EXHIBIT 1

ENTIRE EXHIBIT NOT SUSCEPTIBLE TO PUBLIC SUMMARY

EXHIBIT 2

ENTIRE EXHIBIT NOT SUSCEPTIBLE TO PUBLIC SUMMARY

EXHIBIT 3

VPRA Vanadium Producers & Reclaimers Association
www.vanadiumproducers.org

2017 Vanadium Uses, Military Relevance & Supply Chain Threats in the U.S.

Introduction

Ferrovanadium and vanadium oxides are mission critical chemicals. Forced substitution of any these vanadium chemicals or changes in the supply chain would harm not only those who produce these materials but also the environment and the nation's defense. Having to rely solely on overseas suppliers would be very risky as it is likely that some of these countries may not be willing to supply the required vanadium chemicals and alloys needed for strategic purposes.

Vanadium Background and Military Importance

Vanadium is a naturally occurring element that is mined either alone or in conjunction with other metals such as iron. 90% of all vanadium is processed into ferrovanadium (FeV) that is used in the steel industry. Vanadium is often processed into vanadium pentoxide (V2O5) or vanadium trioxide (V2O3) and then converted to ferrovanadium alloy for addition to steel. V2O5 and V2O3 are thus key intermediates in the production of high strength, low alloy vanadium steels. Ferrovanadium is an important and well-established alloying element traditionally used in the production of higher strength steels – allowing up to 40% reduction in mass for equivalent strength in equipment and structures. ***Some quantity of vanadium is used in virtually every structural application in the military where steel products are employed.*** Examples include some armor steel applications, combat vehicles, tactical vehicles, tactical bridges, material handling equipment, aircraft, watercraft, rail, trailers, and steel structures. Vanadium is alloyed with titanium for application in jet engine components, aircraft structures and vehicle armor. Other military applications that rely on vanadium-bearing compounds include vanadium based batteries and electric vehicle power applications. Vanadium-alloyed steels are also used in mortar tubes and cannon tubes, as well as in howitzers.

No other domestic and reasonably available material can substitute for vanadium in the microalloyed steel industry, and the Department of Defense's (DoD) applies this high-performance steel in specific defense-related infrastructure applications because of its significant benefits in terms of weight savings, reduced structural sizes, and the resulting increased mobility of equipment.

The strategic importance of vanadium-containing materials to the military cannot be overstated. Over 80% of domestically produced vanadium is used for "microalloying" steels at levels of only 0.01 to 0.04 percent of the steel's chemistry. Microalloyed vanadium steels produced in hot rolled thin slabs are manufactured as plate, sheet, and structural shapes with the significant property combination of high strength, good ductility, and excellent weldability. In steels, vanadium refines the solidification grain structure which adds ductility to high strength (toughness), and it increases resistance to cracking and improves fatigue resistance. Vanadium is also important in ultra-high strength steels, like vanadium-modified 4330 chrome-moly alloy. These steels are used in lightweight, high muzzle velocity mortars, howitzers, and cannon tubes for the Army and Marines.

Vanadium is also used as a strengthening element in the highest performing titanium alloys. These titanium alloys are used in light weighting and size reduction of weapon systems (ground, aircraft, missiles, unmanned aerial vehicles, robots). In titanium alloys, vanadium adds plasticity for forming and improves fatigue resistance. In the foregoing steel and titanium alloys, vanadium is used in "low-alloying" quantities such as 1 to 4 percent of the material's chemistry.

Supply Threats in the United States

Although North America accounted for 14.3% of the world's vanadium consumption in 2016, it only produced 4.4%. Approximately 43% of U.S. imports of Ferrovanadium in 2016 came Russian owned production. In 2016 60.7% of the vanadium pentoxide imported into the United States came from China, and South Africa. Approximately 4% of total U.S. imports came from the Republic of Korea (Chinese influenced), and approximately 5% from Austria (Russian controlled raw material). Altogether, 83% of the total amount of Vanadium being imported from the U.S comes from Russian, Chinese, and South African sources.

Ferrovanadium and vanadium oxides are mission critical chemicals. Forced substitution of any these vanadium chemicals or changes in the supply chain would harm not only those who produce these materials but also the environment and the nation's defense. ***In the U.S., vanadium is produced by a small number of companies because of the limited domestic availability of vanadium bearing ores and economic turmoil has recently reduced the size of the industry. In 2016 a major US producer, Gulf Chemical, was shut down and the assets sold. Gulf had been responsible for 50% of the domestic V2O5 production and 30% of the FeV production in the US – that supply is now gone.*** Having to rely solely on overseas suppliers would be very risky as it is likely that some of these countries may not be willing to supply the required vanadium chemical. Even if overseas suppliers were not an issue, the Defense Federal Acquisition Regulation Supplement (DFARS) clause on "Restrictions on Specialty Metals" may prevent the DOD from using this option in any event.

Vanadium production in the U.S. is almost exclusively through the recycling of spent catalysts from oil refineries and residues from power plants. Not only does the recycling of these spent catalysts produce valuable vanadium chemicals and other products, but it also provides an important waste management solution because spent catalyst are K-listed hazardous wastes. Relative to total global production, the

U.S. vanadium pentoxide industry is a small but critical industry. Globally, vanadium production, in all chemical forms, was reported by Vanitec to be 76,530 metric tons in 2016. The majority of world vanadium production comes from vanadium bearing ores.

The alloy Ti-6-4, which is used in essentially all jet engines and other critical parts, uses vanadium aluminum which in turn is produced from V_2O_5 and some V_2O_3 (vanadium oxides). It cannot be made from ferrovanadium. ***There is currently no substitute for vanadium in this titanium alloy for this application and currently there is only a single domestic producer (Evraz Stratcor) of the high purity vanadium needed for titanium production.***

Vanadium Processing

The available choices for microalloying include niobium, titanium, and vanadium. Of these, vanadium is the preferred addition for several reasons. First, and probably most importantly, the high solubility of vanadium carbonitride [V(C,N)] compared to the other microalloying alloy alternatives allows the vanadium to be in solution during normal reheating temperatures, either for rolling or forging. Titanium nitride (TiN) has the lowest solubility, either as a nitride or carbide, and is generally ineffective as a precipitation strengthener in high carbon steels. Niobium carbonitride [Nb(C,N)] also has lower solubility than vanadium. Because carbon is the preferred element for precipitation with Nb, the high carbon levels in these steels reduce the solubility of Nb even further. The amount of Nb in solution during reheating of high carbon steels is limited and dependent on reheat temperature. For higher Nb additions, the strengthening effect will be unpredictable because small variations in reheat temperature will result in significant differences in the amount of Nb in solution.

V(C,N) is more easily dissolved in high carbon steels, and is less sensitive to the carbon level than niobium. Normal reheat temperatures (1150°C to 1250°C) are sufficient for dissolving all vanadium carbonitrides over the full range of expected alloy compositions. As a result, vanadium strengthening is proportional to the amount of vanadium added. This linear relationship between vanadium additions and strengthening is very useful for estimating the amount of alloy addition needed to meet minimum strength levels.

Vanadium has a natural affinity for nitrogen. When adequate nitrogen is available, V(C,N) precipitates have been determined to be primarily nitrides, usually with a ratio of V(C.2N.8). Because of this preference of vanadium for nitrogen, nitrogen enhances the performance of vanadium steels. As a result, nitrogen is no longer is solid solution where it can contribute to embrittlement. Vanadium transforms nitrogen from an unwanted tramp element to an integral part of the alloy system. Because medium and high carbon products are often continuously cast using metering nozzles without flow controls, the use of Al for grain refinement is not feasible because of reoxidation problems. Vanadium is easily cast under these conditions, making V an excellent alternative to Al as a grain refiner for heat-treated products.

DoD Vanadium R&D

The DOD recently invested in excess of $11 million over several years in support of research and development for vanadium technology, which primarily involves the replacement of conventional carbon low alloy steels with vanadium-alloyed steels. The result has been lighter, more mobile systems, with improved airlift capability and decreased logistical support. This investment, through the Vanadium Technology Program, has enhanced mission capabilities by strengthening and hardening fixed Army assets while decreasing weight. Examples include military base buildings, bridges, and blast resistant structures. Case studies from the Vanadium Technology Program include 1) lighter weight, lower cost trailers for in-theatre logistics – a partnership with Program Management (PM) Tactical Vehicles, Research, Development and Engineering Command – Tank Automotive Research, Development and Engineering Center (RDECOM-TARDEC) and Tank-Automotive & Armaments Command (TACOM); 2) Blast-resistant, high strength reinforced concrete buildings – a partnership with Army Corps of Engineers, Engineering Research and Development Center (ERDC), Vicksburg, MS; 3) Longer-span non-standard fixed bridges for bridging gaps in-theatre – also partnered with Army Corps of Engineers, ERDC, Vicksburg, MS; and 4) Lighter, longer-span trusses and joists for large clear span buildings – a partnership with Army Corps of Engineers, ERDC, Champaign, IL. The military has learned and demonstrated that by utilizing vanadium alloys in steel applications, it is able to maintain an increasing emphasis on lightweight weapon systems and the related infrastructure necessary for combat and peacekeeping missions.

New Advanced Vanadium Uses

In an important new class of microalloyed steels, called Advanced High Strength Steels, vanadium industry sponsored research is indicating that vanadium can supplement the strength of these steels without interfering with the mechanisms that make these steels so significant. Advanced High Strength Steels, particularly Transformation Induced Plasticity steels, have a special ability to absorb more energy as they are more deformable than other steels. This attribute is important in crash worthiness of automobiles and could be applied behind armor skins in military ground vehicles to absorb some of the energy of projectile and explosive impacts.

Vanadium redox batteries have demonstrated the potential to store megawatts of electrical energy from utility diesel generators, wind farms, or other renewable energy sources for hours or days and then release the stored electricity into a power grid upon demand. Vanadium redox batteries could potentially replace natural gas-fired peaking plants that electric utilities currently use for demand/capacity leveling. These batteries will be durable, and can be designed in a variety of options, with the ability to release electricity as quickly as it is stored. Potential advantages include ability to manage reactive power for which there are continuous inflows and outflows of electricity and to bridge power outages with large energy capacity and high drain rates, allowing vanadium redox batteries to play an important role in managing power for military bases in combat zones. The use of vanadium in redox batteries continues to grow and will account for a larger percentage of vanadium consumption in the future. Vanadium contained in energy storage applications is expected to reach 5,000 MTV in 2017 (up from less than 1,000 MTV in 2016.)

<u>Summary</u>

Over 90% of vanadium requirements are in the form of ferrovanadium for steel manufacture. Ferrovanadium is critical to military and crucial civilian (infrastructural) requirements. While most V_2O_5 and V_2O_3 is used to produce 80% ferrovanadium and can be done with domestic or imported material, ensuring the availability of vanadium oxides to produce the alloy Ti-6-4 used in jet engine production as well as for their use in chemical applications, flow batteries, etc, is critical since these vanadium chemicals cannot be made from ferrovanadium. The wide breadth of vanadium applications and the new advances in vanadium use in energy storage represent immediate and long-range utility to the Armed Forces. Therefore, a disruption to the supply of vanadium, in its appropriate form, ready to use, would be highly detrimental to the DOD.

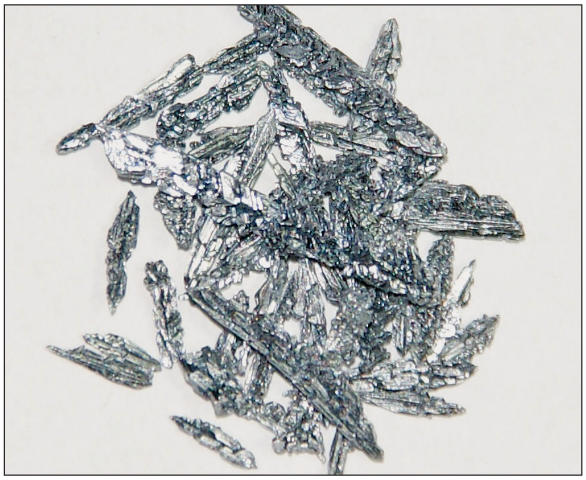
EXHIBIT 4

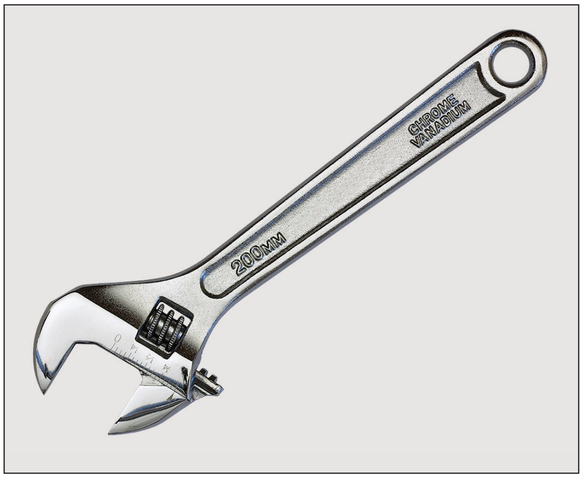
USGS
science for a changing world

Vanadium

Chapter U of

Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply





Professional Paper 1802–U

U.S. Department of the Interior
U.S. Geological Survey

Periodic Table of Elements

1A	2A	3B	4B	5B	6B	7B	8B	8B	8B	11B	12B	3A	4A	5A	6A	7A	8A
1 H hydrogen 1.008																	2 He helium 4.003
3 Li lithium 6.94	4 Be beryllium 9.012											5 B boron 10.81	6 C carbon 12.01	7 N nitrogen 14.01	8 O oxygen 16.00	9 F fluorine 19.00	10 Ne neon 20.18
11 Na sodium 22.99	12 Mg magnesium 24.31											13 Al aluminum 26.98	14 Si silicon 28.09	15 P phosphorus 30.97	16 S sulfur 32.06	17 Cl chlorine 35.45	18 Ar argon 39.95
19 K potassium 39.10	20 Ca calcium 40.08	21 Sc scandium 44.96	22 Ti titanium 47.88	23 V vanadium 50.94	24 Cr chromium 52.00	25 Mn manganese 54.94	26 Fe iron 55.85	27 Co cobalt 58.93	28 Ni nickel 58.69	29 Cu copper 63.55	30 Zn zinc 65.39	31 Ga gallium 69.72	32 Ge germanium 72.64	33 As arsenic 74.92	34 Se selenium 78.96	35 Br bromine 79.90	36 Kr krypton 83.79
37 Rb rubidium 85.47	38 Sr strontium 87.62	39 Y yttrium 88.91	40 Zr zirconium 91.22	41 Nb niobium 92.91	42 Mo molybdenum 95.96	43 Tc technetium (98)	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3
55 Cs cesium 132.9	56 Ba barium 137.3	*	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.9	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.5	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium (209)	85 At astatine (210)	86 Rn radon (222)
87 Fr francium (223)	88 Ra radium (226)	**	104 Rf rutherfordium (265)	105 Db dubnium (268)	106 Sg seaborgium (271)	107 Bh bohrium (270)	108 Hs hassium (277)	109 Mt meitnerium (276)	110 Ds darmstadtium (281)	111 Rg roentgenium (280)	112 Cn copernicium (285)	113 Uut (284)	114 Fl flerovium (289)	115 Uup (288)	116 Lv livermorium (293)	117 Uus (294)	118 Uuo (294)

Lanthanide Series*	57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.2	61 Pm promethium (145)	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.2	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.0	71 Lu lutetium 175.0
Actinide Series**	89 Ac actinium (227)	90 Th thorium 232	91 Pa protactinium 231	92 U uranium 238	93 Np neptunium (237)	94 Pu plutonium (244)	95 Am americium (243)	96 Cm curium (247)	97 Bk berkelium (247)	98 Cf californium (251)	99 Es einsteinium (252)	100 Fm fermium (257)	101 Md mendelevium (258)	102 No nobelium (259)	103 Lr lawrencium (262)

Los Alamos NATIONAL LABORATORY

CHEMISTRY

element names in **blue** are liquids at room temperature
element names in red are gases at room temperature
element names in black are solids at room temperature

Modified from Los Alamos National Laboratory Chemistry Division; available at http://periodic.lanl.gov/images/periodictable.pdf.

Cover. Photographs depicting four examples of sources and uses of vanadium. Upper left, vanadiferous magnetite-rich layer from South Africa. Photograph courtesy of Kevin Walsh/CC BY 2.0 (https://creativecommons.org/licenses/by/2.0/). Upper right, natural vanadinite, which is a main source of vanadium from vanadate deposits. Photograph courtesy of Juergen Kummer, Jumk.de Web Projects/CC BY 3.0 (http://images-of-elements.com/vanadium.php). Lower left, vanadium metal crystals made by electrolysis (the largest crystal is 2 centimeters in length). Photograph courtesy of Juergen Kummer, Jumk.de Web Projects/CC BY 3.0 (http://images-of-elements.com/vanadium.php). Lower right, common hand wrench made with vanadium alloy steel. Photograph courtesy of MrX/CC-BY-SA-3.0 (https://commons.wikimedia.org/wiki/File:Chrome_Vanadium_Adjustable_Wrench.jpg).

Vanadium

By Karen D. Kelley, Clinton T. Scott, Désirée E. Polyak, and Bryn E. Kimball

Chapter U of

Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply

Edited by Klaus J. Schulz, John H. DeYoung, Jr., Robert R. Seal II, and Dwight C. Bradley

Professional Paper 1802–U

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
RYAN K. ZINKE, Secretary

U.S. Geological Survey
William H. Werkheiser, Acting Director

U.S. Geological Survey, Reston, Virginia: 2017

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Tables

Conversion Factors

International System of Units to Inch/Pound

Multiply	By	To obtain
Length		
angstrom (Å) (0.1 nanometer)	0.003937	microinch
angstrom (Å) (0.1 nanometer)	0.000003937	mil
micrometer (µm) [or micron]	0.03937	mil
millimeter (mm)	0.03937	inch (in.)
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
kilometer (km)	0.6214	mile (mi)
Area		
hectare (ha)	2.471	acre
square kilometer (km^2)	247.1	acre
square meter (m^2)	10.76	square foot (ft^2)
square centimeter (cm^2)	0.1550	square inch (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
Volume		
milliliter (mL)	0.03381	ounce, fluid (fl. oz)
liter (L)	33.81402	ounce, fluid (fl. oz)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	264.2	gallon (gal)
cubic centimeter (cm^3)	0.06102	cubic inch (in^3)
cubic meter (m^3)	1.308	cubic yard (yd^3)
cubic kilometer (km^3)	0.2399	cubic mile (mi^3)
Mass		
microgram (µg)	0.00000003527	ounce, avoirdupois (oz)
milligram (mg)	0.00003527	ounce, avoirdupois (oz)
gram (g)	0.03527	ounce, avoirdupois (oz)
gram (g)	0.03215075	ounce, troy
kilogram (kg)	32.15075	ounce, troy
kilogram (kg)	2.205	pound avoirdupois (lb)
ton, metric (t)	1.102	ton, short [2,000 lb]
ton, metric (t)	0.9842	ton, long [2,240 lb]
Deposit grade		
gram per metric ton (g/t)	0.0291667	ounce per short ton (2,000 lb) (oz/T)
Pressure		
megapascal (MPa)	10	bar
gigapascal (GPa)	10,000	bar
Density		
gram per cubic centimeter (g/cm^3)	62.4220	pound per cubic foot (lb/ft^3)
milligram per cubic meter (mg/m^3)	0.00000006243	pound per cubic foot (lb/ft^3)
Energy		
joule (J)	0.0000002	kilowatthour (kWh)
joule (J)	6.241×10^{18}	electronvolt (eV)
joule (J)	0.2388	calorie (cal)
kilojoule (kJ)	0.0002388	kilocalorie (kcal)

International System of Units to Inch/Pound—Continued

Multiply	By	To obtain
Radioactivity		
becquerel (Bq)	0.00002703	microcurie (µCi)
kilobecquerel (kBq)	0.02703	microcurie (µCi)
Electrical resistivity		
ohm meter (Ω-m)	39.37	ohm inch (Ω-in.)
ohm-centimeter (Ω-cm)	0.3937	ohm inch (Ω-in.)
Thermal conductivity		
watt per centimeter per degree Celsius (watt/cm °C)	693.1798	International British thermal unit inch per hour per square foot per degree Fahrenheit (Btu in/h ft^2 °F)
watt per meter kelvin (W/m-K)	6.9318	International British thermal unit inch per hour per square foot per degree Fahrenheit (Btu in/h ft^2 °F)

Inch/Pound to International System of Units

Length		
mil	25.4	micrometer (µm) [or micron]
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Volume		
ounce, fluid (fl. oz)	29.57	milliliter (mL)
ounce, fluid (fl. oz)	0.02957	liter (L)
Mass		
ounce, avoirdupois (oz)	28,350,000	microgram
ounce, avoirdupois (oz)	28,350	milligram
ounce, avoirdupois (oz)	28.35	gram (g)
ounce, troy	31.10 348	gram (g)
ounce, troy	0.03110348	kilogram (kg)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	ton, metric (t)
ton, long (2,240 lb)	1.016	ton, metric (t)
Deposit grade		
ounce per short ton (2,000 lb) (oz/T)	34.285714	gram per metric ton (g/t)
Energy		
kilowatthour (kWh)	3,600,000	joule (J)
electronvolt (eV)	1.602×10^{-19}	joule (J)
Radioactivity		
microcurie (µCi)	37,000	becquerel (Bq)
microcurie (µCi)	37	kilobecquerel (kBq)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Temperature in degrees Celsius (°C) may be converted to kelvin (K) as follows:

$$K = °C + 273.15$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8$$

Datum

Unless otherwise stated, vertical and horizontal coordinate information is referenced to the World Geodetic System of 1984 (WGS 84). Altitude, as used in this report, refers to distance above the vertical datum.

Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in soils and (or) sediment are given in milligrams per kilogram (mg/kg), parts per million (ppm), or parts per billion (ppb).

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L), micrograms per liter (µg/L), nanogams per liter (ng/L), nanomoles per kilogram (nmol/kg), parts per million (ppm), parts per billion (ppb), or parts per trillion (ppt).

Concentrations of suspended particulates in water are given in micrograms per gram (µg/g), milligrams per kilogram (mg/kg), or femtograms per gram (fg/g).

Concentrations of chemicals in air are given in units of the mass of the chemical (milligrams, micrograms, nanograms, or picograms) per volume of air (cubic meter).

Activities for radioactive constituents in air are given in microcuries per milliliter (µCi/mL).

Deposit grades are commonly given in percent, grams per metric ton (g/t)—which is equivalent to parts per million (ppm)—or troy ounces per short ton (oz/T).

Geologic ages are expressed in mega-annum (Ma, million years before present, or 10^6 years ago) or giga-annum (Ga, billion years before present, or 10^9 years ago).

For ranges of years, “to” and (or) the en dash (“–”) mean “up to and including.”

Concentration unit	Equals
milligram per kilogram (mg/kg)	part per million
microgram per gram (µg/g)	part per million
microgram per kilogram (µg/kg)	part per billion (10^9)

Equivalencies

part per million (ppm): 1 ppm = 1,000 ppb = 1,000,000 ppt = 0.0001 percent
part per billion (ppb): 0.001 ppm = 1 ppb = 1,000 ppt = 0.0000001 percent
part per trillion (ppt): 0.000001 ppm = 0.001 ppb = 1 ppt = 0.0000000001 percent

Metric system prefixes

tera- (T-)	10^{12}	1 trillion
giga- (G-)	10^9	1 billion
mega- (M-)	10^6	1 million
kilo- (k-)	10^3	1 thousand
hecto- (h-)	10^2	1 hundred
deka- (da-)	10	1 ten
deci- (d-)	10^{-1}	1 tenth
centi- (c-)	10^{-2}	1 hundredth
milli- (m-)	10^{-3}	1 thousandth
micro- (µ-)	10^{-6}	1 millionth
nano- (n-)	10^{-9}	1 billionth
pico- (p-)	10^{-12}	1 trillionth
femto- (f-)	10^{-15}	1 quadrillionth
atto- (a-)	10^{-18}	1 quintillionth

Abbreviations and Symbols

µg/L	microgram per liter
µg V/L	microgram of vanadium per liter
AMD	acid mine drainage
Ga	giga-annum
HSLA	high-strength, low-alloy
km	kilometer
km^2	square kilometer
LC_{50}	lethal concentration 50 (concentration that kills 50 percent of test population within a given timeframe)
LIP	large igneous province
m	meter
Ma	mega-annum
mg/kg	milligram per kilogram
mg/L	milligram per liter
mg/m^3	milligram per cubic meter
MVT	Mississippi Valley-type
ng/m^3	nanogram per cubic meter
nm	nanometer
PGE	platinum-group element
ppb	part per billion
ppm	part per million
SSV	sandstone-hosted vanadium
VRB	vanadium redox-flow battery
VTM	vanadiferous titanomagnetite

Vanadium

By Karen D. Kelley, Clinton T. Scott, Désirée E. Polyak, and Bryn E. Kimball

Abstract

Vanadium is used primarily in the production of steel alloys; as a catalyst for the chemical industry; in the making of ceramics, glasses, and pigments; and in vanadium redox-flow batteries (VRBs) for large-scale storage of electricity. World vanadium resources in 2012 were estimated to be 63 million metric tons, which include about 14 million metric tons of reserves. The majority of the vanadium produced in 2012 was from China, Russia, and South Africa.

