of wind load design requirements for a single heliostat and a heliostat field by carrying out a variety of experimental measurements at the University of Adelaide wind tunnel facility and Atmospheric Boundary Layer Research Facility (ABLRF). The wind tunnel is equipped with two-dimensional traverses and multi-hole pressure probes to measure three-dimensional turbulent flows of the incoming ABL and wake flows between adjacent heliostats in a field array. An electronic turntable and high frequency base balance with load cells and pressure sensors are used for measuring structural wind loads on instrumented heliostat models. The ABLRF consists of arrays of ultrasonic anemometers to characterize the ABL turbulence parameters and wind loads on a single heliostat instrumented with a load cell and pressure sensors in an open country terrain.

THE UNIVERSITY of ADELAIDE

Project leads: Matthew Emes and Maziar Arjomandi (UoA)

Objectives:

- Develop a detailed measurement procedure to reconcile single heliostat wind load field measurements with wind tunnel experiments
- Develop a correlation between local turbulent flow and wind load variations in low- and high-density arrays of heliostats for wind load prediction in a heliostat field

Approach:

- Compare aerodynamic wind load coefficients of a full-scale heliostat model at the ABLRF with a 1:6 scale wind tunnel heliostat model at a range of elevation and azimuth angles to investigate the impact of ABL turbulence parameters on heliostat wind loads
- Investigate the variation of turbulent flow measured between heliostats in adjacent rows and wind loads on heliostats at different elevation angles in low- and high-density linearly staggered arrays in the wind tunnel

Status:

- Single heliostat load field measurements consistent with wind tunnel data for prevailing wind direction, other wind directions to be analyzed.
- In next year, will investigate the effect of load reduction in downstream rows of heliostat array for increasing elevation angle and increasing field density.

2.1.4.3 Heliostat Soiling Characterization and Mitigation

Figure 24. Soiling Rig at the Atmospheric Boundary Layer Research Facility

Image by QUT

Description: Heliostat soiling is a major detrimental factor in CSP plants because it limits overall energy input to the receiver. High soiling rates may dramatically decrease revenues and can expose CSP projects and investors to high risk of failure. More studies are required to reliably assess the reflectance state of a whole solar field and to boost both active and passive innovative cleaning methods, including issues related to water scarcity in arid locations. This project intends to address the challenges resulting from heliostat by developing efficient soiling characterization and low-cost mitigation strategy.

Project leads: Giovanni Picotti and Michael E. Cholette (QUT)

Objectives:

- Engage with existing plant operators to understand and improve O&M practices around soiling monitoring and cleaning.

- Benchmark soiling prediction approaches and understand state-of-practice in soiling mitigation.

- Develop and validate techniques to characterize soiling early in the plant design process.

Approach:

Develop a soiling database by:

- Developing a standard reporting framework, hosting platform.
- Publishing data from QUT studies as well as planning and executing new lab and field experiments.
- Working with SolarPACES task and other partners (e.g., DLR, Fraunhofer ISE) to develop standard measurement & reporting procedures.
- Perform soiling studies with academic and industry partners to
    - Assess accuracy of soiling models and perform benchmarking studies.
    - Use soiling database discussed below.
- Provide advice and analysis on cleaning plans and other soiling mitigation measures for new and existing plants.
- Refine soiling models to include missing key phenomena.

Status:

- Completed soiling campaign at three locations and currently conducting two new studies in South Australia.
- Carrying out a benchmarking study with different soiling models.
- Engaging international stakeholders to compile a soiling database.
- Conducted two soiling and cleaning studies with industrial partners (one at Ivanpah, one in Australia).
- In next years, will leverage the above activities to develop standard guidelines for soiling characterization.