Vanadium is extracted from several different types of mineral deposits and from fossil fuels. These deposits include vanadiferous titanomagnetite (VTM) deposits, sandstone-hosted vanadium (with or without uranium) deposits (SSV deposits), and vanadium-rich black shales. VTM deposits are the principal source of vanadium and consist of magmatic accumulations of ilmenite and magnetite containing 0.2 to 1 weight percent vanadium pentoxide (V_2O_5). SSV deposits are another important source; these deposits have average ore grades that range from 0.1 to greater than 1 weight percent V_2O_5. The United States has been and is currently the main producer of vanadium from SSV deposits, particularly those on the Colorado Plateau. Vanadium-rich black shales occur in marine successions that were deposited in epeiric (inland) seas and on continental margins. Concentrations in these shales regularly exceed 0.18 weight percent V_2O_5 and can be as high as 1.7 weight percent V_2O_5. Small amounts of vanadium have been produced from the Alum Shale in Sweden and from ferrophosphorus slag generated during the reduction of phosphate to elemental phosphorus in ore from shales of the Phosphoria Formation in Idaho and Wyoming. Because vanadium enrichment occurs in beds that are typically only a few meters thick, most of the vanadiferous black shales are not currently economic, although they may become an important resource in the future. Significant amounts of vanadium are recovered as byproducts of petroleum refining, and processing of coal, tar sands, and oil shales may be important future sources.

Vanadium occurs in one of four oxidation states in nature: +2, +3, +4, and +5. The V^{3+} ion has an octahedral radius that is almost identical to that of Fe^{3+} and Al^{3+} and, therefore, it substitutes in ferromagnesian minerals. During weathering, much of the vanadium may partition into newly formed clay minerals, and it either remains in the +3 valence state or oxidizes to the +4 valence state, both of which are relatively insoluble. If erosion is insignificant but chemical leaching is intense, the residual material may be enriched in vanadium, as are some bauxites and laterites. During the weathering of igneous, residual, or sedimentary rocks, some vanadium oxidizes to the +5 valence state, especially in the intensive oxidizing conditions that are characteristic of arid climates.

The average contents of vanadium in the environment are as follows: soils (10 to 500 parts per million [ppm]); streams and rivers (0.2 to 2.9 parts per billion [ppb]); and coastal seawater (0.3 to 2.8 ppb). Concentrations of vanadium in soils (548 to 7,160 ppm) collected near vanadium mines in China, the Czech Republic, and South Africa are many times greater than natural concentrations in soils. Additionally, if deposits contain sulfide minerals such as chalcocite, pyrite, and sphalerite, high levels of acidity may be present if sulfide dissolution is not balanced by the presence of acid-neutralizing carbonate minerals. Some of the vanadium-bearing deposit types, particularly some SSV and black shale deposits, contain appreciable amounts of carbonate minerals, which lowers the acid-generation potential.

Vanadium is a micronutrient with a postulated requirement for humans of less than 10 micrograms per day, which can be met through dietary intake. Primary and secondary drinking water regulations for vanadium are not currently in place in the United States. Vanadium toxicity is thought to result from an intake of more than 10 to 20 milligrams per day. Vanadium is essential for some biological processes and organisms. For example, some nitrogen-fixing bacteria require vanadium for producing enzymes necessary to convert nitrogen from the atmosphere into ammonia, which is a more biologically accessible form of nitrogen.

Introduction

Vanadium (V) is a strategic metal that is used principally in the production of metal alloys, such as high-strength steel and alloys for use in the aerospace industry. Secondary uses are as catalysts for the chemical industry, and in ceramics, glasses, and pigments. In its native state, vanadium is a hard, silvery gray, ductile, and malleable transition metal. Vanadium consumption trends are heavily influenced by trends in steel production.

The emerging need for large-scale electricity storage makes vanadium redox-flow batteries (VRBs) a major potential future use of vanadium. Because of their large-scale storage capacity, development of VRBs could prompt increases in the use of wind, solar, and other renewable, intermittent power sources. Lithium-vanadium-phosphate batteries produce high voltages and high energy-to-weight ratios, which make them ideal for use in electric cars. Vanadium use in lithium batteries is expected to increase to 1,700 metric tons in 2017 from 200 metric tons in 2012 (Perles, 2013).

Vanadium is the 22d most abundant element in Earth's crust, and it is an essential constituent of many minerals. A total of 156 minerals contain vanadium as a major (>10 weight percent) constituent. Several diverse mineral deposit types contain vanadium-bearing minerals, and vanadium is a common component of petroleum and other fossil fuels. Vanadium deposits are globally distributed (fig. U1) and comprise four principal deposit types: vanadiferous titanomagnetite (VTM), sandstone-hosted vanadium (SSV), shale-hosted vanadium, and vanadate deposits (table U1). Additionally, significant amounts of vanadium are available for commercial use as a byproduct of petroleum refining, and processing of coal, tar sands, and oil shales may be important future sources. World vanadium resources in 2012 were estimated to be 63 million metric tons of vanadium. Reserves were estimated to be 14 million metric tons. The majority of vanadium production in 2012 was from China (37 percent), South Africa (35 percent), and Russia (25 percent) (fig. U2; Polyak, 2013).

Uses and Applications

The vanadium market closely follows that of the steel industry, which in turn follows economic trends. Metallurgical applications in steel continued to dominate United States vanadium usage in 2011 (fig. U3), accounting for 93 percent of reported consumption (Polyak, 2013). Vanadium is used in steel to impart strength, toughness, and wear resistance. The formation of vanadium-rich carbides and nitrides imparts the strength to steel; the addition of only a few kilograms of vanadium per ton of steel increases the strength of the steel by as much as 25 percent. Apart from its strengthening characteristic, vanadium also inhibits corrosion and oxidation.

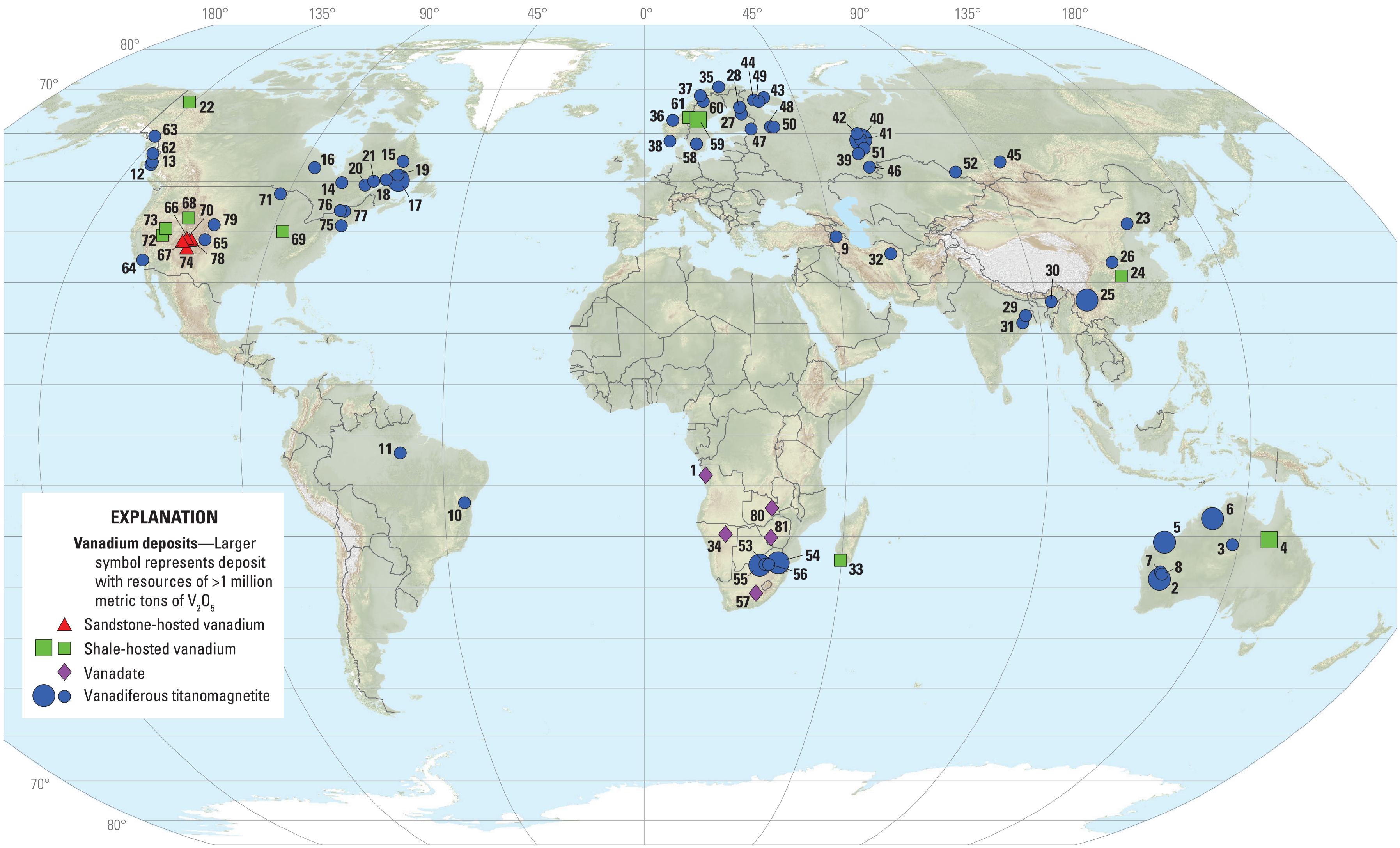
There are many sources of vanadium, and it is used in a number of common products (fig. U4). Commercial products developed through the processing of vanadium ores are mainly ferrovanadium (FeV), which is an iron-vanadium alloy, and vanadium pentoxide (V_2O_5). Most vanadium is added to steel as ferrovanadium. Ferrovanadium is available in compositions containing 45 to 50 percent vanadium and 80 percent vanadium. The 45- to 50-percent grade is produced from slag and other vanadium-bearing residues; the 80-percent grade is produced by the reduction of V_2O_5.

The high-strength, low-alloy (HSLA) steels containing vanadium are widely used for the construction of auto parts, buildings, bridges, cranes, pipelines, rail cars, ships, and truck bodies, including armor plating for military vehicles (Polyak, 2012). Such HSLA steels are increasingly being used in the oil and gas industry to meet demand for pipelines with higher strength and higher low-temperature toughness (Roskill Information Services, Ltd., 2010, p. 150). Vanadium is used in tool steels in various combinations with chromium, niobium (columbium), manganese, molybdenum, titanium, and tungsten. Only a limited degree of substitution is possible among these metals, however. Replacement of vanadium with other mineral commodities requires significant technical adjustments to the steel production process to ensure that product specifications and quality are not compromised. For example, use of vanadium generally requires less energy consumption during production than does niobium to give equivalent steel properties. Therefore, substitution for vanadium is normally not considered for short-term changes in market conditions because of the considerable effort involved in implementing the change.

Vanadium is irreplaceable for its role in aerospace applications because vanadium-titanium alloys have the best strength-to-weight ratio of any engineered material yet discovered. Vanadium, when combined with titanium, produces a stronger and more stable alloy, and when combined with aluminum produces a material suitable for jet engines and high-speed airframes. No acceptable substitutes exist for vanadium in aerospace titanium alloys.

Nonmetallurgical applications of vanadium include catalysts, ceramics, electronics, and vanadium chemicals. For catalytic uses, platinum and nickel can replace vanadium compounds in some chemical processes. Vanadium dioxide is used in the production of glass coatings that block infrared radiation.

Vanadium is becoming more widely used in green technology applications, especially in battery technology. One battery technology that continues to show promise in stabilizing energy distribution in renewable systems is the VRB, which consists of an assembly of power cells in which two vanadium-based electrolytes are separated by a proton exchange membrane. The main advantages of the VRBs are (a) their nearly unlimited capacity, which is made possible simply by using sequentially larger storage tanks; (b) their ability to be left completely discharged for long periods of time with no detrimental effects; (c) the ease of recharging them by replacing the electrolyte if no power source is available to charge it; and (d) their ability to withstand permanent damage if the electrolytes are accidentally mixed (Polyak, 2012).



Base from U.S. Geological Survey Global 30 arc-second elevation data (1996) and from Natural Earth (2014); Robinson projection; World Geodetic System 1984 datum

Figure U1. World map showing locations of major vanadium deposits of the world, by deposit type. Numbers refer to the identifier number in table U1, which contains additional information about the vanadium resources in these deposits.

Table U1. Location, grade, tonnage, and other data for selected vanadium deposits of the world.

[ID, identifier, shown in figs. U1 and U5; WGS 84, World Geodetic System of 1984; negative values for latitude indicate that the deposit is in the Southern Hemisphere; negative values for longitude indicate that the deposit is in the Western Hemisphere; %, percent; V_2O_5, vanadium oxide; VTM, vanadiferous titanomagnetite; n.d., no data available; NA, not available; t, metric ton; SSV, sandstone-hosted vanadium]

ID	Deposit	Country	District, region, or State/ Province	Deposit type	Latitude (decimal degrees, WGS 84)	Longitude (decimal degrees, WGS 84)	Resource tonnage (million metric tons)	Grade (% V_2O_5)	V_2O_5 content (million metric tons)	Production, resources, or reserves	Source of data
1	Lueca Mine	Angola	NA	Vanadate	–7.92	13.65	n.d.	n.d.	n.d.	n.d.	Fischer (1975a)
2	Windimurra	Australia	Mount Magnet	VTM	–28.36	118.84	242.6	0.48	1.16	Resources	Britt and others (2014)
3	Mount Peake	Australia	Northern Territory	VTM	–21.66	133.66	160	0.3	0.48	Resources	TNG Ltd. (2015)
4	Julia Creek	Australia	Queensland	Shale-hosted	–20.65	141.73	411	0.44	1.1	Resources	Lewis and others (2010)
5	Balla Balla	Australia	Western Australia	VTM	–21.14	118.06	456	0.64	2.91	Resources	Britt and others (2014)
6	Speewah	Australia	Western Australia	VTM	–16.47	128.20	4,712	0.3	14.1	Resources	Britt and others (2014)
7	Gabanintha	Australia	Western Australia	VTM	–27.00	118.60	125.8	0.7	0.88	Resources	Britt and others (2014)
8	Barrambie	Australia	Western Australia	VTM	–27.42	119.11	47.2	0.63	0.3	Resources	Britt and others (2014)
9	Svorantskoe	Azerbaijan	Chelyabinskaya Oblast	VTM	39.00	46.00	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
10	Maracas	Brazil	Bahia	VTM	–13.41	–40.43	24.6	1.11	0.27	Resources	Fischer (1975b)
11	Tapajos	Brazil	Pará	VTM	–3.61	–54.49	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
12	Banks Island	Canada	British Columbia	VTM	53.47	–130.13	3	0.6	0.018	Resources	Fischer (1975b)
13	Porcher Island	Canada	British Columbia	VTM	54.00	–130.25	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
14	Lac Doré	Canada	Matagami, Quebec	VTM	49.76	–77.62	100	0.49	0.49	Resources	Fischer (1975b)
15	Lake Michikamau	Canada	Newfoundland and Labrador	VTM	54.12	–63.98	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
16	Ring of Fire	Canada	Ontario	VTM	52.80	–86.50	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
17	Lac Tio (Allard Lake)	Canada	Quebec	VTM	50.56	63.41	350	0.3	1.05	Resources	Fischer (1975b)
18	Sept Îles	Canada	Quebec	VTM	50.34	–66.51	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
19	Magpie Mountain	Canada	Quebec	VTM	51.38	–64.07	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
20	Lac St. Jean	Canada	Quebec	VTM	49.33	–71.50	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)

Table U1. Location, grade, tonnage, and other data for selected vanadium deposits of the world.—Continued

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21	LaBlache-Hervieux-Shmoo Lakes	Canada	Quebec	VTM	50.06	–69.63	101.7	0.18	0.18	Resources	Fischer (1975b)
22	Nick	Canada	Yukon	Shale-hosted	68.65	–135.25	n.d.	n.d.	n.d.	n.d.	Hulbert and others (1992)
23	Luanping	China	Hubei Province	VTM	41.50	117.50	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
24	Maocaoping, Baig-uoyuan	China	Hubei Province	Shale-hosted	31.27	111.08	n.d.	n.d.	n.d.	n.d.	Coveney and Nansheng (1991)
25	Nalaqing, Gongshan, Damakan, Lanjian	China	Panzhihua region, Sichuan Province	VTM	26.65	102.00	3,460	0.3	10.4	Resources[1]	Zhou and others (2005)
26	Shanyang	China	Shaanxi Province	VTM	33.87	109.94	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
27	Otanmaki	Finland	Kajaani, Kainuu Region	VTM	64.13	27.10	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
28	Mustavaara	Finland	Oulu, North Ostro-bothnia Region	VTM	65.78	27.99	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
29	Singhbhum-Mayurb-hanj	India	Bihar and Odisha	VTM	22.00	86.00	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
30	Ganjang	India	Karbi-Anglong District	VTM	26.16	93.33	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
31	Shaltora	India	West Bengal	VTM	23.42	86.92	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
32	Rivash	Iran	Razavi Khorasan Province	VTM	35.64	58.33	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
33	Green giant	Madagascar	Tulear Region	Shale-hosted (meta)	–24.69	44.75	49.9	0.693	0.35	Resources	Energizer Resources, Inc. (2013)
34	Berg Aukas, Abenad, Tsumeb	Namibia	Otavi Moun-tainland	Vana-date	–19.51	18.25	3.2	0.75	0.024	Resources	Fischer (1975a); Boni and others (2007)
35	Stjernoy-Seiland	Norway	Finnmark County	VTM	70.50	23.00	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)

Table U1. Location, grade, tonnage, and other data for selected vanadium deposits of the world.—Continued

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36	Rodsand	Norway	Møre og Romsdal County	VTM	62.85	8.12	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
37	Selvag	Norway	Nordland County	VTM	68.66	15.00	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
38	Tellnes	Norway	Rogaland County	VTM	58.33	6.42	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
39	Kusinskoe	Russia	Chelyabinskaya Oblast	VTM	55.75	57.35	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
40	Gusevogorsk	Russia	Kachkanar, Sverdlovskaya Oblast	VTM	58.70	59.49	16,200	0.084	13.6	Resources	Augé and others (2005); Laznicka (2010)
41	Guseva Gora	Russia	Kachkanar, Sverdlovskaya Oblast	VTM	58.70	59.49	n.d.	n.d.	n.d.	n.d.	Augé and others (2005); Laznicka (2010)
42	Yubryahkinskoe	Russia	Kachkanar, Sverdlovskaya Oblast	VTM	59.93	59.17	n.d.	n.d.	n.d.	n.d.	Augé and others (2005); Laznicka (2010)
43	Tsagin	Russia	Murmanskaya Oblast	VTM	68.00	36.00	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
44	Afrikanda	Russia	Murmanskaya Oblast	VTM	67.42	32.68	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
45	Lysanovskoe	Russia	NA	VTM	54.00	94.00	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
46	Visean	Russia	NA	VTM	53.00	59.00	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
47	Koykara Koyarsk	Russia	NA	VTM	61.00	30.00	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
48	Pudozhgorsk	Russia	Republic of Kareliya	VTM	61.62	36.24	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
49	Yelet' ozero	Russia	Republic of Kareliya	VTM	67.07	34.21	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
50	Pudozhgaraskoe	Russia	Republic of Kareliya	VTM	61.37	36.48	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
51	Pervouralsk	Russia	Sverdlovskaya Oblast	VTM	56.90	59.53	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
52	Kharlovskoe	Russia	Sverdlovskaya Oblast	VTM	52.00	81.00	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)

Table U1. Location, grade, tonnage, and other data for selected vanadium deposits of the world.—Continued

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53	Vantra	South Africa	Brits, North West Province	VTM	–25.63	27.78	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
54	Mapochs Mine	South Africa	Bushveld Igneous Complex, Limpopo Province	VTM	–25.22	29.92	100	1.5	1.5	Resources + reserves	Reynolds (1985); Rohrmann (1985)
55	Rhovan Mine	South Africa	Bushveld Igneous Complex, Limpopo Province	VTM	–25.57	27.57	203	0.52	1.06	Resources	Reynolds (1985); Rohrmann (1985)
56	Krokodilkraal Mine	South Africa	Bushveld Igneous Complex, North West Province	VTM	–25.60	28.18	n.d.	n.d.	n.d.	n.d.	Reynolds (1985); Rohrmann (1985)
57	Kafferskrall Farm	South Africa	North West Province	Vanadate	–31.15	25.85	n.d.	n.d.	n.d.	n.d.	Fischer (1975a)
58	Taberg	Sweden	Jönköping County	VTM	57.75	14.17	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
59	Viken	Sweden	Myrviken, Jämtland County	Shale-hosted	63.12	14.36	685	0.29	1.98	Resources	Aura Energy (2012)
60	Ruoutevare	Sweden	Norrbotten County	VTM	67.08	17.50	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
61	Häggån	Sweden	Storsjön, Jämtland County	Shale-hosted	63.50	12.73	n.d.	n.d.	n.d.	n.d.	Aura Energy (2012)
62	Union Bay	United States	Alaska	VTM	55.77	–132.10	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
63	Klukwan Fan	United States	Alaska	VTM	59.42	–135.88	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
64	San Gabriel Mountains	United States	California	VTM	34.37	–118.30	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
65	McClure Mountain	United States	Colorado	VTM	38.34	–105.42	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
66	Buckmaster Draw	United States	Green River, Utah	SSV	38.68	–110.03	0.67	0.19	0.0012	n.d.	Fischer (1968)
67	Tony M, Frank M	United States	Henry Mtns., Utah	SSV	38.11	–110.81	n.d.	n.d.	n.d.	n.d.	Johnson (1959)

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ID	Deposit	Country	District, region, or State/ Province	Deposit type	Latitude (decimal degrees, WGS 84)	Longitude (decimal degrees, WGS 84)	Resource tonnage (million metric tons)	Grade (% V_2O_5)	V_2O_5 content (million metric tons)	Production, resources, or reserves	Source of data
68	Phosphoria	United States	Idaho	Shale-hosted	42.70	–111.83	n.d.	n.d.	n.d.	n.d.	Love and others (2003); Jasinski (2004)
69	Mecca Quarry shale	United States	Illinois and Indiana	Shale-hosted	40.02	–87.53	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
70	Mike, Pandora Mine	United States	La Sal district, Utah	SSV	38.31	–109.25	0.989	1.46	0.0144	Production	Fischer (1968); Shawe (2011)
71	TiTac	United States	Minnesota	VTM	47.58	–92.07	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
72	Gibellini	United States	Nevada	Shale-hosted	39.21	–116.09	0.082	0.29	0.00017	Resources	American Vanadium Corp. (2012)
73	Carlin Vanadium	United States	Nevada	Shale-hosted	40.61	–116.12	25.4	0.51	0.13	Resources	Scandium International Mining Corp. (2010)
74	King Tut, Carrizo, Lukachukai Mountains	United States	New Mexico and Arizona	SSV	36.74	–109.01	0.846	1.15	0.01	Production	McLemore and Chenoweth (1997)
75	Ossining	United States	New York	VTM	41.17	–73.83	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
76	Diana	United States	New York	VTM	44.15	–75.25	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
77	Tahawus Mine, MacIntyre stone pit	United States	Sanford Lake, New York	VTM	44.00	–74.08	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
78	Slick Rock Mill, Uravan	United States	Uravan Mineral Belt, Colorado	SSV	38.37	–108.74	13.99	1.29	0.18	Production	Fischer (1968); Shawe (2011)
79	Iron Mountain	United States	Wyoming	VTM	41.38	–104.83	n.d.	n.d.	n.d.	n.d.	Fischer (1975b)
80	Broken Hill	Zambia	Kabwe, Central Province	Vanadate	–14.42	28.55	n.d.	n.d.	n.d.	n.d.	Fischer (1975a)
81	Bulawayo	Zimbabwe	Bulawayo	Vanadate	–20.17	28.58	n.d.	n.d.	n.d.	n.d.	Fischer (1975a)

[1]Also includes some production and reserves.

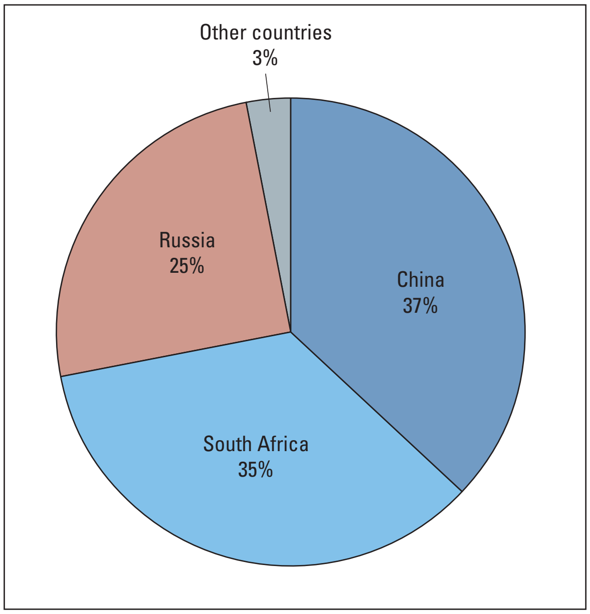

Figure U2. Pie chart showing percentage of world vanadium production in 2012, by country. Compiled using data from Polyak (2013, table 7).

Demand and Availability of Supply

World vanadium resources in 2012 were estimated to total more than 63 million metric tons of vanadium. Reserves were estimated to be 14 million metric tons of vanadium. Because vanadium is usually recovered as a byproduct or coproduct, the identified world resources of this mineral commodity are understated and therefore not fully indicative of available supply. Although domestic resources and secondary recovery are adequate to supply a large portion of domestic needs, a substantial part of U.S. demand is currently met by foreign material (Polyak, 2013). Future demand is expected to increase primarily because such countries as China and Japan are increasing the amount of vanadium used in steelmaking to match the quality of steel produced from other countries, as well as in anticipation of the probable increase in alternative renewable sources of energy that require the use of VRBs (Roskill Information Services, Ltd., 2013).

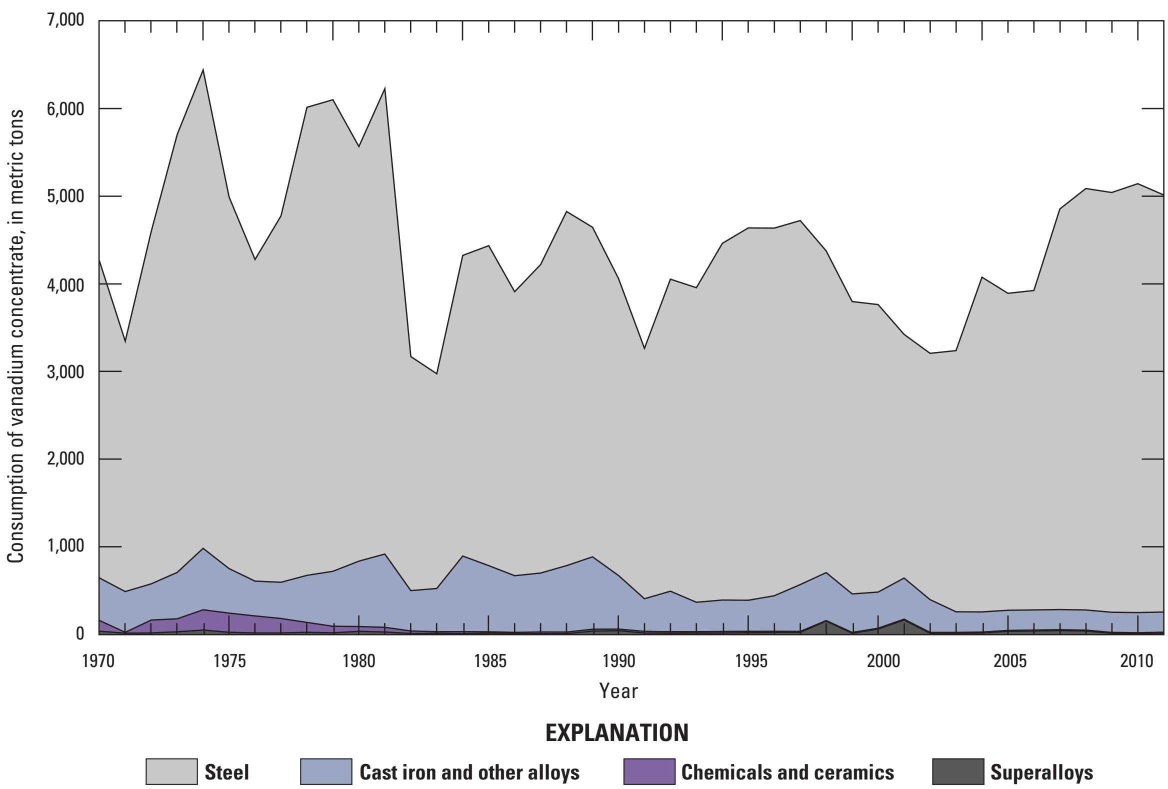

Figure U3. Graph showing major end uses of vanadium in the United States from 1970 to 2011. The layers of the graph are placed one above the other, forming a cumulative total. Compiled using data from U.S. Bureau of Mines (1972–76, 1992–96) and U.S. Geological Survey (1997–2013, 2014).

Geology

Geochemistry

Vanadium is a trace element that is widely distributed in nature. The average abundance of vanadium in the upper continental crust is approximately 60 parts per million (ppm) (Taylor and McLennan, 1995). Vanadium is produced from the combustion of fossil fuels, the mining of ores, and high-temperature industrial activities, including steel refining and the processing of phosphate ores.

The natural oxidation states of vanadium are +2, +3, +4, and +5. The trivalent ion V^{3+} has an octahedral radius (0.061 nanometers [nm]) that is almost identical with that of ferric iron (Fe^{3+}, 0.063 nm). As a consequence, vanadium substitutes in iron-rich minerals, such as amphibole, biotite, magnetite, and pyroxene, and for aluminum (Al^{3+}, 0.054 nm) in iron and ferromagnesian minerals (Fischer, 1973). Vanadium is present in large amounts in mafic igneous rocks (about 250 ppm), is less abundant in ultramafic and intermediate-composition rocks (about 50 ppm), and is present in only small amounts in felsic rocks (about 20 ppm). Vanadium is concentrated in magmatic magnetite deposits, especially those that are titaniferous; the vanadium concentrations in these deposits commonly range from 1,000 to 5,000 ppm.

Vanadium is also closely associated with organic-rich sediments. The average concentrations in shale are about 130 to 205 ppm, but some carbonaceous shales may have up to 5,000 ppm vanadium (for example, shales in eastern Kentucky; Robl and others, 1983). The addition of vanadium to sediments rich in organic carbon is owing to reduction, adsorption, and complexation. Dissolved vanadate species (5^+) in oxic seawater are reduced to vanadyl ions (4^+) by organic compounds or hydrogen sulfide (H_2S) and are readily adsorbed to particle surfaces as they settle during sedimentation. Vanadium^{3+} may also substitute for aluminum in the octahedral sites of clays (Breit and Wanty, 1991).

Because most vanadium in primary minerals is in the weakly soluble +3 valence state, very little vanadium is transported by hydrothermal fluids; therefore, most hydrothermal ore deposits contain low concentrations (10 to 100 ppm) of vanadium. Some hydrothermal deposits related to alkaline igneous rocks contain high concentrations of vanadium, however. Altered titanium-rich syenite intrusions at Potash Sulphur Springs in Garland County, Arkansas, contain high concentrations of vanadium (McCormick, 1978) as do some gold-quartz veins associated with alkaline igneous rocks, especially those with gold-telluride minerals (for example, Spry and Scherbarth, 2006).

During weathering in humid climates, much of the vanadium contained in ferromagnesian minerals apparently partitions into newly formed clay minerals, but it remains in the +3 valence state or oxidizes to the +4 valence state, both of which are relatively insoluble. If erosion is insignificant but chemical leaching is intense, the residual material may be enriched in vanadium, as are some bauxites and laterites (Patterson, Kurtz, and others, 1986). During the weathering of igneous, residual, or sedimentary rocks, some vanadium oxidizes to the +5 valence state (vanadate), especially in the intensive oxidizing conditions that are characteristic of arid climates. In this oxidized valence state and under relatively alkaline conditions, vanadium is enriched in surface waters or groundwaters and remains in solution (Wright and Belitz, 2010). It can be precipitated from solution and locally concentrated in rocks by the following processes (Fischer, 1973, p. 682):

(a) Coprecipitation and adsorption with hydroxides of aluminum or ferric iron. This process forms or enriches the vanadium concentration in some bauxites and in residual or sedimentary iron ores;

(b) Reaction with cations of heavy metals, such as copper, lead, uranium, and zinc. This process forms epigenetic vanadate minerals in the oxidized zones of base-metal deposits; and

(c) Reduction in the presence of organic material or biologically generated H_2S. Interactions of vanadium-bearing solutions with wall rocks during fluid flow may produce epigenetic ore deposits, such as those occurring in sandstones of the Colorado Plateau province in the United States. On the other hand, if the vanadium is carried to the oceans by surface waters, it may concentrate syngenetically in carbonaceous phosphorites, marls, and shales. Furthermore, if the organic materials in these shales are converted to liquid hydrocarbons, the vanadium may be moved with the petroleum in vanadium-organic compounds and in fine inorganic particulates; some crude oils contain as much as several hundred parts per million vanadium. Vanadium accumulates in the ashes of these oils and also in the residues resulting from their natural or industrial distillation. These ashes and residues have been used as commercial sources of vanadium (Fischer, 1973, p. 682; Breit, 1992).

Mineralogy

Vanadium occurs in nature in a wide variety of minerals (table U2). The following four principal types of mineral deposits are recognized: vanadiferous titanomagnetite (VTM) deposits, sandstone-hosted vanadium (SSV) deposits, shale-hosted deposits, and vanadate deposits. Magnetite (Fe_3O_4) and ilmenite ($FeTiO_3$) are the principal vanadium-bearing ore minerals in VTM deposits (fig. U4*A*), but hematite (Fe_2O_3), perovskite ($CaTiO_3$), and rutile (TiO_2) are present in some deposits (Fischer, 1975b). These minerals occur in medium- to fine-grained intergrowths and in exsolution and solid-solution relations; ulvospinel and titanomagnetite are two mineral names commonly applied to some of these exsolution and solid-solution forms. Small blebs and exsolution blades of coulsonite (FeV_2O_4) in magnetite have been recognized in a few VTM deposits (Balsley, 1943).

Ore minerals below the zone of oxidation in SSV deposits are low-valence oxides and silicates of uranium and vanadium. Coffinite, montroseite, paramontroseite, uraninite, and

Table U2. Selected vanadium-bearing minerals, by deposit type.

Mineral name	Chemical formula or description
Vanadiferous titanomagnetite (VTM) deposits	
Coulsonite	$(Fe,V)_3O_4$
Hematite	Fe_2O_3
Ilmenite[1]	$FeTiO_3$
Magnetite[1]	Fe_3O_4
Perovskite	$CaTiO_3$
Rutile	TiO_2
Sandstone-hosted vanadium (SSV) deposits	
Carnotite	$K_2(UO_2)_2(VO_8)\bullet1–3H_2O$
Coffinite	$U(SiO_4)_{1-x}(OH)_{4x}$
Corvusite	$(Na,Ca,K)V_8O_2\bullet4H_2O$
Doloresite	$H_8V_6O_{16}$
Hewettite	$CaV_6^{5+}O_{16}\bullet9H_2O$
Montroseite	$(V^{3+},Fe^{3+},V^{4+})O(OH)$
Paramontroseite	VO_2
Pascoite	$Ca_3(V_{10}O_{28})\bullet17H_2O$
Roscoelite	$K(V^{3+},Al,Mg)[(Si,Al)_4O_{10}](OH)_2$
Tyuyamunite	$Ca(UO_2)2V_2O_8\bullet5–8H_2O$
Uraninite	UO_2 (with Pb, Th, V, Zr)
Vanadium clays	Vanadium-bearing hydrous mica
Vanadian chlorite	Vanadium-bearing chlorite
Volborthite	$Cu_3V_2O_7(OH)_2\bullet2H_2O$
Shale-hosted vanadium deposits	
Illite-smectite[3]	$K_{0.8}(Al_{2.8}Mg_{0.5}Fe_{0.4}V_{0.3})(Si_{7.2}Al_{0.8})O_{20}(OH)_4$
Metahewettite	CaV_6O_{16} H_2O
Quisqueite[2]	Vanadium-bearing organic matter
Patronite[2]	$V^{4+}(S_2^{2-})_2$

Mineral name	Chemical formula or description
Vanadate deposits	
Brachebuschite	$Pb_2(Mn,Fe)(VO_4)_2\bullet H_2O$
Calciovolborthite	$CaCuVO_4(OH)$
Chervetite	$Pb_2V_2O_7$
Curienite	$Pb(UO_2)_2(VO_4)_2\bullet5H_2O$
Descloizite[1]	$PbZn(VO_4)(OH)$
Francevillite	$(Ba,Pb)(UO_2)_2(VO_4)_2\bullet5H_2O$
Heyite	$Pb_5Fe_2(VO_4)_2O_4$
Mottramite[1]	$PbCu(VO_4)(OH)$
Mounanaite	$PbFe_2(VO_4)_2(OH)$
Pyrobelonite	$PbMnVO_4(OH)$
Sengierite	$Cu(UO_2)_2(VO_4)_2\bullet8$ or $10H_2O$
Turanite	$Cu_5(VO_4)_2(OH)_4$
Vanadinite[1]	$Pb_5(VO_4)_3Cl$
Volborthite	$Cu_3(VO_4)_2\bullet3H_2O$
Epithermal/porphyry/magmatic deposits	
Duttonite	$V^{4+}O(OH)_2$
Fervanite	$Fe_4^{3+}(VO_4)_4\bullet5H_2O$
Hewettite	$CaV_6^{5+}O_{16}\bullet9H_2O$
Karelianite[4]	V_2O_3
Metatyuyamunite[6]	$Ca(UO_2)_2VO_4)_2\bullet5–7H_2O$
Montroseite	$(V^{3+},Fe^{3+},V^{4+})O(OH)$
Nolanite[4]	$(V,Fe,Al)_{10}O_{14}(OH)_2$
Roscoelite	$K(V^{3+},Al,Mg)[(Si,Al)_4O_{10}](OH)_2$
Rutile, brookite	TiO_2
Schreyerite[4]	$VSiO_3(OH)$
Vanadium andradite[5]	$Ca^3(Fe^{3+},V^{3+})_2(SiO_4)_3$
Vanadium muscovite[4]	Vanadium-bearing muscovite
Vanadium silicates[4]	$Si_3O_9V_2$
Vanadium- and titanium-bearing mixed layer clay[7]	$(Ca_{0.08}K_{0.02}Na_{0.03})_{0.13}$ $(Al_{0.11}V_{0.90}Ti_{0.19}Fe_{0.64}Mg_{0.14})_{1.98}$ $(Si_{3.79}Al_{0.21})_4O_{10}(OH)_2\bullet nH_2O$

[1] Most common.

[2] Mina Ragra, Peru (Fischer, 1973).

[3] Mecca Quarry Shale, Illinois and Indiana (Peacor and others, 2000).

[4] Tuvatu deposit, Fiji (Spry and Scherbarth, 2006).

[5] Potash Sulphur Springs or Wilson Springs, Arkansas (Howard and Owens, 1995).

[6] Weeks and others, 1959.

[7] Potash Sulphur Springs or Wilson Springs, Arkansas (McCormick, 1978).

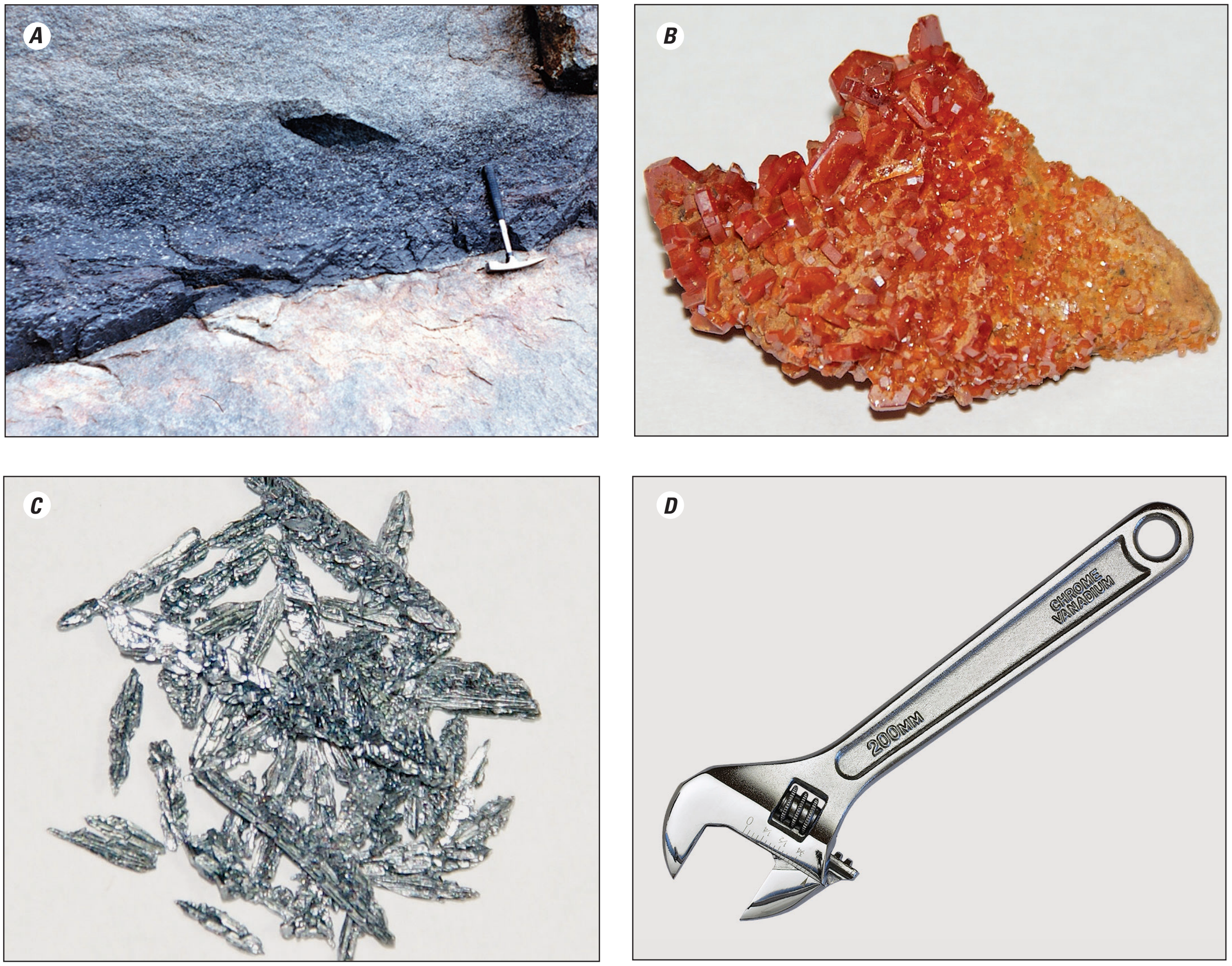

Figure U4. Photographs showing four examples of vanadium. *A*, Magnetite layer (dark) from the Bushveld Complex, South Africa. It is these layers that commonly host vanadium. *B*, Natural vanadinite, which is a main source of vanadium from vanadate deposits. *C*, Vanadium metal crystals made by electrolysis (the largest crystal is 2 centimeters in length). *D*, Common hand wrench made with vanadium alloy steel. Photograph *A* courtesy of Kevin Walsh/CC BY 2.0 (https://creativecommons.org/licenses/by/2.0/). Photographs *B* and *C* courtesy of Juergen Kummer, Jumk.de Web Projects/CC BY 3.0 (http://images-of-elements.com/vanadium.php). Photograph *D* courtesy of MrX/CC-BY-SA-3.0 (https://commons.wikimedia.org/wiki/File:Chrome_Vanadium_Adjustable_Wrench.jpg).

vanadium-rich clay or mica (roscoelite), vanadian chlorite, and vanadium-rich clay minerals are the most common (table U2). Chalcopyrite, clausthalite, ferroselite, galena, naumannite, pyrite, sphalerite, and other sulfides and selenides are common trace minerals (Shawe, 2011). Copper sulfides are widespread in sparse amounts but are abundant enough in a few deposits to constitute ore minerals (Fischer, 1968). Partially oxidized orebodies (for example, those immediately above the water table) contain minerals similar to those of deposits below the zone of oxidation, but with the addition of corvusite-group minerals and hewettite (Shawe, 2011). Oxidized deposits contain carnotite and tyuyamunite, together with vanadium clays and chlorite. The most common authigenic gangue minerals in SSV deposits are barite, carbonates (mostly calcite), and quartz (Breit and Goldhaber, 1996). Ore minerals are typically disseminated in the sandstone or form radiating acicular aggregates that fill open pore spaces (Wanty and others, 1990). The ore minerals are typically concentrated near carbonaceous material (Fischer, 1968; Shawe, 2011).

Vanadate deposits contain a wide variety of vanadium-bearing minerals (table U2). Vanadate minerals are formally described as containing an oxoanion of vanadium generally in its highest oxidation state of +5. Most vanadate minerals are compounds of copper, iron, or lead because these deposits form within the oxidized zones of base-metal deposits in areas of arid climate and deep oxidation (Fischer, 1975a). Descloizite, mottramite, and vanadinite (fig. U4*B*) are the most common vanadium minerals, although numerous others are known (table U2). Wulfenite ($PbMoO_4$), which is a molybdate of lead, is also common in vanadate deposits (Fischer, 1975a). Where paragenetic relations are reported, the vanadium-bearing minerals are late in the sequence. For example, the association of vanadinite and descloizite is paragenetically late in the Berg Aukas and Abenab deposits in the Otavi Mountainland, Namibia (Boni and others, 2007). Fischer (1975a) suggests that vanadate minerals typically coat and partly replace supergene base-metal minerals in deposits in Arizona, but in most cases, the vanadates overlap or precede the last stage of supergene mineral formation (Boni and others, 2007). Once formed, vanadate minerals are stable in the environment of the oxidized zone; these minerals persist from the surface to the bottom of the oxidized zone, and leaching and corrosion of them are rarely reported (Fischer, 1975a). In the Kabwe district (formerly known as Broken Hill), Zambia, the vanadate minerals are persistent to depths of 350 meters (m) below the surface, which defines the lowest depth of oxidation.

Some hydrothermal deposits contain vanadium-bearing minerals, particularly deposits genetically and (or) spatially associated with alkaline igneous rocks. In epithermal gold deposits, roscoelite is the most common mineral, but vanadium-bearing rutile or brookite, karelianite, nolanite, shreyerite, and vanadium-rich muscovite and silicate minerals have also been identified (Spry and Scherbarth, 2006).