2.1.4.4 Heliostat Slope Error Interpretation From Photogrammetry

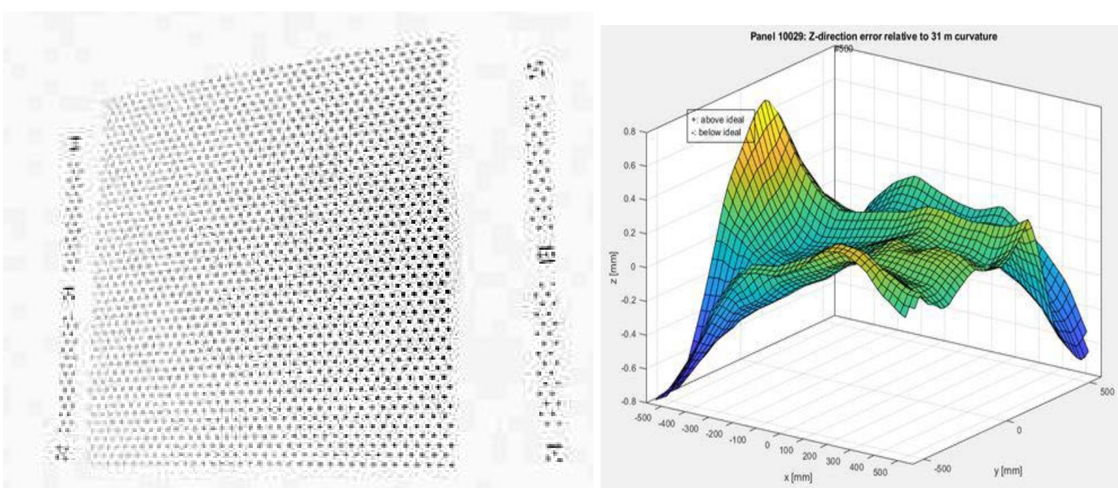


Figure 25. Example point-cloud data and its interpretation from photogrammetry on slope error measurement

Image by ANU

Description: The project intends to address the inconsistency in interpreting slope error data from commonly used photogrammetry techniques.

Project leads: Johannes Pottas, Ye Wang, John Pye, Joe Coventry (ANU)

Objectives:

- To implement, as open-source code, a method for converting photogrammetry point-cloud data to equivalent slope error values.

Approach:

- Acquire point-clouds from images using projected or adhered dots and process using commercial "VMS" photogrammetry tool.
- Implement a new Python script based on previous IDL/MATLAB ANU code: Delauney triangulation, axis alignment, paraboloid fitting, residual fitting to Rayleigh and Normal distributions.

Status:

- Initial code developed and shared at https://github.com/anustg/Solar_concentrator_optics.git
- In the next year, will validate the code by cross-checking flux mapping and ray tracing.

2.1.4.5 Soiling Estimation From DSLR Images

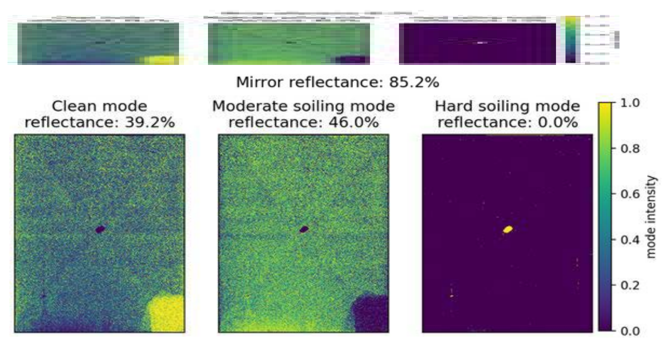


Figure 26. Example soiling images using DSLR camera

Image by ANU

Description: The project intends to address the inefficiency of manual soiling measurement for solar field washing cycle optimization.

Project leads: Charles-Alexis Asselineau, Joe Coventry (ANU)

Objectives:

- Develop a cost-effective way to significantly improve the spatial and temporal resolution of soiling loss estimation.

Approach:

- Use an original color-space processing method to estimate mirror reflectance and soiling loss.
- Gather camera images and reflectometer-based soiling measurements from multiple heliostat technologies and sites to test the method.

Status:

- Controlled conditions result in <1% error in reflectance estimation.
- Currently evaluating the impact of the image acquisition parameters on the accuracy of the method.

2.1.4.6 Using BCS for Heliostat Shape Estimation

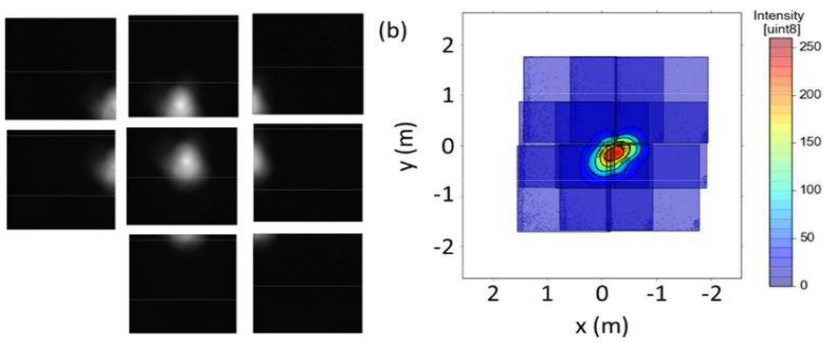


Figure 27. Example soiling images using DSLR camera

Image by ANU

Description: The project intends to develop an efficient method to retrieve slope error measurement from commonly used beam characterization system (BCS) techniques.

Project leads: Ye Wang, Charles-Alexis Asselineau, Felipe Torres, John Pye (ANU)

Objectives:

- To use images from a beam characterization system (BCS) for in- situ heliostat shape and slope error measurements and spillage quantification.

Approach:

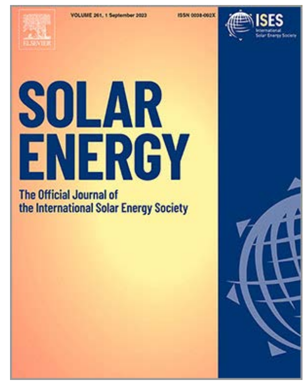
- Acquire beam images of a heliostat at different times of a day using BCS.
- Matching the flux distributions from raytracing and image data by optimizing the shape of the heliostat that is governed by coefficients of a quadric equation.

Status:

- Streamlined software process has been developed and applied to flux image data previously acquired at Vast Solar (Australia)
- New image data were acquired at IMDEA (Madrid, Spain)
- In the next year, will process the collected data to validate against deflectometry data.

2.1.5 Publication Highlights

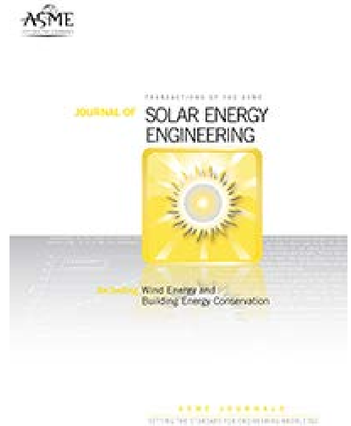
2.1.5.1 HelioCon: A Roadmap for Advanced Heliostat Technologies for Concentrating Solar Power



Citation: Guangdong Zhu, Chad Augustine, Rebecca Mitchell, Matthew Muller, Parthiv Kurup, Alexander Zolan, Shashank Yellapantula, Randy Brost, Kenneth Armijo, Jeremy Sment, Rebecca Schaller, Margaret Gordon, Mike Collins, Joe Coventry, John Pye, Michael Cholette, Giovanni Picotti, Maziar Arjomandi, Matthew Emes, Daniel Potter, and Michael Rae. "A Roadmap for Advanced Heliostat Technologies for Concentrating Solar Power." October 2022, *Solar Energy*.