Deposit Types

Vanadium is present in economic concentrations in four main types of mineral deposits and as a minor constituent in several other types. Fossil fuels are another important source of vanadium.

Vanadiferous Titanomagnetite Deposits

Vanadiferous titanomagnetite (VTM) deposits (Fischer, 1975b) are found throughout the world and are the principal source of vanadium (fig. U1). The most economically significant VTM deposits or regions, both in the past and currently, include the Bushveld Complex in South Africa (Reynolds, 1985); the Panzhihua layered intrusion in Sichuan Province, China (Zhou and others, 2005); the Kachkanar massif in the Ural Mountains in Russia; the Windimurra Complex in Western Australia (Ivanic and others, 2010); and the Bell River Complex (Matagami deposit) and the Lac Doré Complex in Quebec, Canada (fig. U1; Taner and others, 1998).

The VTM deposits consist of magmatic accumulations of magnetite and ilmenite, defined arbitrarily as having grades of more than about 1 percent rutile (Fischer, 1975b). They commonly contain 0.2 to 1 percent V_2O_5, but some zones (for example, the Bushveld Complex) contain greater than 1.5 percent V_2O_5 (Reynolds, 1985). Most exposed VTM deposits are Archean or Proterozoic in age, having formed in intraplate continental tectonic settings; a few deposits (for example, the Panzhihua region in Sichuan Province, China) are younger (table U1; fig. U1). Most deposits are associated with large igneous province (LIP) magmatism; some layered intrusive complexes are linked to mantle plumes and hotspot tracks (Hatton, 1995; Ernst and others, 2005).

VTM deposits are hosted mainly within mafic and ultramafic igneous rocks, most commonly anorthosite and gabbro. Lithologies within the igneous complexes that contain the vanadium-rich ores vary considerably, however. For example, in the Bushveld Complex, lithologies range from dunite and pyroxenite to anorthosite and pure oxide layers (Eales and Cawthorn, 1996). Some vanadiferous deposits are hosted in zoned mafic to ultramafic complexes with high levels of chromium and platinum-group elements (PGEs); these complexes are sometimes referred to as Alaska-type PGE deposits; and examples include the Union Bay deposit in Alaska (United States), and the Kachkanar complex in Sverdlovsk Oblast, Russia. A few deposits are associated with alkalic igneous rocks (for example, syenodiorite is genetically related to layered gabbro in the Panzhihua district of Sichuan Province, China [Shellnut and Jahn, 2010] and in the Ganjang deposit in Assam, northeastern India [Saha and others, 2010]). The mafic to ultramafic igneous host rocks are typically of deep-seated origin, and they occur in stratiform tabular bodies, such as sills and laccoliths that are thick and laterally extensive. For example, the Mesoarchean gabbroic Windimurra Complex in the Yilgarn craton (Western Australia, Australia) covers an area of about 2,500 square kilometers (km^2) and contains layers of gabbroic and ultramafic rocks with cumulative thicknesses of 13 kilometers (km) (Ivanic and others, 2010). The Paleoproterozoic Bushveld Complex (dated at 2.06 giga-annum [Ga]) in the Transvaal basin in South Africa contains layers with cumulative thicknesses (about 9 km) that are comparable to those of the Windimurra Complex, and it has an areal extent of about 65,000 km^2 (Eales and Cawthorn, 1996).

In contrast to laterally extensive and thick tabular bodies, some titaniferous magnetite deposits are hosted in relatively complex intrusive or lens-shaped bodies (Fischer, 1975b). Such deposits are variable in size and shape. In the Panzhihua region of China, the maximum size of the lens-shaped ore bodies is 160 m long and 30 m wide (Zhou and others, 2005). Vanadium-bearing titanomagnetite previously mined in the Sanford Lake District of New York and the Taberg deposit in Jönköping County, Sweden, was contained in small (550 m by 180 m) bodies of gabbro and anorthosite (Balsley, 1943; Gross, 1968; Fischer, 1973, 1975b).

The textures and mineralogy of VTM ores are remarkably similar among the largest known deposits, including the Panzhihua deposit and the Bushveld and Windimurra deposits (Fischer, 1975b; Reynolds, 1985; Rohrmann, 1985; Zhou and others, 2005; Ivanic and others, 2010). Ores typically form discrete layers that are concordant with the igneous layering, which varies between 0.1 and 10 m in thickness, although some oxide layers in deposits in the Panzhihua region of southwestern China attain thicknesses of 60 m (Zhou and others, 2005). Similar to the silicate rocks that host them, the oxide layers are laterally extensive, and they can be traced for hundreds of kilometers in the case of the Bushveld Complex (Rohrmann, 1985; Reynolds, 1985). Most oxide layers have sharp lower boundaries that host silicate rocks and have gradational tops; some oxide layers contain thin intercalations of gabbro (Eales and Cawthorn, 1996; Zhou and others, 2005). Most of the vanadium in titaniferous magnetite deposits is concentrated as a solid solution in magnetite-ulvospinel, where V^{3+} has replaced Fe^{3+} (Fischer, 1975b); the vanadium-rich spinel mineral coulsonite (FeV_2O_4) was reported as small blebs and exsolution blades in magnetite in a few deposits (Balsley, 1943; Fischer, 1975b). Ilmenite, hematite, rutile, and perovskite commonly accompany magnetite (Fischer, 1975b). Where exposed to weathering, the magnetite may oxidize to vanadomaghemite ($(FeTi)_2O_3$) and small concentrations of hematite without any change in the texture of the ore (Rohrmann, 1985).

Ores may be either massive or disseminated. Massive ores typically consist of closely packed, nearly equant grains of more than 80 percent titanomagnetite and contain variable amounts of clinopyroxene, olivine, and plagioclase. If silicate minerals are present, they are completely surrounded by oxides (Zhou and others, 2005). Disseminated ores are generally coarse grained and are composed of about 50 percent titanomagnetite, about 20 percent clinopyroxene, about 20 percent plagioclase, about 10 percent ilmenite, and small amounts of olivine (Rohrmann, 1985; Eales and Cawthorn, 1996; Zhou and others, 2005).

The mechanisms by which millions of tons of vanadium become concentrated in massive iron-titanium oxide deposits remain poorly understood, but most researchers agree that partial melting of mantle rocks and extensive fractionation of the derivative magma are critical early-stage processes. Large-scale, in situ crystallization of plagioclase and other anhydrous phases (olivine, pyroxene) in the basal parts of magma chambers results in an increase in total iron and water contents of the residual magma with eventual formation of immiscible oxide melts (Reynolds, 1985; Eales and Cawthorn, 1996; Ivanic and others, 2010; Shellnut and Jahn, 2010). Such oxide ore melts are denser than silicate melts and therefore settle to the bottom of the magma chamber, where the oxide melts accumulate (Eales and Cawthorn, 1996; Zhou and others, 2005). Many layered intrusions show evidence of multiple magma injections (Eales and Cawthorn, 1996), suggesting that magma mixing may have played a role in the development of some titaniferous magnetite deposits (Von Gruenwaldt, 1993). Other factors involved in forming immiscible oxide melts from silicate magmas are abrupt changes in oxygen fugacity, and (or) an introduction of fluids (Reynolds, 1985; Zhou and others, 2005). The presence of minor disseminated sulfides and apatite (for example, the Panzhihua deposits) suggests that sulfur and phosphorus may have acted as fluxing agents that promoted the concentration of immiscible liquids that led to formation of the Panzhihua deposits (Zhou and others, 2005).

Associated metals.—The igneous rocks that host significant vanadium resources are commonly temporally and spatially associated with magmatic chromium, copper, nickel, and PGE deposits (Cawthorn and others, 2002; Naldrett, 2010; Zientek, 2012). At least minor amounts of copper-nickel-PGE enrichment occurs in igneous complexes adjacent to the vanadiferous zones in the Windimurra region of Australia (Ivanic and others, 2010), the Panzhihua region of China (Zhou and others, 2005), and Kachkanar in the Urals region of Russia (Augé and others, 2005). The largest resources of PGEs and chromium in the world are contained within the Bushveld Complex of South Africa in layers that lie below the vanadiferous zones (Eales and Cawthorn, 1996; Naldrett and others, 2009). Additionally, high contents of scandium (up to 500 grams per metric ton of scandium oxide [Sc_2O_3]) occur in some of the VTM deposits in Russia (Bykhovsky and Tigunov, 2008).

Sandstone-Hosted Vanadium Deposits

Sandstone-hosted uranium deposits have been identified on all continents, and many are known to have enrichments of vanadium (Dahlkamp, 2010). These deposits of vanadium- and uranium-bearing sandstone (known as sandstone-hosted vanadium [SSV] deposits) have average resource and ore grades that range from 0.1 to 1 weight percent vanadium (George Breit, U.S. Geological Survey [retired], written commun., 2013). On a global scale, the United States has been and is currently the main producer of vanadium from SSV deposits, particularly from those on the Colorado Plateau. Additionally, these SSV deposits are the chief domestic source of vanadium in the United States (Fischer, 1968, 1973; Polyak, 2012, 2013). Most deposits are located in western Colorado and eastern Utah, although some are also located in northern Arizona and New Mexico (fig. U1). Vanadium enrichments in sandstones elsewhere in the world include the Bigrlyi deposit in Northern Territory, Australia, which has a grade of 0.13 weight percent vanadium (McKay and Miezitis, 2001); deposits in the Tonco-Amblyo district in Argentina, which have grades of 0.1 to 0.3 weight percent vanadium (Dahlkamp, 2010); and a deposit in the Karamurun district of Almaty Oblysy, Kazakhstan (Dahlkamp, 2009).

The Colorado Plateau province covers an area of 337,000 km^2 and was developed through a series of geologic and tectonic events. Important processes in this region that promoted the formation of SSV deposits include deposition of evaporitic-sapropelic strata from which brine fluids were derived; deposition of fluvial, fine-grained, locally carbonaceous sandstone that served as host rocks for the deposits; and magma generation and emplacement of laccoliths during the Tertiary that may have heated and driven brine fluids upwards along favorable structures (Shawe, 2011).

The SSV deposits occur in fluvial sandstone lenses of the Chinle Formation (Upper Triassic) and the Jurassic Morrison and aeolian Entrada Formations. The most economically significant vanadium deposits occur within the Salt Wash Member, which is the basal unit of the Morrison Formation (Northrop and others, 1990; McLemore and Chenoweth, 1997; Shawe, 2011). The Salt Wash Member is 30 to 150 m thick and contains laterally continuous fluvial sandstone and interbedded mudstone. This member was deposited by a west-to-east aggrading alluvial system (Shawe, 2011).

The SSV deposits form subhorizontal lenses or tabular bodies that are variable in thickness but are typically less than a few meters thick (Northrop and others, 1990; McLemore and Chenoweth, 1997) and up to 150 m long (Shawe, 2011). Some elongate mineralized zones are parallel to paleostream channels in the fluvial sandstone (McLemore and Chenoweth, 1997; Shawe, 2011). Deposits are typically concordant with bedding, although discordant lenses of uranium-vanadium minerals cut bedding planes locally. Most commonly, the orebodies are entirely within sandstone, although some occur at the interface between sandstone and less permeable shale or siltstone (Northrop and others, 1990; McLemore and Chenoweth, 1997). Tabular bodies display sharp to gradational transitions into unmineralized sandstone, and generally terminate abruptly against mudstone or claystone seams (Shawe, 2011). The SSV deposits are typically found in areas with local accumulations of detrital carbonaceous material. Pyrite is common within all forms of carbonized plant material (Shawe, 2011). Northrop and others (1990) reported that pyrite from mineralized intervals has distinctly lower sulfur isotope compositions (–4.8 to –2 per mil) than pyrite in unmineralized rocks (which average 12.1 per mil). Some tabular deposits have been reworked over time by groundwater, resulting in the formation of redistributed orebodies (Shawe, 2011).

Vanadium concentrations in SSV ores (expressed as V_2O_5) are commonly 1 percent or greater, and some deposits in southwestern Colorado have grades of more than 2.5 percent (Shawe, 2011). Vanadium-to-uranium weight ratios in deposits within the Morrison Formation vary from 2:1 to 6:1 among most areas of production, and therefore, are considered vanadium deposits with accessory uranium (Northrop and others, 1990; Shawe, 2011). Deposits with high vanadium-to-uranium weight ratios are located in southeastern Utah and southwestern Colorado; those in east-central Utah and west-central Colorado are characterized by lower vanadium-to-uranium weight ratios (George Breit, U.S. Geological Survey [retired], written commun., 2013). Many deposits have multiple ore zones, consisting of two (or more) closely spaced intervals enriched in vanadium and uranium, separated by an interval (or intervals) containing no uranium but enriched in vanadium (Northrop and others, 1990). The uranium-vanadium minerals form the matrix of the mineralized sandstones and locally replace detrital quartz and feldspar grains (Kovschak and Nylund, 1981; McLemore and Chenoweth, 1997). Vanadium, as +2, +3, +4, or +5, occurs as oxide phases or is combined with other elements, forming more than 40 different minerals in SSV ores (Weeks and others, 1959). Primary SSV ores are characterized by a consistent black-mineral suite composed of coffinite, montroseite, uraninite, and vanadium aluminosilicates (that is, low-valence V^{3+} minerals). These primary minerals are modified by progressive secondary oxidation above the water table to form an oxidized mineral assemblage dominated by carnotite, corvusite, and tyuyamunite (Weeks and others, 1959). Tabular vanadium-uranium deposits in the Salt Wash Member are unusual in that one of the major ore phases is typically roscoelite (a vanadium-bearing mica) accompanied by chlorite, mixed layer “chloritemontmorillonite” (chlorite-smectite), mixed-layer illite-montmorillonite, and “vanadium-hydromicas” (vanadium-bearing illite) (Northrop and others, 1990; Wanty and others, 1990). Gangue minerals that have been introduced or redistributed during formation of the deposits are anatase, barite, carbonates (mostly calcite and dolomite), and quartz (mostly calcite and dolomite) containing appreciable amounts of iron and (or) magnesium (Breit and Goldhaber, 1996).

Most proposed models for the formation of SSV deposits suggest that deposition occurred at an interface between two fluids of different chemical compositions and (or) states of oxidation-reduction (Fischer, 1968; Northrop and others, 1990; Shawe, 2011). Deposition involving two fluids was proposed many years ago during the early stages of exploration and production, and subsequent models, such as the brine-interface model, have refined or incorporated portions of these early theories. Although details differ, most models suggest that these deposits form by multistage processes: (1) shallow burial and diagenesis (<400 m), and reduction of dissolved uranium and vanadium by organic matter and bacteriogenic hydrogen sulfide that create local ore-grade accumulations; (2) progressive burial of the sandstone, creating changes in pore-water composition, pressure, and temperature and recrystallization of ore phases; and (3) migration of brines that move upward along faults and outward into permeable sandstone, mix with dilute meteoric water, and result in alteration of existing uranium and vanadium deposits (Breit and Goldhaber, 1996). The source of the vanadium is not well constrained, but is likely from the dissolution of iron-titanium-oxide minerals (ilmenite and magnetite) in volcanic detritus and sandstones within the Morrison Formation, or from unspecified source rocks that could be either younger or older than the host formation (Thamm and others, 1981; Northrop and others, 1990). Critical to the development of brines and the location of the SSV deposits in the Salt Wash Member was the deposition of evaporitic-sapropelic sedimentary units of Middle and Late Pennsylvanian age beneath the Morrison Formation (Shawe, 2011). Determinations of the age of formation of the deposits varies greatly; some estimates are that primary ores formed close to the time of deposition of the host rock (about 130 mega-annum [Ma]), whereas others suggest a much later time (about 30 Ma or latest Oligocene) (Shawe, 2011).

Associated metals.—Uranium occurs with vanadium in all SSV deposits, although the uranium-to-vanadium ratio varies greatly. Most deposits in the southwestern part of the United States (New Mexico and Arizona) have high uranium-to-vanadium ratios that decrease to the north (because of the increasing contents of vanadium). After initial mining for uranium, these deposits were sought as a source of radium. In the 1930s and 1940s, the deposits were of interest mainly for vanadium. Most mines were closed for nearly a decade, but mining resumed again in 1949 (until about 1983) for major production of uranium, with vanadium as a byproduct (Shawe, 2011). Copper accompanies uranium or vanadium in many of the deposits (Shawe, 2011).

Shale-Hosted Vanadium Deposits

Vanadium-rich metalliferous black shales occur primarily in late Proterozoic and Phanerozoic marine successions. The term shale is used here broadly to include a range of carbonaceous rocks that include marls and mudstones. These fine-grained sedimentary rocks were deposited in epeiric (inland) seas and on continental margins. They typically contain high concentrations of organic matter (greater than 5 percent) and reduced sulfur (greater than 1 percent; mainly as pyrite), as well as a suite of metals, such as copper, molybdenum, nickel, PGEs, silver, uranium, vanadium, and zinc (Desborough and others, 1979; Coveney and Martin, 1983; Coveney and others, 1992; Hatch and Leventhal, 1992; Piper, 1999). Concentrations regularly exceed 0.18 percent V_2O_5 and can be as high as 1.7 percent V_2O_5. Vanadiferous black shales are commonly found with phosphorite deposits and marine oil shales and, in North America, are marine equivalents of coal-bearing cyclothems. Well-characterized vanadiferous black shales include the Woodruff Formation in Nevada (Desborough and others, 1979), the Meade Peak Phosphatic Shale Member of the Phosphoria Formation in Idaho and Wyoming (McKelvey and others, 1986; Love and others, 2003), the Mecca Quarry Shale Member of Illinois and Indiana (Coveney and others, 1987), the Doushantuo Formation in Hubei Province in southern China (Fan and others, 1992), and portions of the Toolebuc Formation in Queensland, Australia (Lewis and others, 2010). Although these black shales have long been recognized as potential sources of vanadium, they are not currently exploited. Project development is underway at the Gibellini vanadium prospect in Nevada (Woodruff Formation), and if production begins, it will be the first primary shale-hosted producer of vanadium in the United States. The Julia Creek deposit (Toolebuc Formation) is also in the planning stages. The Green Giant deposit in southern Madagascar (Energizer Resources, Inc., 2013) consists of metamorphosed vanadiferous shale that extends for at least 21 km along strike and is reported to contain about 350,000 metric tons of V_2O_5 (table U1; fig. U1).

The ultimate source of vanadium in metalliferous black shales is dissolved vanadium in seawater (Breit and Wanty, 1991; Piper, 1994). Whereas the specific mechanisms of enrichment are disputed, all require the reduction of dissolved V^{5+} (Breit and Wanty, 1991), which is the predominant redox state in the oceans (Collier, 1984). Vanadium is used by various phytoplankton species (Robson and others, 1986; Moore and others, 1996), and sedimentation of phytoplankton debris likely acts as a minor source of vanadium in black shales (Piper, 1994). In oxygen-deficient bottom waters and pore waters, dissolved vanadium is reduced to particle-reactive V^{4+} and is incorporated into the sedimentary fraction (Wehrli and Stumm, 1989). Further reduction to V^{3+} requires the presence of dissolved aqueous sulfide (H_2S) and promotes the incorporation of vanadium into sedimentary organic matter and authigenic clays (Lewan and Maynard, 1982; Lewan, 1984; Breit and Wanty, 1991).

Vanadium concentrations correlate with organic carbon in black shales, suggesting that vanadium is incorporated into organic matter upon burial (Breit and Wanty, 1991). Black shales that have been buried to depths sufficient to pass through the oil window typically produce petroleum that has high vanadium concentrations (Lewan and Maynard, 1982; Lewan, 1984). Conversely, vanadium can become incorporated into illite upon burial (Peacor and others, 2000). Because no modern analogues for vanadiferous black shales are known, the processes of vanadium enrichment are not well understood.

Vanadium-rich black shales of North America occur in Devonian to Permian marine successions. Black shale of the Upper Devonian Woodruff Formation (Nevada) contains 0.5 to 1.2 percent V_2O_5 in unaltered rocks containing high concentrations of organic matter (greater than 10 percent) (Desborough and others, 1979, 1981). Oxidized zones of the Woodruff Formation contain 1.1 to 1.4 percent V_2O_5, reflecting secondary enrichment of vanadium during oxidation; the principal vanadium mineral in the oxidized shales is metahewettite ($CaV_6O_{162}•H_2O$).

Vanadiferous black shales are also found with Pennsylvanian cyclothems of North America (Coveney and Martin, 1983; Coveney and others, 1987; Coveney and Glascock, 1989; Hatch and Leventhal, 1992). These typically thin, metalliferous black shales occur throughout the midcontinent region. The Mecca Quarry Shale of Illinois and Indiana is conspicuously rich in various metals, including vanadium, with concentrations of up to 10,000 ppm (Coveney and Martin, 1983). These concentrations of vanadium exceed that of many VTM deposits; however, because the Mecca Quarry Shale is only a few tens of centimeters thick, it is not considered an economically viable vanadium resource (Coveney and Martin, 1983). Vanadium enrichments in the Mecca Quarry Shale could be related to the action of basinal brines, similar to processes that concentrate lead-zinc in Mississippi Valley-type (MVT) deposits (Coveney and Glascock, 1989), although direct evidence for this mineralizing process is lacking.

The Permian Phosphoria Formation in Idaho and Wyoming contains a world-class phosphate deposit that also includes vanadium-rich strata (McKelvey and others, 1986; Piper, 1999). The black-shale interval within the Meade Peak Phosphatic Shale Member contains an average of 1.2 percent V_2O_5 (Piper, 1999) and, since the early 1940s, has been considered a potential economic source of vanadium (Love and others, 2003). In the 1960s, vanadium and uranium were produced from ferrophosphorus, a byproduct of an elemental phosphorus plant in southeastern Idaho (McKelvey and others, 1986). The occurrence of vanadium-rich shale with black-shale-hosted phosphorite deposits is common worldwide and suggests that steep and (or) fluctuating redox gradients existed within bottom waters and pore waters of the sedimentary basin (Piper, 1994).

The Julia Creek deposit in the Cretaceous Toolebuc Formation in Queensland, Australia, is an example of a vanadium-rich oil shale (Riley and Saxby, 1982; Patterson, Ramsden, and others, 1986). The oil shale was deposited in a shallow, epicontinental sea under reducing bottom water conditions that promoted the enrichment of vanadium. Concentrations range from 0.1 to 1.0 percent V_2O_5. Other known vanadium-rich (greater than 0.17 percent V_2O_5) oil shales include the Mississippian Heath Formation in Montana (Desborough and others, 1981; Derkey and others, 1985) and the Cretaceous La Luna Formation, which is a major petroleum source rock in Colombia and Venezuela (Alberdi-Genolet and Tocco, 1999).

Associated metals.—Vanadium-rich black shales commonly contain high contents of other metals, such as silver, barium, cobalt, copper, molybdenum, nickel, phosphorus, PGEs, uranium, and zinc. Well-characterized deposits include the following (metals associated with vanadium are in parentheses): Julia Creek (molybdenum) in Queensland, Australia (Lewis and others, 2010); Nick (nickel, PGEs, and zinc) in Yukon Territory, Canada (Hulbert and others, 1992); and Viken (molybdenum, nickel, phosphorus, and uranium) and Häggån (uranium, molybdenum, and nickel) in Sweden (Hallberg, 2012; Aura Energy, 2012). As reported by Coveney and others (1992), carbonaceous and phosphatic black shales of Cambrian age in China, which have reported values exceeding 4 percent V_2O_5, contain exceptionally high grades of nickel (from 2 to 4 percent) and molybdenum (>2 percent), and high concentrations of PGEs (20 to 80 parts per billion for platinum and palladium combined). Although vanadium has not been recovered from these strata, molybdenum and nickel have been mined on a small scale in China since about 1985. Metamorphosed sulfide- and phosphate-rich black shale in southwestern Catalonia, Spain, contains unusually high concentrations of vanadium and chromium (as silicates and oxides) together with palladium and platinum minerals (Canet and others, 2003). The Talvivaara deposit in Finland has elevated contents of vanadium (averages 600 ppm) (Loukola-Ruskeeniemi and Heino, 1996; Loukola-Ruskeeniemi and Lahtinen, 2013), and until recently, was mined for cobalt, copper, nickel, and zinc, all of which were extracted using a bioheapleach mineral processing method (Jowitt and Keays, 2011; Saari and Riekkola-Vanhanen, 2012; Loukola-Ruskeeniemi and Lahtinen, 2013). Vanadium is not currently recovered by this process, however.

Vanadate Deposits

Vanadates of lead, zinc, and copper (vanadinite and minerals of the descloizite-mottramite series) form in the oxidized zones of base-metal deposits, especially in areas of arid climate and deep oxidation (Fischer, 1975a). The copper-lead-zinc vanadate ores in the Otavi Mountainland of northern Namibia were once considered to be among the largest vanadium deposits in the world, with an estimated resource of several million metric tons (Boni and others, 2007). Other areas with known vanadate deposits include Angola, South Africa, Zambia (Broken Hill district, now known as the Kabwe Mine), and Zimbabwe (fig. U1). Small deposits occur in Argentina, Mexico, and the United States (Arizona, California, Nevada, and New Mexico), but are unlikely ever to be economically significant resources. Vanadates as a supply of vanadium essentially ceased in 1978 when the last producing vanadium mine at Berg Aukas (Otavi Mountainland) in Namibia was closed.

Vanadate minerals and wulfenite (a lead molybdate mineral) within these deposits form crusts on open cavities or are intergrown with residual clays (Fischer, 1975a). The vanadate ores in the Otavi Mountainland occur in collapse breccias and solution cavities related to karst development in Neoproterozoic carbonate rocks of the Otavi Supergroup and are spatially associated with primary sulfide orebodies within the carbonate strata (Boni and others, 2007). Mottramite and copper descloizite are particularly abundant around copper sulfide deposits (Tsumeb type), whereas descloizite occurs in areas surrounding primary sphalerite-willemite (a zinc silicate mineral) orebodies (Berg Aukas type).

Vanadate deposits are secondary accumulations that form during supergene processes. The vanadate ores of the Otavi Supergroup are interpreted to have formed during several stages, preferentially within a karstic network. The vanadate ores, formed by low-temperature fluids related to weathering, are clearly distinct in age from that of the associated primary sulfide concentrations (Boni and others, 2007). The source of vanadium in such deposits is most likely the surrounding country rocks, especially shales (Fischer, 1975a), or in the case of the Otavi Mountainland deposits, mafic rocks of the older Paleoproterozoic basement (Boni and others, 2007).

Other Magmatic-Hydrothermal Vanadium Resources

Some magmatic-hydrothermal niobium-titanium deposits contain elevated concentrations of vanadium. Deposits at Potash Sulphur Springs (also called Wilson Springs) in Arkansas were the most important sources of vanadium in North America in the 1970s and 1980s, and nearly 4.3 million metric tons of 1.2 percent V_2O_5 was produced. By 1990, all the mines at Wilson Springs were closed (Howard and Owens, 1995). The deposits are located within secondary enrichment zones and fenite that formed during and after intrusion of syenite and mafic alkalic igneous rocks (McCormick, 1978). The Wilson Springs deposits host a variety of vanadium-bearing minerals (Howard and Owens, 1995), including several minerals specific to these deposits (table U2). Adjacent carbonatite and alkaline igneous complexes at the Christy deposit within the Magnet Cove complex in Arkansas have high concentrations of vanadium together with titanium, niobium, and (or) rare-earth elements (Verplanck and Van Gosen, 2011; Flohr, 1994), and carbonatites and related rocks in Kenya are enriched in vanadium (Barber, 1974). Typical vanadium concentrations in such deposits are about 1 percent and are contained in magnetite and titanium minerals. At Magnet Cove and Wilson Springs, sodic pyroxene and magnetite contain up to 3.19 and 1.43 weight percent V_2O_3, respectively, and high concentrations occur in goethite (Flohr, 1994; Howard and Owens, 1995).

Several other deposit types contain vanadium concentrations that are noteworthy, but all are presently uneconomic and are unlikely to be considered vanadium resources in the future. For example, heavy-mineral-concentrate samples from iron ores (Kiruna-type apatite-magnetite deposits) in Sweden and Chile have reported high concentrations (1,000 to 2,000 ppm) of vanadium (Nyström and Henríquez, 1994) and iron oxide mineral separates (magnetite and hematite) from such deposits contain up to 0.479 weight percent vanadium (Dupuis and Beaudoin, 2011). Vanadium concentrations of a few tenths of a percent are also common in titanium-bearing minerals, such as rutile and brookite (table U2) in some epithermal gold-silver and porphyry copper deposits (Fischer, 1973). For example, porphyry deposits in Australia contain rutile with vanadium contents of 0.2 and 1.3 weight percent (Scott, 2005), and rutile from the Pebble porphyry deposit in Alaska has vanadium concentrations that average 6.3 weight percent (Kelley and others, 2011). Even iron-rich minerals that do not contain titanium, such as magnetite and hematite, in some porphyry deposits contain elevated concentrations (up to 0.619 weight percent) of vanadium (Dupuis and Beaudoin, 2011).

In some gold-quartz veins, especially those containing gold-telluride minerals, roscoelite and other vanadium-bearing minerals are common as fine-grained intergrowths with quartz and other gangue minerals (Richards, 1995). In the Tuvatu gold-telluride deposit in Viti Levu, Fiji, vanadium occurs in roscoelite together with karelianite, vanadian muscovite, titanium-free nolanite, vanadian rutile, schreyerite, and an unnamed vanadium silicate mineral (Spry and Scherbarth, 2006). Rutile in the Tuvatu deposit contains up to 5.2 weight percent V_2O_3; roscoelite contains 32.71 weight percent V_2O_3, which is among the highest reported vanadium value for roscoelite from an epithermal gold-tellurium deposit (Spry and Scherbarth, 2006). The source of the vanadium is probably magnetite-bearing mafic alkalic igneous rocks that are spatially associated with the gold ores (Spry and Scherbarth, 2006).

Fossil Fuels

Vanadium closely correlates with organic carbon and, therefore, is enriched in many oil shales. It follows that significant amounts of vanadium are available for commercial use as a byproduct of petroleum, and minor amounts are produced as byproducts of coal and tar sands (Breit, 1992; Polyak, 2012, 2013). At least 10 percent of the world's supply of vanadium comes from coal, crude oil, and petroleum (Polyak, 2012, 2013). The highest concentrations of vanadium are in heavy crude oils (Breit, 1992). Most of the world's heavy oil and vanadiferous petroleum resources are located in Venezuela. These oilfields contain consistently high (up to 1,400 ppm) concentrations of vanadium (Kapo, 1978). Other oils with greater than 50 ppm vanadium are produced in Iran and Japan, and from several fields within the United States, including Alaska, Arkansas, California, Louisiana, Mississippi, Oklahoma, Texas, and Wyoming. Vanadium is recovered from oil by processing ash generated in thermoelectric powerplants, petroleum coke residues generated during refining of heavy oils, and residues plated onto catalysts (Breit, 1992).

Vanadium abundances in ashes formed by burning coals generally range from 0.01 to 0.3 weight percent, with some as high as 8 percent (Reynolds, 1948). The lowest values are contained in coals formed from subaerial plant material; the highest concentrations are in marine sapropelic coals (Breit, 1992). Although China is the only producer of vanadium from coal, coal deposits in Venezuela contain high vanadium contents. The average vanadium content of coal in the United States is 20 ppm (Swanson and others, 1976).

Tar sands are large deposits of bitumen or extremely heavy crude oil. The sands were originally named for those in the Athabasca region in northeastern Alberta, Canada, and tar sand deposits in this region are the best known examples in the world. Other documented occurrences are in Alabama, Alaska, California, Kansas, Kentucky, Oklahoma, Missouri, New Mexico, Texas, and Utah in the United States (Wever and Kustin, 1990), and in other countries, such as Jordan (Breit, 1992; Dill and others, 2009). The oil sands consist of a mixture of crude bitumen (a semisolid form of crude oil), silica sand, clay minerals, and water. Production of refinery-grade oil from the tar sand deposits generates a substantial amount of petroleum coke fly ash that may contain appreciable amounts of valuable metals, such as nickel, titanium, and vanadium. The amount and form of vanadium varies, depending on the nature of the sands. Tar sands in the Athabasca region average several hundred ppm vanadium, whereas other localities contain lower concentrations (Wever and Kustin, 1990; Breit, 1992).

Resources and Production

Identified Resources (United States and World)

A majority of the world's supply of vanadium (approximately 80 to 85 percent) is derived from mined ore that comes either directly from deposits or from steelmaking slags produced by processing the ores mined from VTM deposits. The remaining 15 to 20 percent of the world's supply of vanadium comes from (a) spent catalysts that collected vanadium during the refining of crude oils; (b) residues from the production of alumina, uranium, and some hydrocarbons; and (c) ash derived from burning high-vanadium-content coal or petroleum. Although the leading vanadium-producing countries in 2012 (fig. U2) were China (37 percent), South Africa (35 percent), and Russia (25 percent), Australia is poised to become a major world producer of vanadium in the future (Moskalyk and Alfantazi, 2003). World vanadium resources in 2012 were estimated to be 63 million metric tons of vanadium, and world reserves were estimated to be 14 million metric tons (Polyak, 2013). Because vanadium is usually recovered as a byproduct or coproduct, the demonstrated world resources of this mineral commodity are understated and. therefore. not fully indicative of available supply. Although domestic resources and secondary recovery are adequate to supply a large portion of domestic needs, a substantial part of U.S. demand is currently met by foreign material (Polyak, 2013).

Among the vanadium-rich ore deposits currently being mined, VTM deposits contain the largest tonnages of ore (table U1; fig. U5) and are the reason that China, South Africa, and Russia lead the world in vanadium production. Sandstone-hosted deposits commonly have the highest grades of vanadium, but most are small; that is, they have less than 1 million metric tons of ore (table U1; fig. U5). Among the three deposit types, however, the leading producers of vanadium in the United States have been SSV deposits. In 2010, production from a mill facility in Utah that recovered vanadium from SSV ores was sufficient to meet 20 percent of the vanadium demand for the United States, which amounted to nearly 2 percent of global vanadium production (Polyak, 2011).

Some carbonaceous and phosphatic shale-hosted deposits (Julia Creek, Australia; Viken, Sweden; and Green Giant, Madagascar) have reported high tonnages of vanadium, but these deposits are not currently in production. Technology to recover vanadium profitably in current markets is still being developed. Small amounts of vanadium were produced during World War II from the organic-rich Alum Shale in southern and central Sweden (Dyni, 2006). Also, until 1999, approximately 2,000 metric tons of V_2O_5 was produced annually from the ferrophosphorus slag generated during the reduction of phosphate to elemental phosphorus in ore from the Phosphoria Formation in Idaho and Wyoming (Jasinski, 2004).

Bauxite is another source of vanadium. The vanadium content depends on the origin and nature of the bauxite, but average V_2O_5 contents typically range from 0.05 to 0.25 percent. France, Germany, and India host important occurrences of vanadium-rich bauxite (Patterson, Kurtz, and others, 1986). During the processing of bauxite and the production of alumina, vanadium accumulates in residual sludge (red mud) and other byproducts that contain as much as 10 to 18 percent V_2O_5.

Vanadium is present in crude oil or the residues (bitumen or asphalts) of crude oils remaining in petroleum source rocks. Japan and the United States have recovered significant quantities of vanadium from petroleum residues. Asphaltine or bitumen in the Mina Ragra deposit in the Pasco Region of Peru, was extensively exploited for vanadium from 1907 until 1955. It was the principal source of vanadium in the world in the early 1900s (Fischer, 1973). Unoxidized ore at Mina Ragra consists of quisqueite (a vanadium hydrocarbon) and patronite (vanadium sulfide) (table U2). Vanadates and vanadium oxide minerals form the near-surface oxidized ore, some of which is extremely rich and contains as much as 40 percent V_2O_5 (Fischer, 1973). Bitumen and asphaltine that contain vanadium-rich minerals occur in fractures and as disseminations in the host shale, forming a lens-shaped body (Fischer, 1973).

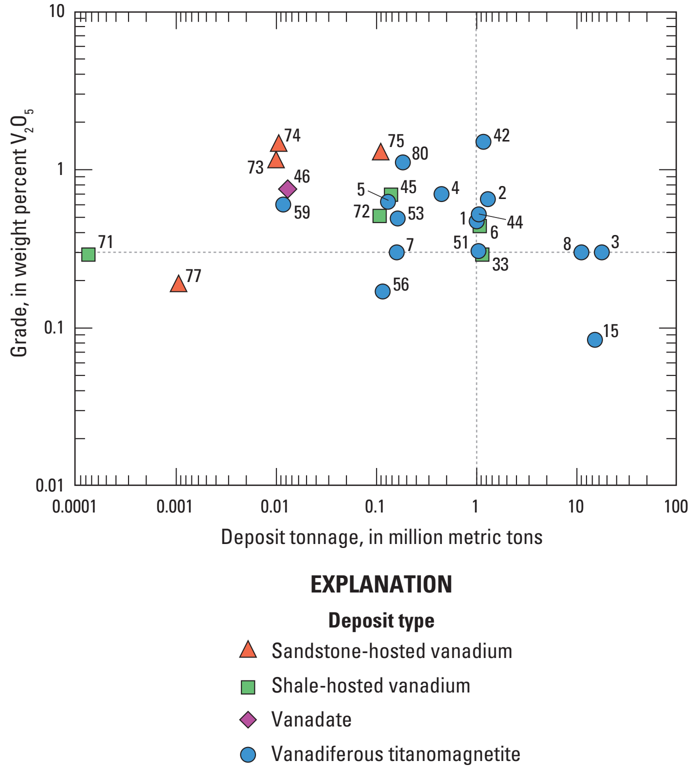

Figure U5. Plot of grade and tonnage of vanadium deposits for which data were available. Each symbol represents an individual deposit. Numbers next to the symbol correspond to the deposit numbers given in table U1 and figure U1. The deposits with the highest grades (greater than or equal to 0.3 percent vanadium oxide [V_2O_5]) and tonnages (greater than 1 million metric tons of V_2O_5) are located in Africa, Australia, Canada, and China.

Undiscovered Resources

Given that most of the present-day vanadium comes from VTM deposits and steelmaking slags produced from these deposits, it is likely that additional vanadium resources will come predominantly from VTM deposits and districts. VTM deposits in Australia, Brazil, Canada, Chile, India, and Malaysia have been identified only recently, and the full extent of the resources has not yet been evaluated fully. Among the largest regions with potential for widespread VTM resources is the 5,000-km^2 region known as the "Ring of Fire" in northern Ontario (fig. U1). Results from early exploration programs indicate that vanadium grades for deposits within mafic and ultramafic complexes in this region (for example, 0.64 percent V_2O_5 at the Butler Lake area, Ontario, Canada; MacDonald Mines Exploration Ltd., 2013) are comparable to economic deposits elsewhere in the world.

Some uranium SSV ores in southwestern South Dakota and northeastern Wyoming are part of the Wyoming basin's uranium province and have recently been distinguished from deposits elsewhere in the province by their substantially higher vanadium contents (George Breit, U.S. Geological Survey [retired], written commun., 2013). These are possible deposits for future vanadium production in the United States.

The amount of vanadium recovered from processing crude oils, coals, and tar sands will undoubtedly increase with future technological advances. Oil from large fields in the Caribbean Basin, the Middle East, and Russia are known to contain anomalously high vanadium contents (Mukhametshin and Punanova, 2011). Tar sands in North America may become an important resource of vanadium in the future. The effectiveness of recovery of vanadium is dependent on the silica and alumina contents of the fly ash; high silica and alumina contents tie up metal values in a silica-alumina matrix (Gomez-Bueno and others, 1981). Results of experimental work show that such matrixes can be broken down by application of a saline water roast of the carbon-free fly ash (Gomez-Bueno and others, 1981). Additional research on development of processing techniques of fly ash may lead to further enhanced recoveries of vanadium (Holloway and Etsell, 2006).

Iron sands are another potential source of vanadium. Iron sands are placer deposits that contain abundant concentrations of iron-bearing heavy minerals, including vanadium-rich magnetite. These iron sands are distributed extensively on the west coast of New Zealand's North Island (Sweatman and others, 2012), but other placer occurrences most likely are present on the east coast of the conterminous United States and the coasts of Africa and Brazil, as well as fluvial iron-titanium-vanadium placer deposits (for example, interior Iran; Razmara and Asadi, 2010). Vanadium concentrations in the New Zealand sands are as high as 0.5 percent. Although vanadium is currently not produced as a byproduct, research that is focused on methods to optimize its recovery is reportedly underway (Sweatman and others, 2012).

Most known occurrences of vanadium in shale are currently uneconomic but are estimated to contain large resources (table U1). Targets may become more viable in the future with advances in extraction technology. For example, development of a method to extract vanadium from the Gibellini vanadium deposit in central Nevada (American Vanadium Corp., 2012) is underway. Similar efforts to produce vanadium from metashales are reported for the Green Giant deposit in Madagascar (Energizer Resources, Inc., 2013). Graphitic deposits in Alabama and China (Liu Mao Mine) contain mica and garnet with elevated vanadium concentrations (up to 0.2 percent V_2O_5) that may be similar to the Green Giant deposit (Pallister and Thoenen, 1948; this volume, chap. J). Other vanadiferous shales include the low- to medium-grade Okcheon metamorphic belt in Korea (Jowitt and Keays, 2011), where metalliferous black shales were used locally as fuel, and contain up to 2.04 percent vanadium, together with high concentrations of gold, molybdenum, nickel, PGEs, and uranium (Jeong, 2006). The Alum Shale in Sweden is an organic-rich marine sequence that is 15 to 60 m thick and contains up to 3,100 ppm vanadium and high concentrations of molybdenum, nickel, uranium, and zinc (Dyni, 2006). Although small amounts of vanadium have already been produced from the Alum Shale, new technologies may allow industrial-scale extraction from this laterally extensive unit (Dyni, 2006; Aura Energy, 2012; Hallberg, 2012). Black shales in Russia that occur within the Mongolia/Ural and Pacific gold belts have local concentrations of vanadium and uranium and therefore are also potential resources for these metals (Karpuzov and others, 2008). Although it lies at great depths (about 2,000 m below the surface), the oil-bearing Bazhenov Formation in the West Siberian Basin is another potential source of byproduct metals (Laznicka, 2010), with reported average concentrations of 105 ppm uranium, 285 ppm molybdenum, and 1,015 ppm vanadium in a laterally extensive interval that is at least 15 to 20 m thick.

Exploration for New Deposits

Exploration methods for vanadium-rich ores vary with deposit type. An understanding of how each type of deposit forms is essential for predicting the potential for undiscovered deposits.

Exploring for Vanadiferous Titanomagnetite Deposits

Most vanadiferous titanomagnetite (VTM) deposits that formed on cratons of Archean to Proterozoic age are closely associated with LIPs; consequently, exploration for this deposit type is focused on LIPs. Mafic to ultramafic complexes that host VTM deposits are generally apparent as aeromagnetic anomalies, even if not exposed at the surface. Most commonly, airborne geophysical surveys that show coincident magnetic and electromagnetic anomalies are further investigated with followup ground geophysical surveys, including gravity, induced polarization, resistivity, and electromagnetic methods. Modeling of aeromagnetic and gravity data can indicate the extent, thickness, and form of intrusions (Cawthorn and Webb, 2001; Ivanic and others, 2010), which can help delineate intrusive bodies having the potential to host vanadium-rich magnetite layers. Paleomagnetic investigations of the Bushveld Complex have shown that different mineralized zones have different paleomagnetic signatures (that is, ages), allowing for regional correlation and delineation of the lateral extent of selected zones (Eales and others, 1993).

An important frontier issue in the exploration for VTM deposits is development of better exploration models that integrate the characteristics of these deposits with an improved understanding of LIP plumbing systems (Ernst and others, 2005). LIPs can have direct links to ore deposits (as hosts or heat engines) or indirect links, and can be used as guides for determining Precambrian paleocontinental reconstructions and related tracing of metallogenic belts between formerly adjacent tectonic blocks (Ernst and Peck, 2010).

Moreover, the compositions of igneous rocks in LIPs can be used to assess fertility and ore potential. For example, specific element ratios can be used to identify whether particular igneous rocks are permissive for hosting vanadium mineralization (Ernst and Peck, 2010). Lithogeochemistry, therefore, provides a guide for selecting the most prospective LIPs and LIP segments for exploration for VTM deposits, or for associated chromium, copper-nickel, or PGE deposits (Augé and others, 2005; Ivanic and others, 2010).

Major known ore-bearing magmatic intrusions are widespread within, or can be traced to the edge of, host continental blocks, suggesting that the intrusions likely continued into a formerly adjacent block. Examples include intrusions such as the Bushveld Complex (Kaapvaal craton), and the Great Dyke of Zimbabwe (Zimbabwe craton). From an exploration standpoint, robust Precambrian reconstructions aid in tracking well-documented metallogenic belts from heavily explored to frontier regions. New methods that use comprehensive data for LIPs can make such Precambrian reconstructions much more efficient (Ernst and Peck, 2010).

Exploring for Sandstone-Hosted Vanadium Deposits

All sandstone-hosted vanadium (SSV) deposits in the Colorado Plateau province contain uranium; therefore, methods used to explore for uranium deposits of this type are applicable to the search for vanadium. The recognition and documentation of meander bends and possible bifurcating paleochannels in the sandstone host rocks are important broad characteristics. Features that may be used as guides to ore include sandstone-mudstone facies, trunk channel systems, stratigraphic pinchouts, individual channels, thick sandstone lenses, and carbonaceous material (Kovschak and Nylund, 1981). Models for the formation of SSV deposits suggest that bacteriogenic hydrogen sulfide acted as a reducing agent for ore formation (Northrop and others, 1990; Wanty and others, 1990). In addition, pyrite in mineralized zones typically has lower sulfur isotope values than pyrite above or below the zone (Northrop and others, 1990), indicating that isotopically light pyrite is an indicator of mineralizing processes in an area.

Some deposits have readily recognizable alteration zones, whereas others show only subtle differences between unmineralized, altered, and mineralized zones. Principal criteria used to distinguish the alteration zones are color, pyrite morphology, kaolinization of feldspar, and low gamma-ray counts commonly accompanied by gamma-ray anomalies at the upper and lower margins of the altered zone (Rackley and others, 1968). The presence of limonite stains, green and blue secondary copper minerals, gray-green alteration of brown or reddish mudstone seams or lenses, and iron and (or) copper sulfide minerals were used as guides to ore in the 1950s (Johnson, 1959).

Geophysical methods assist in determining regional subsurface geology as it may relate to SSV deposits. Conspicuous gravity lows may indicate evaporite units that typically underlie the deposits, although many units may be too thin for detection. Magnetic anomalies highlight depths to basement, major faults that serve as conduits for ore fluids, and the presence of laccolithic intrusions that are interpreted as a possible source of metals in some deposits (Case and Joesting, 1972). More refined geophysical methods are needed to resolve the shape and position of channel sands. Airborne electromagnetic techniques have recently been applied in Nebraska to map the three-dimensional configuration of aquifers and paleochannels (Abraham and Cannia, 2011) and may be useful for delineating channels that are SSV ore hosts.

Exploring for Shale-Hosted Vanadium Deposits

High vanadium concentrations in shales are closely correlated with elevated contents (greater than 5 percent) of organic carbon. Many vanadiferous shales with more than 20 percent organic carbon are considered oil shales (for example, Julia Creek deposit, Queensland, Australia). Deposits of oil shale occur worldwide, and include major deposits in the United States (INTEK, Inc., 2011). Some of these oil shales are known to have high vanadium contents (for example, Heath Formation in Montana; La Luna Formation in Venezuela), but many others likely have not been analyzed for trace metals. Existing and new geochemical data for vanadium and other trace elements in shales would need to be examined to locate potential shale-hosted vanadium deposits.

A good understanding of how vanadiferous shales form is critical for exploration. It is generally accepted that the source of vanadium is seawater, but the enrichment mechanism is uncertain. The close occurrence of vanadium-rich shales with black-shale-hosted phosphate deposits suggests control by fluctuating redox gradients within a sedimentary basin (Piper, 1994). If this suggestion is correct, then exploration will likely be focused in marine successions that were deposited along continental margins or inland seas, where redox gradients are likely to have occurred. Furthermore, because shales can be laterally extensive but have variable grades, understanding the distribution of metal enrichments may help target areas of interest.