Abstract: Heliostat-based concentrating solar-thermal power (CSP) systems can offer immense potential to provide low-cost, dispatchable renewable thermal and electrical energy to help achieve 100% decarbonized energy infrastructure in the United States. Heliostats are a major determinant of both capital cost and performance of state-of-the-art commercial molten salt towers and Generation 3 CSP systems. In 2021, the U.S. Department of Energy (DOE) Solar Energy Technologies Office (SETO) launched the Heliostat Consortium (HelioCon), a five-year initiative to advance heliostat technologies. The HelioCon mission is threefold: (1) establish strategic core testing and modeling capabilities and infrastructure at national labs; (2) support heliostat technology development in relevant industries; and (3) serve as a central repository to integrate industry, academia, and other stakeholders for heliostat technology research, development, validation, and deployment. In this Perspective, HelioCon presents a roadmapping study on advancing heliostat technologies, intended as a central reference for the entire CSP community.

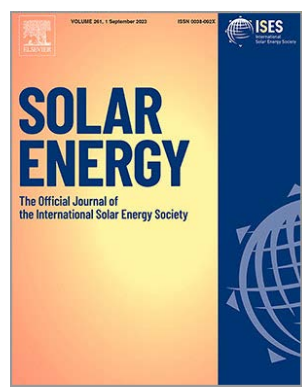
2.1.5.2 Compilation of a Solar Mirror Materials Database and an Analysis of Natural and Accelerated Mirror Exposure and Degradation



Citation: Tucker Farrell, Yue Cao, Frank Burkholder, Daniel Celvi, Christa Schreiber, Guangdong Zhu. "Compilation of a Solar Mirror Materials Database and an Analysis of Natural and Accelerated Mirror Exposure and Degradation" October 2022, *the ASME Journal of Solar Energy Engineering*, 240, 121-130.

Abstract: The National Renewable Energy Laboratory (NREL) has been conducting exposure experiments on solar reflectors for over four decades. Thousands of mirror samples from over 100 suppliers have been exposed to and monitored in a range of relevant environments. These test conditions include outdoor test settings and several controlled laboratory environments. These samples have been rigorously individually characterized using a series of reflectance measurements, visual inspections and, in some cases, in-depth composition analysis to identify degradation modes, reflectance losses, and other mirror properties integral to understanding the solar reflector's life cycle. This article compiles the decades of measurement data into a concise statistical analysis. It includes exposure and degradation data for numerous reflector types, including secondary-surface reflector permutations of polymer and glass superstrates with silver and aluminum reflectors as well as front-surface reflectors. The results herein are intended to analyze environmental stressors and degradation trends among various historical and state-of-the-art solar reflectors. This article may be used to support solar reflector design, effective testing methodology, and inform manufacturing decisions moving forward. Presented are the results of the compiled database and an initial analysis for degradation rate modeling using full-spectrum and wavelength-dependent approaches. The database is a growing resource hosted on a live, publicly accessible website. In conjunction with the analysis presented here, the database provides a valuable resource to the solar reflector manufacturing and testing industry.

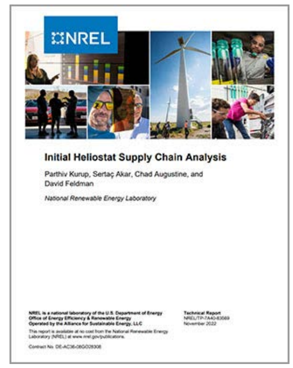
2.1.5.3 A Feasibility Study on the Application of Mesh Grids for Heliostat Wind Load Reduction



Citation: Emes, M.J., Jafari, A., and Arjomandi, M. "A feasibility study on the application of mesh grids for heliostat wind load reduction." May 2022, *Solar Energy*, 240, 121-130.