National-scale geochemical datasets also may be useful in highlighting regions with black shales that are permissive for hosting vanadium deposits. Preliminary soil and sediment maps of the United States (Smith and others, 2015) show arcuate highs for a range of elements, including cobalt, molybdenum, nickel, and vanadium in central Kentucky—an area that is underlain by the New Albany Shale (Ripley and others, 1990) and stratigraphically equivalent shales that are known to contain high concentrations of these metals. Although less pronounced, similar high concentrations are evident in east-central Nevada and could be related to shales of the metal-rich Woodruff Formation.

Geophysical methods may prove valuable for delineating the distribution of black shales, although many of these shales may not contain significant concentrations of vanadium.

Shales are good conductors, particularly if graphite is present, and therefore, electromagnetic and resistivity surveys may prove useful in delineating the extent of shale units under shallow cover. Recent studies show that combined seismic and electromagnetic methods are effective in highlighting zones of high gas potential in shale reservoirs (Kumar and Hoversten, 2012); such methods could be tested for use in the search for high-organic intervals in shales. Because many vanadium-rich carbonaceous shales also contain high uranium concentrations, downhole geophysical techniques (gamma logs) may be useful in identifying the position of metalliferous shales. Aerial radiometric surveys may also resolve the outcrop position of uranium-rich (and, by association, other metal-rich) shales (Pirkle and others, 1982). The arcuate trend of metals in surficial materials described above for Kentucky is readily mapped in an aeroradiometric survey (Hill and others, 2009).

Environmental Considerations

Sources and Fate in the Environment

Vanadium commonly occurs in one of three oxidation states in weathering environments: +3, +4, and +5. Vanadium +3 and +4 are relatively insoluble ions because they tend to form solid (oxy)hydroxides (for example $V(OH)_3$ and VO(OH)), respectively, but the V^{5+} state is generally dissolved in solution as various oxyanions (for example VO_4^{3-}, HVO_4^{2-}, and $H_2VO_4^{-}$). Under a wide pH range, these high-valence vanadium oxyanions may sorb to iron and aluminum (oxyhydr)oxide minerals. Most dissolved vanadium in rivers and streams derives from the weathering of silicate minerals (Shiller and Mao, 2000). Dissolved V^{4+} and V^{3+} are known to form strong complexes with organic compounds, many of which originated as V^{5+}-organic complexes that were reduced. The formation of strong vanadium-organic compound complexes is one of the mechanisms by which fossil fuels and black shales may become enriched in vanadium.

Examples of natural concentrations of vanadium in rocks, soils, water, and air are given in table U3. Vanadium contents in soils away from known vanadium deposits, mines, or smelters range from 13 to 227 ppm (Shacklette and Boerngen, 1984; Tyler, 2004), whereas streams and rivers contain vanadium concentrations that range from 0.23 to 3.7 micrograms per liter (µg/L) or ppb (Shiller and Mao, 2000; Gaillardet and others, 2003). The concentration of vanadium in suspended particulates in world rivers averages 129 mg/kg (Viers and others, 2009). Dissolved vanadium in coastal seawater ranges from 0.31 to 2.8 µg/L (Shiller and Mao, 1999; Wang and Sañudo-Wilhelmy, 2008; Strady and others, 2009). In North Pacific seawater, dissolved vanadium concentrations generally increase with depth with a total range of 1.5 to 1.9 µg/L (Collier, 1984). In contrast, concentrations in particulate matter (with diameters greater than 53 micrometers) decrease in the upper 100 to 200 m of seawater, then remain relatively constant over a range of 0.0001 to 0.0004 µg/L (Collier, 1984). Among nearly 9,000 samples of filtered and unfiltered groundwaters collected in California, 90 percent contained vanadium concentrations ranging from 3 to 24 µ/L (Wright and Belitz, 2010). Vanadium occurs naturally in the atmosphere as part of mineral dust particles, and ranges in concentration from 0.0006 to 0.002 nanogram per cubic meter (ng/m^3) over the South Pole and from 0.8 to 1.4 ng/m^3 over Greenland (Kabata-Pendias and Pendias, 2001).

Mining and industrial activities can lead to above-background concentrations of vanadium in the environment (table U3). For example, the concentration of vanadium in soils (548 to 7,160 ppm) collected near a vanadium mine in the North West Province of South Africa (Mandiwana and Panichev, 2004) is roughly an order of magnitude greater than natural concentrations in soils. In the Panzhihua region, China, soil vanadium concentrations depend upon the predominant land use and decrease in the following order: smelting (208 to 938 ppm), mining (112 to 591 ppm), agricultural (86 to 227 ppm), and urban use (94 to 184 ppm) (Teng and others, 2011). The Bílina River in the Czech Republic receives drainage from municipal and industrial areas; vanadium concentrations range from 2.5 to 85.6 µg/L, with the highest concentrations observed in the industrial region (Kohušová and others, 2011). Primary inputs of vanadium to the atmosphere result from mining, ore processing, and combustion of fuel oils and coal. Vanadium concentrations in air in urban and industrial areas range from 5 to 200 ng/m^3 (Kabata-Pendias and Pendias, 2001).

Mine Waste Characteristics

Mine waste is generally considered to be the material that originates and accumulates at a mine site but has no current economic value (Lottermoser, 2010), and it includes both solid and liquid waste. Because vanadium can be recovered as a byproduct of the mining of bauxite, carnotite, phosphate, and titanomagnetite ores, the character of the mine waste will vary according to the methods used to extract the primary ore. Vanadium mining of black shales and copper-lead-zinc vanadate deposits, as well as recovery of vanadium from fly ash, generates additional types of mine and processing waste. Mining of vanadium from VTM deposits in Australia is projected to generate 12 million cubic meters of waste rock at the Windimurra deposit (Environmental Protection Authority, 2008) and 59 million metric tons of tailings at the Balla Balla deposit (Environmental Protection Authority, 2009). American Vanadium Corp. is planning to mine vanadium from the Gibellini vanadium deposit in Nevada. Production is to involve open pit mining and processing on site by heap leaching; the total amount of ore and waste to be extracted is projected to be 24 million metric tons (Hanson and others, 2011). Plans to mine vanadium at the metashale-hosted Green Giant deposit in Madagascar includes a well-known process called alkaline press leaching, which is expected to produce a battery-grade form of V_2O_5 that has a purity of greater than 99.5 percent.

Table U3. Vanadium concentrations in rocks, soils, waters, and air.

[DOE, U.S. Department of Energy; EPA, U.S. Environmental Protection Agency; V, vanadium; cm, centimeter; µg/L, microgram per liter; µm, micrometer; ng/m^3, nanogram per cubic meter; ppm, part per million; %, percent]

Environment and (or) location	Vanadium concentration	Unit	Comments	Reference(s)
		Rocks		
Upper continental crust	60	ppm	Average	Taylor and McLennan (1995)
Bulk continental crust	230	ppm	Average	Taylor and McLennan (1995)
Lower continental crust	285	ppm	Average	Taylor and McLennan (1995)
Basalt	250	ppm	Average	Levinson (1974, p. 44)
Black shale	205	ppm	Average	Ketris and Yudovich (2009)
Granite	20	ppm	Average	Levinson (1974, p. 44)
Limestone	15	ppm	Average	Levinson (1974, p. 44)
Shale	130	ppm	Average	Levinson (1974, p. 44)
		Soils		
Western United States	70	ppm	Mean for 20 cm depth	Shacklette and Boerngen (1984)
Eastern United States	43	ppm	Mean for 20 cm depth	Shacklette and Boerngen (1984)
North West Province, South Africa	548 to 7,160	ppm	Composite of upper 20 cm; proximal to V mining	Mandiwana and Panichev (2004)
Panzhihua, China	94 to 184	ppm	Composite of upper 20 cm; urban soil	Teng and others (2011)
Panzhihua, China	86 to 227	ppm	Composite of upper 20 cm; agricultural soil	Teng and others (2011)
Panzhihua, China	112 to 591	ppm	Composite of upper 20 cm; proximal to V mining	Teng and others (2011)
Panzhihua, China	208 to 938	ppm	Composite of upper 20 cm; proximal to V smelting	Teng and others (2011)
Sweden	13 to 47	ppm	Range of profile developed on quartzite and gneiss	Tyler (2004)
Proposed DOE benchmark	2	ppm	Screening benchmark for terrestrial plants	Efroymson and others (1997)
Soil-quality guideline	130	ppm	Canadian agricultural soil guideline	Canadian Council of Ministers of the Environment (2007)
		Waters		
Seawater, North Pacific	1.5 to 1.9	µg/L	Dissolved	Collier (1984)
Seawater, North Pacific	0.0001 to 0.0004	µg/L	Particulate (<53 µm)	Collier (1984)
Seawater, coastal New York, United States	0.31 to 1.78	µg/L	Dissolved (<0.2 µm)	Wang and Sañudo-Wilhelmy (2008)
Seawater, Louisiana Shelf, United States	0.32 to 1.70	µg/L	Dissolved and colloidal (<0.45 µm)	Shiller and Mao (1999)
African rivers	0.59 to 0.65	µg/L	Dissolved load (< 0.2 µm); nonpolluted	Gaillardet and others (2003) and references therein
European rivers	0.4 to 2.9	µg/L	Dissolved load (< 0.2 µm); nonpolluted	Gaillardet and others (2003) and references therein
North American rivers	0.4 to 1.84	µg/L	Dissolved load (< 0.2 µm); nonpolluted	Gaillardet and others (2003) and references therein
Amazon River	0.703	µg/L	Mean dissolved load (<0.2 µm); nonpolluted	Gaillardet and others (2003) and references therein
Bílina River	2.5 to 85.6	µg/L	Receives municipal and industrial drainage	Kohušová and others (2011)

Table U3. Vanadium concentrations in rocks, soils, waters, and air.—Continued

[DOE, U.S. Department of Energy; EPA, U.S. Environmental Protection Agency; V, vanadium; cm, centimeter; µg/L, microgram per liter; µm, micrometer; ng/m^3, nanogram per cubic meter; ppm, part per million; %, percent]

Environment and (or) location	Vanadium concentration	Unit	Comments	Reference(s)
Waters—Continued				
Mississippi River tributaries, United States	0.23 to 1.77	µg/L	Dissolved and colloidal (<0.4 µm)	Shiller and Mao (2000)
Stream water, California, United States	0.29 to 3.7	µg/L	Dissolved and colloidal (<0.4 µm)	Shiller and Mao (2000)
Gironde Estuary, France	0.89 to 2.76	µg/L	Dissolved	Strady and others (2009)
Groundwater, California	3 to 24	µg/L	Filtered and unfiltered; range is for 90% of samples	Wright and Belitz (2010)
Sediment, world river (average)	129	ppm	Suspended sediment	Viers and others (2009)
Proposed EPA benchmark	280	µg/L	Tier II Secondary acute value	Suter and Tsao (1996)
Proposed EPA benchmark	20	µg/L	Tier II Secondary chronic value	Suter and Tsao (1996)
Air				
South Pole	0.0006 to 0.002	ng/m^3	None	Kabata-Pendias and Pendias (2001)
Greenland	0.8 to 1.4	ng/m^3	None	Kabata-Pendias and Pendias (2001)
Urban/industrial	5 to 200	ng/m^3	None	Kabata-Pendias and Pendias (2001)

The mineralogy of solid mine waste derived from vanadium mining is similar to that of the deposit from which it is extracted, but the proportion of vanadium minerals is smaller. Tailings from the VTM deposit in Panzhihua, China, contain ilmenite (15 to 18 mass percent), augite (46 mass percent), plagioclase (31 to 34 mass percent), and pyrite (2 to 3 mass percent) (Dahe, 2004). The Slick Rock SSV deposit in Colorado typically contains low contents of uranium and vanadium ore minerals, as well as anatase, barite, calcite, jordisite, pyrite, and quartz; selenium- and copper-bearing minerals are found in some deposits (Shawe, 2011). In the Gibellini vanadium deposit, vanadium is concentrated in organic material; associated phases are apatite, calcite, clay, microcline, pyrite, and sphalerite (Desborough and others, 1979). Copper-lead-zinc vanadate deposits may contain the ore minerals descloizite, mottramite, and vanadinite (table U2), which at the Otavi Mountainland deposits in Namibia host trace amounts of arsenic, cadmium, chromium, iron, manganese, molybdenum, nickel, and phosphorus (Boni and others, 2007). The most common gangue minerals in the Otavi Mountainland deposits are calcite and dolomite, which have high concentrations of iron, phosphorus, and lead and trace amounts of arsenic, barium, cadmium, copper, nickel, strontium, and vanadium (Boni and others, 2007).

In weathering environments, trace metals in vanadium deposits are expected to remain immobile under oxic, near-neutral pH conditions (5<pH<8), especially in the presence of iron-rich solids (Smith and Huyck, 1999). Under anoxic and (or) acidic conditions, however, vanadium minerals, some gangue minerals, and associated trace metals may dissolve. In those deposits that contain sulfide minerals (for example, chalcocite, pyrite, and sphalerite), generation of acidity is possible if sulfide dissolution is not balanced by the acid-neutralizing capacity of carbonate minerals (for example calcite and dolomite). The dissolution of sulfide minerals releases metals and produces sulfuric acid, and the subsequent acidic pH values of the solutions allow higher concentrations of metals to be dissolved—potentially causing the environmental problem known as acid mine drainage (AMD). Mining of VTM, SSV, and black shale deposits that contain sulfides and lack appreciable quantities of carbonate minerals increases the potential for AMD generation. Alternatively, some of these deposit types, particularly some SSV and black shale deposits, contain appreciable amounts of carbonate minerals, thereby lowering the acid-generation potential.

Recovery of vanadium from mine tailings and other wastes is becoming an increasingly important source, particularly because the fraction of vanadium in discarded products that are recycled is less than 1 percent (Graedel and others, 2011). The main challenge of vanadium recycling is that it is often included in alloys in small amounts, making recovery technologically and economically unfeasible (Reck and Graedel, 2012).

Human Health Concerns

The Agency for Toxic Substances and Disease Registry provides a useful summary of the human toxicology of vanadium (Agency for Toxic Substances and Disease Registry, 2012).

The general public is most likely to be exposed to vanadium through consumption of contaminated food. Occupational exposure to vanadium usually results from the inhalation of V_2O_5 dust during the production of FeV and steel. Exposure to high oral doses of vanadium may lead to nausea, diarrhea, stomach cramps, decreased numbers of red blood cells, and increased blood pressure. Inhalation of V_2O_5 may cause extended coughing and is suspected to cause cancer.

Vanadium is believed to be a micronutrient, with a postulated requirement for humans of less than 10 micrograms per day, which can be met through dietary intake (Anke, 2004, and references therein). Vanadium in the form of vanadyl sulfate and sodium metavanadate has been administered to diabetic patients as a dietary supplement because these compounds have been observed to mimic the actions of insulin in isolated cell systems (Anke, 2004, and references therein), but clear therapeutic benefit has yet to be established (Wiernsperger and Rapin, 2010). Primary and secondary drinking-water regulations for vanadium currently do not exist in the United States, but the Occupational Safety and Health Administration has set an exposure limit of 0.05 milligrams per cubic meter (mg/m^3) for V_2O_5 dust (Occupational Safety and Health Administration, 2013b) and 0.1 mg/m^3 for V_2O_5 fumes (Occupational Safety and Health Administration, 2013a) in workplace air over an 8-hour workday. Vanadium toxicity is believed to result from an intake of more than 10 to 20 milligrams per day (Anke, 2004).

Ecological Health Concerns

Vanadium is essential for some biological processes and organisms, as well as a potential toxicant. For example, some nitrogen-fixing bacteria require vanadium for producing vanadium nitrogenase, an enzyme used to convert nitrogen (N_2) from the atmosphere into ammonia, which is a more biologically accessible form of nitrogen (Madigan and others, 2003). This process is critical to the health of the biosphere. Vanadium is also essential to certain species of algae for chlorophyll production and overall growth (Anke, 2004).

Compared with other metals and metalloids, the ecological impacts of vanadium in the environment are not well known. Because fish tend to be sensitive to low concentrations of dissolved metals, they are often indicators of contamination in aquatic systems. One of several useful endpoints used in toxicity tests is that which determines the lethal concentration that leads to 50 percent mortality (LC_{50}) after exposure to a substance for a specified amount of time. Chronic toxicity tests (that is, lower doses over longer time periods) of dissolved vanadium in developing rainbow trout (*Oncorhynchus mykiss*) revealed a mean LC_{50} value of 0.17 milligrams per liter (mg/L) after 28 days of exposure (Birge and others, 1980). Acute toxicity tests (higher doses over shorter times) of vanadium to a fish known as the threespine stickleback (*Gasterosteus aculeatus*) revealed LC_{50} values that ranged from 2.4 to 4.1 mg/L after 4 days of exposure (Gravenmier and others, 2005). Similar acute toxicity tests of vanadium to three species of endangered fish from the Green River, Utah, which runs through carnotite deposits, showed no difference in sensitivity among species, but LC_{50} values ranged from 5.3 to 8.8 mg/L for young specimens and 2.2 to 5.1 mg/L for older stages (Hamilton, 1995) after 4 days of exposure. These dissolved vanadium concentrations are much greater than those observed in many rivers and streams (table U3). Some regions of the United States have adopted secondary acute and chronic screening benchmarks of 280 micrograms of vanadium per liter of water (µg V/L) and 20 µg V/L, respectively, for aquatic freshwater life (Suter and Tsao, 1996).

The essentiality of vanadium to higher plants is debated, but clear evidence exists for vanadium phytotoxicity. After amending soils with vanadium in the form of dissolved ammonium metavanadate (NH_4VO_3), Wang and Liu (1999) found that soybean seedling growth was markedly stunted in flood plain soils (fluvaquents) with greater than 30 ppm of vanadium, whereas little to no stunting occurred in red earth soil (Oxisol), even at vanadium concentrations as high as 75 ppm. Likewise, in phytotoxicity tests with forb (a herbaceous flowering plant), crop, and grass species, LC_{50} values ranged from 21 to 59 ppm of V_2O_5 after exposure for 4 to 5 weeks; higher LC_{50} values (90 to greater than 130 ppm of V_2O_5) were observed under similar conditions, but with greater soil nutrient levels (Smith and others, 2013). These studies highlight how vanadium toxicity to plants varies, depending upon the prevailing soil conditions, the type of plant species, and the chemical form of vanadium, which determines its bioaccessibility. The chemical form of vanadium in ecotoxicity studies may be more bioaccessible than the chemical form of vanadium in soils. Furthermore, the amount of bioaccessible vanadium is likely to be smaller than the amount of total vanadium in soils. For example, the concentration of bioaccessible vanadium in soils of Northern Ireland was determined to be about 7.5 to 17 percent of the total soil vanadium content (Barsby and others, 2012). Some regions of the United States have adopted a soil screening benchmark of 2 ppm of vanadium for terrestrial plants (Efroymson and others, 1997). The Canadian agricultural soil quality guideline for vanadium is 130 ppm of vanadium (Canadian Council of Ministers of the Environment, 2007).

Mine Closure

Most recent and new mining operations include closure plans that address issues related to the mine footprint. A mine's footprint includes the waste left on site and the locally affected soil and water, as well as ecological impacts, such as habitat destruction and loss of biodiversity. Mine closure issues that could have the greatest environmental impacts depend upon the type of deposit being mined, and if applicable, the methods employed to process the ore on site. Given the variety of deposit types from which vanadium is obtained, all mine closure issues related to vanadium mining are too numerous to describe here. Instead, the focus is on potential issues related to mining of the largest and economically most important deposit type (VTM deposits), and to the new mining operation planned in the Gibellini vanadium deposit in Nevada.

Some VTM and shale-hosted deposits contain sulfide minerals, and, therefore, the potential for AMD exists at both types of mine sites. Acidic drainage may seep from waste piles or tailings ponds. Common methods for treating AMD include active water-treatment facilities, passive limestone-lined channels, and constructed wetlands (Plumlee and Logsdon, 1999). The end result of both active and passive approaches is eventual precipitation of dissolved metals. Precipitated metals in passive wetland systems tend to be more stable under the prevailing anoxic conditions, whereas the metal-rich precipitates that result from active treatment facilities form a sludge that can cause environmental problems if not disposed of responsibly. When the potential for AMD exists at a mine site, common preventative measures include conducting water quality surveys before, during, and after mining.

The great size of VTM deposits tends to result in large mine waste piles. These waste piles have the potential to become unstable and can be a source of metal-rich dust. If using mine waste as backfill into dry mine workings is not an option, problems of mine-waste-pile stability and dust generation can often be addressed through grading and covering the piles with vegetation.

Vanadium-rich black shale at the Gibellini vanadium deposit is planned to be processed on site using acid heap leaching and solvent extraction—a recovery process that has yet to be applied to vanadium ores (Hanson and others, 2011). Acid heap leaching is commonly used on low-grade cobalt, copper, and nickel ores. In general, heap leaching involves placing crushed ores on top of impervious liners to form a slightly sloped leach pad, applying leach solutions to the pad, then collecting the leachates delivered by the impervious liners into ponds or tanks for further processing. During solvent extraction, leachates are mixed with a vanadium-optimized organic extractant (that is, a chelating agent), thereby forming vanadium-organic complexes that can be separated from other undesired metals present in the solution. At the Gibellini vanadium deposit, the resulting metal solution is planned to be recirculated back through the leaching process, while the vanadium-organic solution will undergo acidic stripping of vanadium from the organics, followed by precipitation of V_2O_5 (Hanson and others, 2011). Potential seepage or spillage of leachates into local surface and groundwater can have negative impacts on the environment, however, given that leachates may contain metals, such as arsenic, cadmium, chromium, copper, mercury, lead, and zinc (U.S. Environmental Protection Agency, 1994). Best practices for this type of operation include engineering for leak prevention, ongoing seepage testing, and post-closure monitoring of mine waste discharges and downstream water quality (U.S. Environmental Protection Agency, 1994).

Problems and Future Research

Infrastructure development and the need for steel products are the main sources of demand for vanadium worldwide. The current worldwide resources of about 63 million metric tons of vanadium appear to be adequate to meet current demand. Future demand is expected to increase because of the following factors (Roskill Information Services, Ltd., 2013):

- China is the top steel producer and consumer of vanadium in the world (the country accounted for about 34 percent of the world's vanadium consumption in 2012), and China's demand for vanadium to use in the production of steel is expected to remain strong for the next 10 to 20 years.
- China and Japan have legislated increased vanadium content in steel rebar so that the quality of their steel matches that of other major steel-producing countries; therefore, use of vanadium for steel production in China and Japan is expected to increase dramatically.
- India's steel production is projected to almost double owing to industrialization of that country.
- Development of alternate renewable sources of energy will likely require increased use of VRBs.

With the anticipated increase in demand for vanadium and the limited supply, maintaining a constant supply would likely mean that new sources of vanadium would need to be identified and the extraction of vanadium from currently defined sources would need to be optimized. Many future resources are likely contained within VTM deposits in unexplored regions. Another potential source is vanadium-rich shale because known deposits of this type have large tonnages and grades that are similar to those of presently mined VTM deposits (fig. U5). For shale-hosted deposits to be a viable resource, however, methods of profitably extracting the vanadium and producing a product that could be used in VRBs would be required, and future research would need to be designed to optimize these methods. Other sources, such as iron sands (placers) likely exist in many parts of the world; identification and quantification of these sands in terms of tonnage and vanadium content could be undertaken. Research on optimizing the recovery of vanadium from crude oil, bauxite, and tar sands also may increase global identified resources of this valuable metal.

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Note: All Web links listed were active as of the access date but may no longer be available.

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EXHIBIT 5

USGS
science for a changing world

Draft Critical Mineral List—Summary of Methodology and Background Information—U.S. Geological Survey Technical Input Document in Response to Secretarial Order No. 3359

Open-File Report 2018–1021

U.S. Department of the Interior
U.S. Geological Survey

Draft Critical Mineral List—Summary of Methodology and Background Information—U.S. Geological Survey Technical Input Document in Response to Secretarial Order No. 3359

By Steven M. Fortier, Nedal T. Nassar, Graham W. Lederer, Jamie Brainard, Joseph Gambogi, Erin A. McCullough

Open-File Report 2018–1021

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
RYAN K. ZINKE, Secretary

U.S. Geological Survey
William H. Werkheiser, Deputy Director
exercising the authority of the Director

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Draft Critical Mineral List—Summary of Methodology and Background Information—U.S. Geological Survey Technical Input Document in Response to Secretarial Order No. 3359

By Steven M. Fortier, Nedal T. Nassar, Graham W. Lederer, Jamie Brainard, Joseph Gambogi, Erin A. McCullough

Statement of Issue

Pursuant to the Presidential Executive Order (EO) No. 13817, "A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals," the Secretary of the Interior, in coordination with the Secretary of Defense, and in consultation with the heads of other relevant executive departments and agencies, was tasked with developing and submitting a draft list of minerals defined as "critical minerals" to the Federal Register within 60 days of the issue of the EO (December 20, 2017; Executive Office of the President, 2017). U.S. Department of the Interior (DOI) Secretarial Order (SO) No. 3359, "Critical Mineral Independence and Security," tasked the Director of the U.S. Geological Survey (USGS), in coordination with the Bureau of Land Management (BLM), with developing and submitting a proposed draft list of minerals defined as "critical minerals" within 30 days of the issue of the SO (U.S. Department of the Interior, 2017). USGS and BLM developed the unranked draft list presented herein in cooperation with the U.S. Departments of Defense (DOD), Energy, State, and Commerce, and other members of the National Science and Technology Council Subcommittee on Critical and Strategic Mineral Supply Chains (CSMSC).

Summary of the Proposed Draft List

Based on an analysis using multiple criteria explained below, 35 minerals or mineral material groups have been identified that are currently (February 2018) considered critical. These include the following: aluminum (bauxite), antimony, arsenic, barite, beryllium, bismuth, cesium, chromium, cobalt, fluorspar, gallium, germanium, graphite (natural), hafnium, helium, indium, lithium, magnesium, manganese, niobium, platinum group metals, potash, rare earth elements group, rhenium, rubidium, scandium, strontium, tantalum, tellurium, tin, titanium, tungsten, uranium, vanadium, and zirconium. The categorization of minerals as critical may change during the course of the review process and is thus provisional.

Definition

A "critical mineral," as defined by EO No. 13817, is a mineral (1) identified to be a nonfuel mineral or mineral material essential to the economic and national security of the United States, (2) from a supply chain that is vulnerable to disruption, and (3) that serves an essential function in the manufacturing of a product, the absence of which would have substantial consequences for the U.S. economy or national security. Disruptions in supply chains may arise for any number of reasons, including natural disasters, labor strife, trade disputes, resource nationalism, conflict, and so on. The draft list provided herein is based on the definition of a "critical material" provided in the EO. The U.S. Government and other organizations have other definitions and rely on other criteria to identify a material or mineral as "critical" or otherwise important. This draft list is not intended to replace related terms and definitions of materials that are deemed strategic, critical, or otherwise important (for example, the National Defense Stockpile).

Introduction

Lists of critical minerals, although useful to identify and prioritize materials of concern, are, by necessity, a simplification of a complex issue; there is no one method that will meet the needs of all interested parties. A number of factors are relevant when using such information. First, what constitutes a critical mineral depends, in some respects, on who is asking the question. A company producing hydrocarbons, for example, may have a very different idea of what materials are critical than an electronics manufacturer or the DOD. The USGS tracks nonfuel mineral information on a continuous and annual basis, in part, to monitor the criticality and import dependence of critical minerals. The U.S. Energy Information Administration tracks uranium mineral information in a similar way. The USGS also completes geologic mapping, mineral resource assessments, and basic research that allow the distribution of critical minerals to be identified and understood. Without this background information, it is not possible to fully understand the criticality and security of the Nation's mineral supply. Specifically, various agencies, including the DOI, DOD, U.S. Department of Commerce, U.S. Department of Energy, U.S. Department of Agriculture, and the United States Trade Representative, would be expected to prioritize specific minerals in the draft list presented herein differently based on the importance to their missions.

Previous work in this field has resulted in several methodologies and produced a variety of lists of critical minerals particularly during the decade after the seminal work of the National Academy of Sciences in 2008 (National Research Council, 2008). All such studies differed somewhat in the approach taken and the resulting lists that were produced; a review of these studies is beyond the scope of this document. For the purposes of meeting the objectives of the above referenced EO and SO, the approach described in the next paragraph was used to generate the draft list proposed herein.

The critical mineral early warning screening methodology developed by the CSMSC in 2016 (U.S. National Science and Technology Council, 2016), and updated in 2017 (McCullough and Nassar, 2017), served as the starting point for the development of the draft list. The screening methodology was designed to identify and prioritize minerals or mineral materials for in depth study to evaluate risks to security of supply. The screening methodology is global in scope and did not specifically address U.S. import reliance. It only addressed nonfuel minerals and, thus, did not include uranium. One of the principle metrics used in the CSMSC screening methodology was the Herfindahl-Hirschman index (HHI). The HHI is used by the Department of Justice and the Federal Trade Commission to identify highly concentrated markets when a company may control market share above an established threshold of 2,500 on a dimensionless scale that ranges from 0 to 10,000. Additional tools and sources of information used to produce the draft list, make it U.S. specific, and that include consideration of uranium were as follows: (1) U.S. net import reliance (NIR) statistics as published annually in the USGS Mineral Commodity Summaries (U.S. Geological Survey, variously dated); (2) USGS Professional Paper 1802 "Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply" (Schulz and others, 2017); (3) various inputs from the DOD; (4) the National Defense Authorization Act for fiscal year 2018 (H.R. 2810); (5) U.S. Energy Information Administration uranium statistics in the "2016 Uranium Marketing Annual Report" (U.S. Energy Information Administration, 2017); and (6) the judgment of subject-matter experts of the USGS, and other U.S. Government agencies including representatives of other DOI Bureaus and members of the CSMSC Subcommittee. Additional information and references on these tools and sources are provided in appendix 1.

The draft list resulting from the application of these metrics is shown in table 1 with materials listed in alphabetical order. Most of entries in the table are materials for which production concentration and net import reliance are high (typically HHI greater than 2,500 and NIR greater than 50 percent for either the years 2016, 2017, or both). Entries that are below the chosen threshold based on one metric or the other, but for which a case for inclusion can be made on grounds of particularly critical applications, also are included. The latter is based on the judgment of subject-matter experts of the CSMSC Subcommittee. The countries that are the largest producers and largest U.S. suppliers are listed adjacent to the respective metrics for those categories. As an example, China dominates the production of antimony and is the largest import source to the United States. It should be noted that import reliance is not the same as import vulnerability (defined as a material with high NIR that is sourced from a country or countries with high governance risk). Many of the countries identified as the largest source of U.S. imports also have relatively high governance risks. Key end use sector data also are shown in a matrix format indicative of the industrial sectors in which a particular material finds important end uses. Finally, notable examples of end use applications are given for each listed material. A more detailed view of the industrial sectors and key technologies for which the listed commodities find important end uses is provided in table 2. A brief summary of information relevant to the criticality for each listed material is included in appendix 2.

A supply chain approach was used for some of the materials on the draft list, consistent with the definition of a critical mineral in the EO. For example, aluminum is included to represent the aluminum supply chain because the United States is 100 percent reliant on imports of metallurgical grade bauxite, and some forms of high purity alumina and aluminum metal used for important applications also are considered critical. Likewise, several important ferroalloys used to manufacture specialty steels and superalloys are not listed individually; instead, they are included by inference in the supply chain of the material alloyed with iron. Ferroniobium, for example, is captured by the presence of niobium on the draft list in recognition that niobium is part of the ferroniobium supply chain. It should be noted that potential supply chain vulnerabilities relating to critical minerals extend beyond what is described herein and should be considered as part of the strategy within the report to the President required by the EO. For example, enhancing domestic mineral processing capability is important to prevent the immediate export of domestically mined ore.

Table 1. Draft list of critical minerals.

[X, applicable sector; --, not applicable]

Mineral commodity	Sectors: Aerospace (nondefense)	Defense	Energy	Telecommunications and electronics	Transportation (nonaerospace)	Other	Top producer	Top supplier	Notable example application
Aluminum	X	X	X	X	X	X	China	Canada	Aircraft, power transmission lines, lightweight alloys.
Antimony	--	X	X	X	X	X	China	China	Lead-acid batteries.
Arsenic	--	X	X	X	--	X	China	China	Microwave communications (gallium arsenide).
Barite	--	--	X	X	--	X	China	China	Oil and gas drilling fluid.
Beryllium	X	X	X	X	--	X	United States	Kazakhstan	Satellite communications, beryllium metal for aerospace.
Bismuth	--	X	X	X	--	X	China	China	Pharmaceuticals, lead-free solders.
Cesium and rubidium	X	X	X	X	--	X	Canada	Canada	Medical applications, global positioning satellites, night-vision devices.
Chromium	X	X	X	X	X	X	South Africa	South Africa	Jet engines (superalloys), stainless steels.
Cobalt	X	X	X	X	X	X	Congo[1] (Kinshasa)	Norway	Jet engines (superalloys), rechargeable batteries.
Fluorspar	--	--	X	X	--	X	China	Mexico	Aluminum and steel production, uranium processing.
Gallium	X	X	X	X	--	X	China	China	Radar, light-emitting diodes (LEDs), cellular phones.
Germanium	X	X	X	X	--	X	China	China	Infrared devices, fiber optics.
Graphite (natural)	X	X	X	X	X	X	China	China	Rechargeable batteries, body armor.
Helium	--	--	--	X	--	X	United States	Qatar	Cryogenic (magnetic resonance imaging [MRI]).
Indium	X	X	X	X	--	X	China	Canada	Flat-panel displays (indium-tin-oxide), specialty alloys.
Lithium	X	X	X	X	X	X	Australia	Chile	Rechargeable batteries, aluminum-lithium alloys for aerospace.
Magnesium	X	X	X	X	X	X	China	China	Incendiary countermeasures for aerospace.
Manganese	X	X	X	X	X	X	China	South Africa	Aluminum and steel production, lightweight alloys.
Niobium	X	X	X	X	--	X	Brazil	Brazil	High-strength steel for defense and infrastructure.
Platinum group metals[2]	X	--	X	X	X	X	South Africa	South Africa	Catalysts, superalloys for jet engines.
Potash	--	--	X	X	--	X	Canada	Canada	Agricultural fertilizer.
Rare earth elements[3]	X	X	X	X	X	X	China	China	Aerospace guidance, lasers, fiber optics.
Rhenium	X	--	X	X	--	X	Chile	Chile	Jet engines (superalloys), catalysts.
Scandium	X	X	X	X	--	X	China	China	Lightweight alloys, fuel cells.
Strontium	X	X	X	X	X	X	Spain	Mexico	Aluminum alloys, permanent magnets, flares.
Tantalum	X	X	X	X	--	X	Rwanda	China	Capacitors in cellular phones, jet engines (superalloys).
Tellurium	--	X	X	X	--	X	China	Canada	Infrared devices (night vision), solar cells.
Tin	--	X	--	X	--	X	China	Peru	Solder, flat-panel displays (indium-tin-oxide).
Titanium	X	X	X	X	--	X	China	South Africa	Jet engines (superalloys) and airframes (titanium alloys), armor.
Tungsten	X	X	X	X	--	X	China	China	Cutting and drilling tools, catalysts, jet engines (superalloys).
Uranium	X	X	X	--	--	X	Kazakhstan	Canada	Nuclear applications, medical applications.
Vanadium	X	X	X	X	--	X	China	South Africa	Jet engines (superalloys) and airframes (titanium alloys), high-strength steel.
Zirconium and hafnium	X	X	X	X	--	X	Australia	China	Thermal barrier coating in jet engines, nuclear applications.

[1]Democratic Republic of the Congo.

[2]This category includes platinum, palladium, rhodium, ruthenium, iridium, and osmium.

[3]This category includes yttrium and the lanthanides.

Table 2. Important technologies and applications by mineral commodity and industrial sector.

[NA, not applicable; SOFC, solid oxide fuel cell; PEM, polymer electrolyte membrance]

Mineral commodity	Aerospace (nondefense)	Defense	Energy	Telecommunications and electronics	Transportation (nonaerospace)	Other
Aluminum	• Airframes • Fuselage	• Aerospace • Naval vessels • Ground vehicles	• Power transmission lines • Lightweight alloys • Land based turbines (superalloys, coating) • Aluminum oxide catalyst supports	NA	• Marine vessels • Ground vehicles • Lightweight alloys	• Infrastructure • Packaging • Aluminum oxide refractories
Antimony	NA	• Lead-acid batteries • Infrared devices (night vision)	• Lead-acid batteries	• Semiconductors	• Lead-acid batteries	• Flame-retardant materials • Glass and ceramics manufacturing • Plastics manufacturing
Arsenic	NA	• Semiconductors	• Solar cells	• Cellular phones	NA	• Gallium arsenide integrated circuits • Optoelectronic devices
Barite	NA	NA	• Oil and gas drilling fluid	NA	NA	• Radiation shielding • Medical applications
Beryllium	• Structural and optical components • Aluminum alloys	• Guidance systems • Radar	• Oil and gas drilling equipment • Nuclear applications	• Undersea cable housings • Contacts	NA	• X-ray windows
Bismuth	NA	• Thermoelectric devices • Machining alloys	• Bismuth oxide sofc applications	• Solder • Semiconductor manufacturing	NA	• Pharmaceutical • Glass and ceramics manufacturing • Metallurgical applications
Cesium and rubidium	• Global positioning satellites • Guidance systems	• Infrared devices (night vision)	• Fuel cells • Solar cells	• Cellular phones • Motion sensor devices • Fiber optics • Photoelectric cells	NA	• Medical applications • Scintillation • Atomic clocks • Specialty glass
Chromium	• Jet engines (superalloys)	• Superalloys • Specialty steels	• Land-based turbines • SOFC applications	NA	NA	• Stainless steel • Specialty steels • Corrosion resistance
Cobalt	• Jet engines (superalloys) • Rechargeable batteries	• Superalloys • Permanent magnets • Rechargeable batteries	• Rechargeable batteries • Petroleum catalysts • Land-based turbines • Superalloys •SOFC catalysts • High temperature boiler tubing	• Rechargeable batteries	• Rechargeable batteries	• Cemented carbides • Specialty steels

Table 2. Important technologies and applications by mineral commodity and industrial sector.—Continued

[NA, not applicable; SOFC, solid oxide fuel cell; PEM, polymer electrolyte membrance]

Mineral commodity	Aerospace (nondefense)	Defense	Energy	Telecommunications and electronics	Transportation (nonaerospace)	Other
Fluorspar	NA	NA	• Uranium processing	• Semiconductor manufacturing	NA	• Hydrofluoric acid • Steelmaking • Aluminum production • Metallurgical applications • Fluorochemicals
Gallium	• Solar cells in satellites • Microwave power transistors	• Radar • Radio frequency amplifiers • Infrared imaging	• Solar cells • Light-emitting diodes	• Cellular phones • Light-emitting diodes • Integrated circuits	NA	• Optoelectronic devices • Lasers • Photodetectors
Germanium	• Solar cells in satellites	• Infrared devices (night-vision) • Guidance systems	• Solar cells	• Fiber optics • Integrated circuits	NA	• Optoelectronic devices • Polymer manufacturing
Graphite	• Rechargeable batteries • Jet engine components	• Munitions • Rechargeable batteries • Body armor • Superalloy components	• Rechargeable batteries • Nuclear applications • PEM fuel cell applications • Land based turbines	• Rechargeable batteries	• Rechargeable batteries	• Lubricant • Refractories • Electrodes • Steelmaking
Helium	NA	NA	NA	• Semiconductor manufacturing	NA	• Magnetic resonance imaging • Cryogenic cooling • Shielding gas • Tank purging • Leak detection
Indium	• Aircraft wind shield	• Infrared imaging	• Solar cells • Alkaline batteries • Nuclear applications • Light-emitting diodes	• Fiber optics • Flat-panel displays • Light-emitting diodes • Semiconductors • Thermal interface materials	NA	• Lasers • Solder
Lithium	• Rechargeable batteries • Aluminum alloys (structural)	• Rechargeable batteries • Aerospace alloys • Tritium production support	• Rechargeable batteries • Cooling water chemistry in nuclear power reactors	• Rechargeable batteries	• Rechargeable batteries	• Glass and ceramics manufacturing • Lubricant • Medical applications
Magnesium	• Aluminum alloys	• Incendiaries • Munitions • Aluminum alloys • Radar	• Lightweight alloys	NA	• Automobile components	• Metallurgical applications • Corrosion resistance

Table 2. Important technologies and applications by mineral commodity and industrial sector.—Continued

[NA, not applicable; SOFC, solid oxide fuel cell; PEM, polymer electrolyte membrance]

Mineral commodity	Aerospace (nondefense)	Defense	Energy	Telecommunications and electronics	Transportation (nonaerospace)	Other
Manganese	• Jet engines (superalloys) • Aluminum alloys	• Aluminum alloys	• Land-based turbines • Lightweight alloys • Rechargeable batteries	NA	• Aluminum alloys	• Specialty steel
Niobium	• Jet engines (superalloys)	• Jet engines (superalloys) • Specialty steels	• Land-based turbines • Oil and gas pipelines (specialty steel) • SOFC catalysts Nickel based superalloys	NA	NA	• Superconducting alloys
Platinum-group metals	• Jet engines (casting, coatings)	NA	• Petroleum catalysts • Land-based turbines • Fuel cells • Autocatalysts	• Hard-disk drives • Capacitors • Flat-panel displays	• Autocatalysts • Fuel cells • Automotive components	• Chemical catalysts • Medical applications • Refractory crucibles • Metallurgical applications • Integrated circuits
Potash	NA	NA	• Oil and gas drilling fluid	NA	NA	• Agricultural fertilizer
Rare earth elements	• Jet engines (ceramics, superalloys)	• Guidance systems • Lasers • Radar • Sonar	• Petroleum catalysts • Permanent magnets for electric motor and wind turbines • Fuel additives • Wind turbines • Nuclear applications • Rechargeable batteries • SOFC applications • Turbines (superalloys, coating)	• Fiber optics • Signal amplifiers • Cellular phones • Flat-panel displays • Hard-disk drives • Lighting • Electric motors • Sensors	• Autocatalysts • Electric motor magnets • Automotive glass	• Steel and nonferrous alloys • Chemical catalysts • Ceramics • Permanent magnets • Polishing compounds • Lasers • Optical glass • Medical imaging • X-ray scintillometers
Rhenium	• Jet engines (superalloys)	NA	• Petroleum catalysts • Land-based turbines	• High-temperature applications	NA	• Refractory crucibles
Scandium	• Aluminum-scandium alloys	• Aluminum alloys • Lasers	• Fuel cells • Lighting • Petroleum refining	• Lasers • Lighting • Phosphors • Piezoelectrics	• Fuel cells	• Catalysts • Ceramics • Flares and pyrotechnics
Strontium	• Aluminum alloys • Superalloys	• Flares, tracer ammunition	• Oil and gas drilling • Permanent magnets	• Permanent magnets • Semiconductors	• Permanent magnets • Aluminum alloys	• Ceramics • Metal refining • Flares and pyrotechnics

Table 2. Important technologies and applications by mineral commodity and industrial sector.—Continued

[NA, not applicable; SOFC, solid oxide fuel cell; PEM, polymer electrolyte membrance]

Mineral commodity	Aerospace (nondefense)	Defense	Energy	Telecommunications and electronics	Transportation (nonaerospace)	Other
Tantalum	• Jet engines (superalloys)	• Armor-piercing munitions • Aircraft components	• Land-based turbines	• Capacitors • Cellular phones • Semiconductors • Flat-panel displays	NA	• Cemented carbides • Chemical processing equipment • Corrosion resistance • Medical devices
Tellurium	NA	• Infrared devices (night-vision) • Temperature control systems	• Solar cells	• Photoreceptor devices • Semiconductors	NA	• Specialty steels • Nonferrous alloys • Thermoelectric applications
Tin	NA	• Nonferrous alloys (bearings)	NA	• Solder • Flat-panel displays	NA	• Solder • Packaging • Polymer manufacturing • Catalysts • Glass manufacturing
Titanium	• Jet engines (superalloys) • Airframes	• Aerospace • Ground vehicle armor • Artillery • Corrosion resistance	• Oil and gas drilling equipment • Corrosion resistance • Land based turbines	NA	NA	• Medical devices • Photocatalysts
Tungsten	• Jet engines (superalloys)	• Armor-piercing munitions	• Oil and gas drilling equipment • Land-based turbines • Petroleum catalysts	• Cellular phones • Contacts • Filaments • Lighting	NA	• Cemented carbides • Specialty steels • Chemical catalysts • Corrosion resistance
Uranium	• Space missions	• Nuclear applications • Support for tritium production • Naval propulsion	•Electricity production, including supporting manufacturing	NA	NA	• Medical isotope production and development
Vanadium	• Jet engines (superalloys) • Titanium alloys	• Specialty steel • Titanium alloys • Land based turbines	• Petroleum catalysts • Grid scale batteries	NA	NA	• Chemical catalysts • Specialty steel • Titanium alloys
Zirconium and hafnium	• Jet engines (ceramics, superalloys)	• Incendiaries	• Nuclear applications • SOFC applications • Land based turbines (coating)	NA	NA	• Corrosion resistance • Technical ceramics • Chemical catalysts

Another simplification used is categorization into mineral groups. Rare earth elements, for example, include yttrium and all the lanthanides. All these elements are typically present together in mineral deposits and, thus, share the same high levels of HHI and NIR. Scandium, which is often included with yttrium and the lanthanides under rare earth elements, behaves differently in natural systems and is not necessarily always present together with the other rare earths, so it is listed separately. The platinum group elements include platinum, palladium, rhodium, ruthenium, and iridium. Hafnium is produced solely as a byproduct of zirconium processing, so the two are combined on the draft list.

Notably, several materials on the draft list are recovered only as byproducts of other more-common mineral commodities. These ubiquitous materials may not meet the criteria to be included on the draft list. Tellurium, for example, is a byproduct of copper refining. Rhenium is a byproduct of molybdenum processing. Despite these codependencies, neither copper nor molybdenum is designated as critical. Other major mineral commodities such as gold, lead, zinc, nickel, and iron also are important potential sources for byproduct critical mineral production. A strategy for addressing the special characteristics of byproduct mineral supply needs to be an important part of the report submitted on implementation of the EO. Additional discussion of byproduct mineral commodities is included in appendix 1.

There are many mineral materials not included on the draft critical minerals list that are still of substantial importance to the U.S. economy. These materials are not considered critical in the conventional sense because the United States largely meets its needs for these through domestic mining and processing; thus, a substantial supply disruption is considered unlikely. Industrial minerals, for example, are the materials that form the physical basis for much of our Nation's infrastructure. These include materials for making cement (limestone, clays, shales, and aggregates); materials (such as iron and steel) used in rebar, steel mesh, and wire grids to reinforce concrete structures; and materials on which to place infrastructure, such as base courses composed of crushed stone and aggregates. These construction commodities are the largest (by volume) sectors of the U.S. mineral industries. Other important mineral materials include inputs into the chemical industries or agricultural sector including sulfur, salt, phosphate, and gypsum. The manufacturing of products such as glass, ceramics, refractories, and abrasives require quartz, soda ash, feldspar, kaolin, ball clays, mullite, kyanite, industrial diamonds, garnets, corundum, and borates. Many others could be listed.

Finally, it should be noted that mineral criticality is not static, but rather changes over time. This analysis represents a snapshot in time that should be reviewed and updated periodically using the most recently available data to accurately capture rapidly evolving technological developments and the consequent material demands.