Abstract: This study examines the effectiveness of mesh grids in heliostat field perimeter fences and edge-mounted devices for heliostat wind load reduction. Two experimental studies were conducted: (1) the effect of mesh porosity and non-dimensional longitudinal distance of a perimeter fence upstream on the forces on a heliostat, and (2) the effect of mesh porosity and non-dimensional height-chord ratio of a heliostat edge-mounted mesh device on the heliostat loads. The experiments were conducted using an instrumented heliostat model positioned in the atmospheric test section of the Adelaide Wind Tunnel. It was found that perimeter mesh fences reduce peak loads by up to 50% and edge-mounted porous mesh devices reduce peak loads by up to 30% at the expense of increasing loads at different elevation angles. The porosity and height-chord ratio of an edge-mounted mesh were found to be important parameters influencing the maximum drag and lift reductions in operating and stow positions. The results of this work show the potential of mesh grids for reducing wind load on heliostats, and the importance of conducting a detailed techno-economic analysis on mesh grids throughout a heliostat field. The application of mesh grids on commercial-scale heliostats requires a further evaluation of the reduction of heliostat wind loads and thus cost of a field through mitigation of the incoming ABL turbulence and wake-induced turbulence from upstream heliostats.

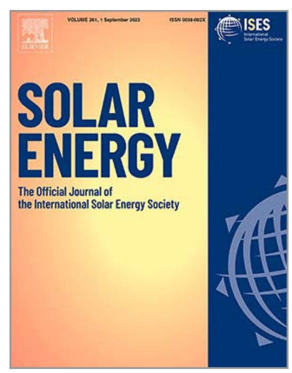
2.1.5.4 Initial Heliostat Supply Chain Analysis



Citation: Parthiv Kurup, Sertac Akar, Chad Augustine, David Feldman. "Initial Heliostat Supply Chain Analysis." November 2022, *National Renewable Energy Laboratory*.

Abstract: Globally, the growing demand for concentrating solar power (CSP) technologies, primarily for electricity generation plants has been met with supply chains primarily composed of plentiful commodity materials such as steel, aluminum, and glass. Often the majority of the commodity materials are sourced within the domestic market where generating plants are constructed. Although specialty components are required for CSP solar field components - including mirror panels used for heliostat applications - these specialty components constitute about 30%-50% of total system installed costs. Only a few companies and countries, including the United States, have developed the capacity to supply such specialty components. This report is an initial assessment of the global and U.S. heliostat supply chain.

2.1.5.5 Stochastic Soiling Loss Models for Heliostats in Concentrating Solar Power Plants



Citation: Picotti, G., Cholette, M.E., Anderson, C.B., Steinberg, T.A., Manzolini, G., 2023. Stochastic soiling loss models for heliostats in Concentrating Solar Power plants. Solar Energy, October 2023 https://doi.org/10.1016/j.solener.2023.111945

Abstract: Reflectance losses on solar mirrors due to soiling are a significant challenge for Concentrating Solar Power (CSP) plants. Soiling losses can vary significantly from site to site — with (absolute) reflectance losses varying from fractions of a percentage point up to several percentage points per day (pp/day), a fact that has motivated several studies in soiling predictive modeling. Yet, existing studies have so far neglected the characterization of statistical uncertainty in their parameters and predictions. In this paper, two reflectance loss models are proposed that model uncertainty: an extension of a previously developed physical model and a simplified model. A novel uncertainty characterization enables Maximum Likelihood Estimation techniques for parameter estimation for both models and permits the estimation of parameter (and prediction) confidence intervals.

The models are applied to data from ten soiling campaigns conducted at three Australian sites (Brisbane, Mount Isa, Wodonga). The simplified model produces high-quality predictions of soiling losses on novel data, while the semi-physical model performance is mixed. The statistical distributions of daily losses were estimated for different dust loadings. Under median conditions, the daily soiling losses for Brisbane, Mount Isa, and Wodonga are estimated as 0.53 ± 0.66, 0.08 ± 0.08, and 0.58 ± 0.15 pp/day, respectively. Yet, higher observed dust loadings can drive average losses as high as 2 pp/day.

Overall, the results suggest a relatively simple approach characterizing the statistical distributions of soiling losses using airborne dust measurements and short reflectance monitoring campaigns.

3 Heliostat Advancements in Partnership With the Heliostat Consortium

3.1 Heliostat Prize

DOE's SETO is seeking to reduce the cost of heliostats and launched the $3 million American-Made Heliostat Prize in 2023 to help reach that goal. This prize is a three-contest challenge specifically focused on reducing the cost or validating the performance of novel components. This prize is designed to accelerate heliostat component technology innovation through the design, development, demonstration, and eventual commercialization of selected heliostat components. The first nine semifinalists were announced in November 2023.

3.2 Impact of Wind Loads on Heliostats: Measurement, Simulation and Optical Performance

Description: Wind-loading is one of the primary drivers of structural design costs of CSP collector structures (heliostats and parabolic troughs). To date, the design of these structures has relied on data from wind-tunnels that do not adequately capture the dynamic effects observed at-scale. This project is conducting a comprehensive field measurement campaign to measure the exact wind conditions and resulting loading on heliostats at Crescent Dunes. This dataset will be used to quantify optical performance of heliostats and will also be used to develop and validate computational models capable of predicting the unsteady flow environment and loading in deep array configurations.

Project Lead: Shashank Yellapantula (NREL)

Objectives:

- Measure wind and loads on large heliostats at Crescent Dunes. Investigate differences in loads typically observed in wind tunnel against the loads seen in the field. Quantify impact of wind loading on optical performance of the heliostats at Crescent Dunes.
- Develop, verify, and validate computationally inexpensive techniques for modeling dynamic loads on Heliostats.

Approach:

- Install wind and load measurement instrumentation at Crescent Dunes power plant. Measure wind conditions inflow into the plant along with wakes behind the heliostats. Focus would be on characterizing static and dynamic loads on the heliostats at the plant edge and deep in the array.
- Computationally efficient actuator source modeling capability will be utilized to simulate heliostats in complex deep array configurations. The focus of the modeling activity in FY24 would be to develop techniques for modeling dynamic behavior of heliostats.

Status:

- The Crescent Dunes wind and loads measurement campaign is being planned with deployment scheduled for January 2024.

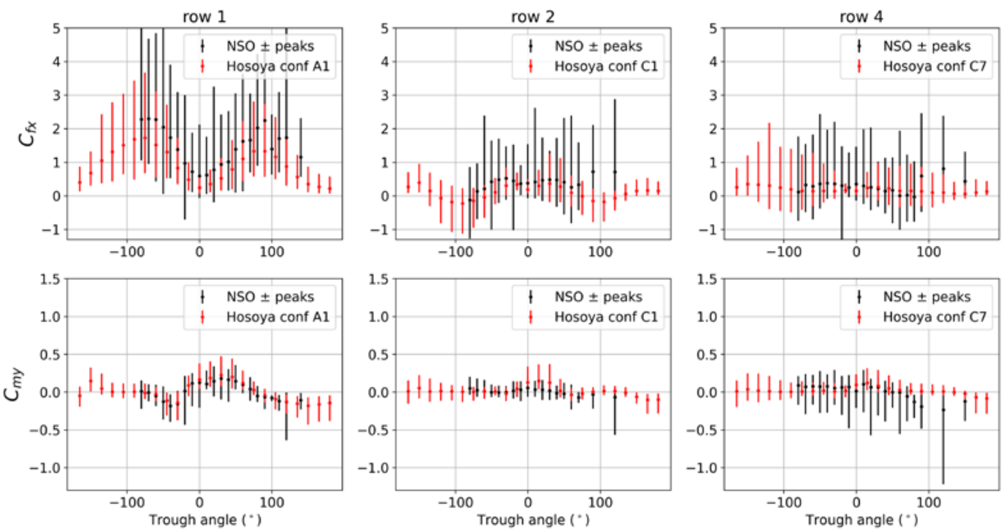


Figure 28. Comparison of load coefficients to wind tunnel results: Dependence on trough angle and on row position

3.3 Surveillance and Mitigation to Actively Reduce Avian Flux Hazards at Concentrating Solar Power Towers (SMART)

Description: At CSP facilities with power towers, concentrated sunlight is reflected off heliostats, directing the solar flux toward one or more towers hundreds of feet in the air, which can result in the singeing and even death of birds that fly through it. The project team will develop an autonomous artificial intelligence-based avian detection system that can trigger a deterrent subsystem to repel or divert avian wildlife from high flux volumes around the CSP towers before they incur serious injury.

Project Lead: Daniel Small (Sandia)

Objectives:

- Protect avian wildlife at operating CSP tower facilities.
- Inform site design and operation decisions of future CSP tower facilities that optimize for minimum disruption to avian wildlife.

Approach:

The team will reconfigure the temporal frequency analysis, an algorithm developed by Sandia National Laboratories for the purpose of detecting and localizing drones within the field of view of digital cameras to focus on the detection of birds. The project will create the Avian Detection and Collection System (ADACS), which will collect a video database of birds flying close to CSP towers, to train a highly sensitive avian detection algorithm using the temporal frequency analysis techniques. Once trained, the temporal frequency analysis algorithm will be incorporated into the ADACS to enable autonomous detection of birds and quickly trigger a deterrent subsystem designed to keep birds away from high flux volumes around the towers. Avian species of highest interest will be identified through a review of avian fatality data from the Ivanpah CSP facility, which will inform ADACS development and deterrent subsystem selection decisions. In addition, a new industry-focused full-field irradiance analysis model will be developed and designed to summarize the expected irradiance of a heliostat field when in standby. The full-field irradiance analysis model will be focused on avian interactions with CSP high flux volumes and will be validated at the NSTTF at Sandia National Laboratories and the Crescent Dunes Solar Power Project.

Status:

- Completed an initial optical design and prototype of ADACS.
- Began work on the full-field irradiance analysis model tool.
- Began work on the avian mortality review of the Ivanpah CSP.

3.4 Technology Commercialization Fund Award to Adapt NREL's ReTNA Method for Commercial Deployment

Description: Over the last two years under HelioCon, NREL has developed a new optical measurement system for CSP mirrors in the laboratory, called Reflected Target Non-Intrusive Assessment. ReTNA is designed to use much lower cost equipment than conventional methods: a thin, printed target and camera moving on a simple off-the-shelf cable system. It is designed to use photogrammetry to locate the target, mirror, and camera, removing the need for careful positioning during setup and precise calibration, and work in ambient warehouse lighting. These benefits come at the expense of lower resolution measurement results, but make it well suited for fast, low-cost, assembly line optical measurements.

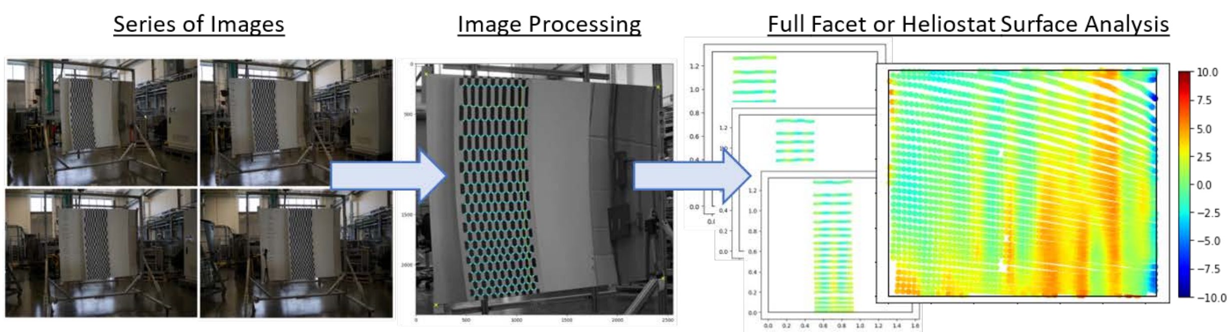


Figure 29. A diagram of ReTNA's process flow, from a series of deflection images to surface slope measurement

Image by Devon Kesseli, NREL

Project Lead: Devon Kesseli (NREL)

Objectives:

- **Adapt software for commercial deployment** - automation with computer vision and photogrammetry, restructure for commercial users.
- **Commercial ReTNA installation** - streamline setup and data collection

- **Tech to market** - industry and market analysis, determine the most impactful path forward for ReTNA

Approach:

- Work closely with industry partners to identify specifications for a commercial ReTNA system.
- Add additional software features to ReTNA, to decrease reliance on third-party software.
- Demonstrate and evaluate a commercial ReTNA system on Solar Dynamics' SunRing heliostat.

Status:

- Continue software development.
- Industry engagement is ongoing. Solar Dynamics is the planned industry partner in this work. Additional companies may be engaged.

3.5 Commercialization of a Non-Intrusive Optical (NIO) Technology to Measure Heliostat Optical Errors in Utility-Scale Concentrating Solar Power Plants

Description: Drone-based NIO technology has been developed at NREL to allow for efficient and automated optical characterization of heliostats in CSP plants. The technology will be developed into a commercial tool package, including software and user-interface, operations manual, and training and support services.

Project Lead: Rebecca Mitchell (NREL)

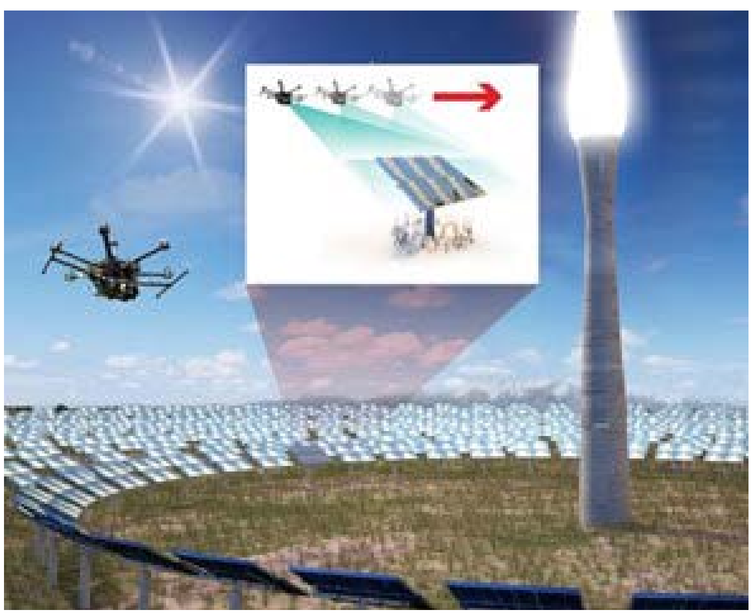


Figure 30. NIO technology can characterize optical errors of heliostats in a commercial power tower CSP plant by using a UAS to scan the solar field

Image by Joshua Bauer, NREL

Objectives:

- Create a commercial NIO package with a user-interface, documentation and training, and capability services to meet stakeholder needs.
- Perform a commercial demonstration of the NIO tool by performing data collection activities and providing optical error data deliverables to a plant partner.
- Produce a business strategy to market and launch a beta version of the commercial tool package at the conclusion of the project.

Approach:

- Design NIO services and capabilities based on industry stakeholder feedback.
- Test NIO commercial tool capabilities and operation procedures with a large-scale data collection campaign at a commercial plant.

Status:

- Streamlining and validating NIO algorithm performance.
- Coordinating with candidate commercial plants for data collection activities.

4 Summary

113 Staff

33 Projects

~72,000 Interactions

35 Publications/Seminars

28 Lead Researchers

In 2023, HelioCon successfully completed its key milestones and further defined goals and objectives for 2024.

HelioCon will continue to advance U.S. heliostat technology, capabilities, and the national workforce by:

- Carrying out high-impact R&D and technology validation projects at national labs for strategic core capabilities and infrastructure.
- Engaging relevant industries and research institutes to advance heliostat technologies and minimize commercial deployment risks through new round of RFP.
- Expanding workforce through student internships and collaboration with universities and community colleges.
- Enhancing the impact of HelioCon activities such as participating researchers, students, publications, seminars, and R&D projects.

We look forward to engaging with industry and academia through direct partnerships, workshops, conferences, meetings, and other in-person/virtual opportunities in the upcoming years.