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Appendix 1. Criticality Methodology and Other Considerations

National Science and Technology Council Critical Mineral Early Warning Screening Methodology

The National Science and Technology Council Critical Mineral Early Warning Screening Methodology (U.S. National Science and Technology Council, 2016; McCullough and Nassar, 2017) applies a country-agnostic view when screening 77 nonfuel mineral commodities. The methodology consists of two stages, starting with an indicator-based approach that then informs deep-dive studies completed in the second stage. The three fundamental indicators used in the first stage are supply risk (*R*); production growth (*G*); and market dynamics (*M*). Each indicator aims to capture a different yet complementary aspect of criticality: *R* attempts to capture the risk associated with the concentration of production in countries with low governance, *G* evaluates the growth of world production to highlight a commodity's growing importance, and *M* examines price volatility to capture the stability of the commodity's market. The outputs provided by each indicator are normalized on a common scale from 0 to 1 in which higher values indicate a relatively higher degree of criticality. This scale gives each indicator an equal weight before being combined into a criticality potential score (*C*) through a geometric mean. Each indicator is applied consistently to every screened commodity on an annual basis. Data are primarily sourced from the U.S. Geological Survey. The minerals identified in the first stage as having a statistically significant high *C* score then undergo "deep-dive" studies in the second stage designed to closely evaluate circumstances specific to each commodity.

Production Concentration

The mining and processing of many nonfuel mineral commodities has become increasingly concentrated in only a few nations (for example, Chinese refining of cobalt). This trend reflects changes in global demand for materials, comparative advantages in production (aluminum production from low-cost energy in United Arab Emirates), or government policies to secure domestic supplies of strategic materials (beryllium in the United States), whereas historic production concentrations typically have reflected geological distributions (platinum-group metals in South Africa). Highly concentrated production is an important component of criticality for geologically derived materials. Mineral production that is concentrated in a small number of countries poses a higher risk of triggering a supply disruption than a mineral with widely dispersed production. Highly consolidated supply chains have an increased risk of supply disruption from foreign government action, trade disputes, civil unrest, natural disasters, and other hazards. Production concentration was quantified using a metric of market concentration known as the Herfindahl-Hirschman Index (HHI), which is calculated as the sum of the squares of each producing nation's global production share of a commodity in a given year. HHI is used by the Department of Justice and the Federal Trade Commission to identify highly concentrated markets where firms exhibit elevated control above an established threshold of 2,500 on a scale that ranges from 0 to 10,000. Similarly, a threshold of 2,500 was used to identify commodities with highly concentrated production, and the largest producer of each mineral commodity was indicated.

United States Net Import Reliance

The United States relies on imports of many mineral commodities because domestic production is either lacking or insufficient to satisfy domestic demand by consumers. As a metric of this foreign dependency, net import reliance (NIR) is calculated as the amount of imported material (including changes in stockpiles) minus exports and changes in government and industry stocks and is expressed as a percentage of domestic consumption (U.S. Geological Survey, 2017). For example, a mineral commodity that is not produced in the United States has an NIR of 100 percent. When U.S. production of a mineral commodity exceeds domestic consumption, the United States is a net exporter. For this analysis, materials that require imports to satisfy more than one-half of domestic consumption are deemed to have a high U.S. NIR. The largest foreign suppliers of these targeted mineral commodities have been included in addition to the NIR to provide broader strategic context, which highlights that not only does the United States require foreign supplies, but that 12 out of the 26 commodities with high United States NIR are sourced primarily from China. However, high NIR should not be construed to always pose a potential supply risk. For example, three of the commodities deemed critical or near critical are primarily imported from Canada, a nation that is integrated with the United States defense industrial base.

Byproduct Commodities

Many commodities are not mined directly, but are instead recovered during the processing, smelting, or refining of a host material and are, therefore, deemed "byproducts" (fig. 1.1). These byproducts are typically chemically similar to their host material and are present in the same ores, albeit at a small fraction of the concentration (for example, tellurium in copper ores). Byproducts are almost never independently economically viable to mine, thus relying on the economics of the host material being mined, which may then yield an economically recoverable concentration of the byproduct in slag, ash, flue gasses, or other “waste” streams. The recovery of these byproducts typically is low compared to the total amount of material that was made available from mining, and recovery facility capacity poses a greater restriction on supply than geologic availability. Of the 30 commodities deemed herein as critical or near critical, 12 are byproducts, including helium, which is recovered from oil and gas extraction. Therefore, strategies to increase the domestic supply of these commodities also should consider the mining and processing of the host materials because enhanced recovery of byproducts alone may be insufficient to meet U.S. consumption.

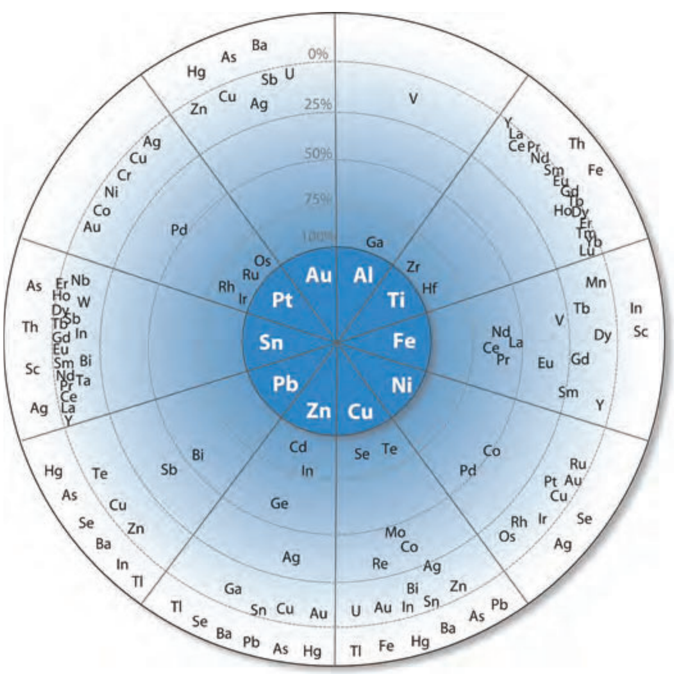

Figure 1.1. Relation between byproducts and host materials (from Nassar and others, 2015). The principal host metals form the inner circle. Byproduct elements are in the outer circle at distances proportional to the percentage of their primary production (from 100 to 0 percent) that originates with the host metal indicated.

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Appendix 2. Brief Commodity Summaries—Critical Minerals

Table 2.1. Critical mineral commodity summaries.

[Commodities are listed alphabetically. Supply chain considerations were utilized in the selection process, meaning a commodity is included if any step in its supply chain is deemed problematic. Information in this table is from U.S. Geological Survey (2017, 2018, variously dated)]

Mineral commodity	Summary
Aluminum	Historically, the United States has had a low import reliance on aluminum metal, although this has been changing in recent years because of the loss of domestic smelting capacity; moreover, production of aluminum has become increasingly concentrated in China in recent years. The larger concern for aluminum is, however, the bauxite ore, on which the United States is highly import reliant, which is used to produce alumina (the feedstock for primary aluminum smelters). Bauxite is imported from tropical regions, dominantly Jamaica, as well as Brazil, Guinea, and Guyana. Alumina imports from Australia and Brazil are important sources for specific aluminum smelters, although these imports generally are offset by alumina exports.
Antimony	Antimony is not mined domestically. The United States produces primary antimony metal and oxide from imported feedstocks and secondary (recycled) antimony from antimonial lead recovered from spent lead-acid batteries. Alloys of antimony and lead provide enhanced electrical properties to batteries. In addition to its use in antimonial lead for lead-acid batteries, other major uses are flame-retardants, lead alloys, as a catalyst for plastics, polyvinyl chloride stabilizers, ceramics, and glass.
Arsenic	Despite an abundance of domestic resources, primary arsenic metal has not been produced in the United States in decades. Arsenic is used mostly as arsenic trioxide for the generation of chromated copper arsenide for pressure-treating lumber. However, arsenic, as a metal, also has uses as a hardener for lead alloys and in gallium arsenide semiconductors. The United States is reliant entirely on imports, largely from China and Morocco. Currently (February 2018), arsenic is not recovered from end-of-life electronics. Manufacturers, however, recycle new scrap.
Barite	Barite is used overwhelmingly in the oil and gas industry as a high-density component of drilling mud, and consumption mirrors the activity of the petroleum industry. The United States is highly reliant on barite imports, largely from China, and additional concerns address the supply of high-specific-gravity material required by the petroleum industry. Recent exploration of domestic barite resources has been limited, although significant resources have been identified.
Beryllium	The United States produces about 85 percent of global beryllium mine production from one deposit in Utah, and the remainder is produced in China and other countries. Only three countries process beryllium ores into beryllium products: China, Kazakhstan, and the United States. Most beryllium is used to make beryllium-copper and other alloys, whereas 20 percent of consumption is in the form of beryllium metal, composites, and oxides. Beryllium alloys are used widely in telecommunications, electrical components, electronics, and many other products. Beryllium metal is used mainly in defense, aerospace, and nuclear applications. The Defense Logistics Agency maintains an inventory of beryllium metal in the National Defense Stockpile. The only domestic beryllium metal processing facility was constructed under Title III of the Defense Production Act and began operation in 2012.
Bismuth	Aside from small quantities of bismuth recycled from old and new scrap, all bismuth consumption in the United States is imported, mainly from China, which is the world's largest producer. Bismuth is contained in some of the lead ores mined domestically, but all lead concentrate is exported for smelting since the closure of the last primary lead smelter in 2013. Bismuth has major applications in chemicals for cosmetic, industrial, laboratory, and pharmaceutical uses. Bismuth also is used in a number of metallurgical applications, including use as a nontoxic replacement for lead. Bismuth can be replaced in many of its major applications.
Cesium and rubidium	The United States relies on imports for cesium and rubidium. Only a few thousand kilograms of cesium and rubidium are consumed in the United States every year. By gross weight, cesium formate brines used for high-pressure, high-temperature well drilling for oil and gas production and exploration are the primary applications for cesium. Rubidium is used in specialty glass and night-vision devices. The United States sourced most of its pollucite, the principal mineral source of cesium, from the largest known deposit in North America at Bernic Lake, Manitoba, Canada; however, that operation ceased mining at the end of 2015 but continued to produce cesium products from stocks. The company indicated it had sufficient stocks of raw materials to continue producing its cesium products for the near future. Rubidium concentrate is produced as a byproduct of pollucite (cesium) and lepidolite (lithium) mining and is imported from other countries for processing in the United States.

Table 2.1. Critical mineral commodity summaries.—Continued

[Commodities are listed alphabetically. Supply chain considerations were utilized in the selection process, meaning a commodity is included if any step in its supply chain is deemed problematic. Information in this table is from U.S. Geological Survey (2017, 2018, variously dated)]

Mineral commodity	Summary
Chromium	Chromium is used predominantly in the production of stainless steel and superalloys where it adds temperature and corrosion resistance. U.S. chromite reserves are small, with no mining, resulting in chromium-bearing materials being produced from imported chromite ores and ferrochromium. Globally, South Africa has the largest chromite reserves and is the leading source of chromium-bearing imports. Limited substitutes exist for chromium in alloy applications; however, recycling is extensive, accounting for about 40 percent of consumption.
Cobalt	Congo (Kinshasa) is increasingly becoming a dominant miner of cobalt, with more than one-half of world production in 2016. This production was mainly a byproduct of copper operations. Cobalt also is recovered as a byproduct of nickel mining in Russia and other countries. Like the United States, China lacks sufficient domestic supplies for its industries and, thus, has aggressively sought to secure its supplies through overseas acquisitions. Cobalt demand is expected to grow significantly because of its use in rechargeable batteries for electric vehicles and other technologies. Other uses of cobalt are in superalloys for jet engines and cemented carbides for cutting tools and wear-resistant applications.
Fluorspar	The United States is highly import reliant on foreign sources of fluorspar, chiefly Mexico, with limited domestic production. Fluorspar's uses typically are categorized into three broad categories: in the production of hydrofluoric acid, in the production of aluminum fluoride (essential for aluminum smelting), uranium processing, and as a flux in steelmaking. Fluorspar also is important in the manufacturing of welding rods. Through its use in the production of hydrofluoric acid, it is the main source of fluorine in almost all chemical applications. The United States produces fluorosilicic acid from phosphate processing; however, this potential domestic fluorine source has not been widely adopted for acid generation and metallurgical uses.
Gallium	Gallium is recovered primarily as a byproduct of processing bauxite; smaller quantities are recovered from zinc processing residues. No primary gallium has been recovered in the United States since 1987. Current production of low-grade, unrefined gallium is dominated by China; however, the United States can and does refine gallium to high-grade from primary low-grade gallium imports and from new scrap (recycled materials). Gallium finds major application in integrated circuits and optoelectronic devices such as light emitting diodes, photodetectors, and solar cells.
Germanium	Germanium is a minor constituent of some lead and zinc ores mined in the United States. The United States lacks processing facilities for recovering germanium from primary ores. Zinc concentrates containing germanium are exported to Canada and Belgium for processing and germanium recovery. The Unites States is reliant on imports of processed material or end products. Currently (February 2018), China is by far the world's largest germanium producer. Germanium is used in fiber optics, infrared optics, electronics, and solar cells.
Graphite (natural)	China is by far the largest producer of natural graphite, accounting for roughly two-thirds of world production. Only 4 percent of the world's natural graphite comes from North America, with no U.S. production in decades. Although natural graphite was not produced in the United States in 2016, about 98 U.S. firms, primarily in the Northeastern and Great Lakes regions, consumed graphite in various forms from imported sources for use in brake linings, foundry operations, lubricants, refractory applications, and steelmaking. Graphite's use in rechargeable batteries, as well as technologies under development (such as large-scale fuel-cell applications), could consume as much graphite as all other uses combined.
Helium	Helium is extracted from natural gas produced in the United States. Crude helium production exceeds domestic consumption, making the United States a net exporter of helium. Helium is used in magnetic resonance imaging, welding, semiconductor manufacturing, analytical and laboratory applications, engineering and scientific applications, and various other uses. The Bureau of Land Management manages the Federal Helium Program. Public law requires the Bureau of Land Management to dispose of all Federal helium-related assets when the remaining helium stockpile falls below 83 million cubic meters or no later than 2021.
Indium	Indium is primarily consumed as indium tin oxide, largely in flat-panel displays. Other notable uses of indium include semiconductors and low-temperature alloys. Indium is recovered as a byproduct of zinc ores. Although the United States has substantial production of zinc ore, there is no recovery of indium from ores in the United States. The United States is, therefore, exclusively reliant on imports. China is the world's largest producer of indium; however, Canada is the largest source of United States imports. New indium tin oxide (manufacturer's) scrap is recycled domestically, though there is limited information on the quantity of this production. There are no known commercial substitutes for indium tin oxide in flat-panel displays.

Table 2.1. Critical mineral commodity summaries.—Continued

[Commodities are listed alphabetically. Supply chain considerations were utilized in the selection process, meaning a commodity is included if any step in its supply chain is deemed problematic. Information in this table is from U.S. Geological Survey (2017, 2018, variously dated)]

Mineral commodity	Summary
Lithium	Lithium can be recovered from hard-rock deposits and brines. Lithium demand is expected to grow substantially because of its use in rechargeable batteries, particularly for electric vehicles. Lithium hydroxide also is used for cooling water chemistry control in pressurized water reactors and may be required in some advanced concept nuclear reactors (molten salt). The U.S. import reliance is moderate, but increasing foreign consumption in addition to U.S. demand growth has driven a substantial exploration boom.
Magnesium	Magnesium metal is produced from brines, which are virtually unlimited in comparison to demand. The United States only has one magnesium metal producer, which creates a potential single point of failure. Magnesium metal production is an important component of domestic titanium production; therefore, the loss of this domestic producer could result in broader effects. The United States only has a moderate import reliance on magnesium metal; Israel and Canada provide more than 50 percent of imports. There is substantial secondary recovery from magnesium castings and aluminum alloys that is comparable to the reported primary consumption.
Manganese	The United States has not mined manganese in decades and is reliant entirely on imports of manganese for ferroalloys, silicomanganese, and chemical compounds, and ore and alloy imports largely come from African nations and Australia. The United States does not possess economically viable resources, and manganese only is recycled incidentally during steel scrap processing.
Niobium	Most of the world's niobium production comes from one country, Brazil. Niobium is used primarily in high-strength low-alloyed steels that are necessary for infrastructure development and superalloys in the aerospace industry. Like the United States, China has no domestic niobium primary production and has invested in overseas acquisitions to secure its supplies. As developing countries construct their infrastructure and developed nations, including the United States, redevelop theirs, demand for niobium will likely increase.
Platinum-group metals	Platinum-group-metal (PGM) production is concentrated in South Africa and, to a lesser degree, in Russia and Zimbabwe. Although some primary PGMs are produced in the United States, as well as secondary (recycled) production, these are insufficient to satisfy domestic demand. Economic conditions, labor issues, and electricity shortages in South Africa in recent years have highlighted the risk associated with high production concentration in a single country. PGMs are used in a wide variety of applications ranging from electronics to anticancer drugs and biomedical devices to glass manufacturing equipment but are especially widely used as catalysts. Use in catalytic converters for the reduction of harmful emissions from internal combustion engines is essential but are likely to decrease with increased use of electric vehicles. Given their high value, PGMs have relatively high recycling rates except in their use in electronic applications because of the lack of collection of postconsumer electronics. Substitution of PGMs is limited because PGMs often are the best substitutes for other PGMs.
Potash	Potash denotes a variety of mined and manufactured salts that contain the element potassium in water-soluble form. Potash is used extensively in agriculture; fertilizers account for more than 85 percent of use, and the chemical industry accounts for the remainder. The United States is 90 percent reliant on imports to meet domestic demand for potash, and 85 percent of potash imports originate in Canada. Potash is produced in New Mexico and Utah from underground mining of ores and processing of brines. Estimated domestic potash resources total about 7 billion tons, whereas domestic reserves are estimated to be about 520 million tons. No substitutes exist for potassium as an essential plant nutrient and as an essential nutritional requirement for animals and humans.
Rare earth elements	With the closure of the Mountain Pass Mine in California, rare earth elements (REEs) are not mined in the United States. Most REEs, especially heavy REEs, are mined and processed in China. REEs are used in a wide range of applications ranging from magnets to phosphors for which there are limited substitutes. Furthermore, little postconsumer recycling happens for most of the REEs. Efforts by the Critical Materials Institute to develop substitutes and enhance recycling technologies are ongoing.
Rhenium	Rhenium is used primarily as an alloying agent in high-temperature steels for jet engines. Rhenium is produced as a byproduct of molybdenum, which itself is often a byproduct of porphyry copper mining. Although rhenium is present in domestic molybdenum-copper resources, the United States has insufficient processing capacity to meet domestic demand for rhenium. The United States ships rhenium-bearing molybdenum concentrates to Chile for recovery and imports refined rhenium. Rhenium recycling plays an important role in its global supply, but demand for new commercial and military jet aircraft will likely make it impossible for recycling alone to be sufficient. Given its high value and small market, substitution of rhenium is evaluated continually, and some substitutes have achieved commercial success. Reduced rhenium and rhenium-free alloys are being evaluated currently (2018) by major aerospace companies.

Table 2.1. Critical mineral commodity summaries.—Continued

[Commodities are listed alphabetically. Supply chain considerations were utilized in the selection process, meaning a commodity is included if any step in its supply chain is deemed problematic. Information in this table is from U.S. Geological Survey (2017, 2018, variously dated)]

Mineral commodity	Summary
Scandium	Scandium-bearing minerals are neither mined nor recovered domestically from mine tailings. The principal source for scandium metal and scandium compounds is imports from China. The principal uses for scandium are in aluminum-scandium alloys and solid oxide fuel cells. Other uses for scandium included ceramics, electronics, lasers, lighting, and radioactive isotopes used as tracing agents in oil refining.
Strontium	The United States is completely import reliant for strontium, sourcing all celestite from Mexico and other strontium compounds from Mexico, Germany, and China. Historically, the United States did have some domestic production of strontium carbonate, but this ended in 2006. Several companies do produce downstream chemicals domestically but in small amounts.
Tantalum	There has been no substantial U.S. domestic production of tantalum since the 1959. Moreover, tantalum is the only conflict mineral (the other three being tungsten, tin, and gold) whose primary production is mostly in the Great Lakes region of Africa, namely in Rwanda, the Democratic Republic of the Congo (Kinshasa), and, to a lesser extent, Burundi. Large, conventional tantalum mines in developed countries, including Australia and Canada, have largely been placed on care and maintenance indefinitely because of competition from lower-cost artisanal operations in Africa. Tantalum has a number of important uses in electronics, mainly in capacitors, and in superalloys that are used in jet engines and gas turbines.
Tellurium	Tellurium is recovered mainly as byproduct of anode slimes from certain copper refineries. Most of the tellurium contained in the copper anode slimes is not recovered currently (2018). Therefore, tellurium production in the United States and globally could be increased substantially without increasing copper production, but only under the appropriate economic conditions. Tellurium demand may increase substantially if the solar photovoltaic technology that uses tellurium, namely cadmium telluride, gains market-share. There are, however, a number of competing solar photovoltaic technologies. Aside from solar cells, tellurium's other major uses include thermoelectric devices and thermal imaging devices. Tellurium also is used in metallurgical applications.
Tin	Tin has a wide variety of end uses, including containers, chemicals, nonferrous alloys, and solders. U.S. mineral reserves of tin are small, and neither domestic mining nor smelting has happened in more than 20 years. However, tin has robust recycling from old (postconsumer) and new (manufacturing) scrap in the United States. The United States relies entirely on foreign imports of primary smelted tin; however, these imports are distributed broadly between South America and Southeast Asia. China is the world's largest miner of tin, providing more than one-third of the world's production.
Titanium	The United States is highly import reliant on titanium mineral concentrates, which have a variety of uses including pigments but also are required for metal production. The United States has a moderate import reliance on titanium metal (sponge), and imports mostly scrap and raw metal, while exporting finished wrought products. Titanium mineral reserves exist in the southeastern United States; however, these reserves are small compared to foreign supplies. Titanium recycling makes up a substantial part of domestic consumption, and few acceptable substitutes exist. Titanium is critical in aerospace components, in rotating parts in turbine engines, and for its use in corrosive environments.
Tungsten	Tungsten is produced domestically from imported materials or recovered from waste and scrap. China possesses the world's largest tungsten reserves and also is the largest producer with more than 80 percent of the world's primary production. China also supplies nearly 40 percent of tungsten material imported to the United States. Tungsten materials are widely recycled, which decreases foreign reliance. Substitutes for tungsten in high-wear and high-density applications exist and could reduce tungsten consumption, albeit at both increased price and performance loss.
Uranium	Uranium is critical for U.S. defense needs, energy production, the development of medical isotopes and energy generation in space vehicles and satellites. Current (2018) U.S. Department of Energy inventory is meeting most defense needs in the short term. However, U.S. sourced uranium will be needed in the future to meet defense requirements that, according to international agreements, must be free from peaceful use restrictions. Uranium also is critical in ensuring a reliable supply of fuel for the 99 nuclear power reactors that supply about 20 percent of U.S. electricity. Only 8 percent of uranium loaded into U.S. nuclear power reactors in 2016 was of U.S. origin; the remaining 92 percent was imported uranium. Under the American Isotope American Medical Isotope Production Act of 2012, the U.S. Department of Energy carries out a program of assistance for the development of fuels, targets, and processes for domestic molybdenum-99 medical isotope production. Uranium also is needed for production of fuel for certain space missions.

Table 2.1. Critical mineral commodity summaries.—Continued

[Commodities are listed alphabetically. Supply chain considerations were utilized in the selection process, meaning a commodity is included if any step in its supply chain is deemed problematic. Information in this table is from U.S. Geological Survey (2017, 2018, variously dated)]

Mineral commodity	Summary
Vanadium	Vanadium production is concentrated largely in a small number of foreign producers, including China (with more than one-half of world production), South Africa, Russia, and, increasingly, Brazil. The U.S. import reliance of vanadium is high, largely for consumption in alloy steel production. However, substantial domestic resources exist, although there is currently no primary production.
Zirconium and hafnium	Zirconium is recovered as a coproduct of mining and processing titanium and zircon mineral concentrates in Florida and Georgia. In addition to domestic sources of zirconium, the United States imports zircon mineral concentrates, mainly from South Africa, zirconium metal from China, as well as zirconium chemicals. Zirconium metal and hafnium metal are produced in Oregon and Utah from zirconium chemical intermediates. Typically, zirconium and hafnium are contained in zircon at a ratio of about 50 to 1, respectively. The leading consumers of zirconium metal are the nuclear energy and chemical process industries, whereas hafnium metal is used in superalloys for jet engines and land-based turbines.

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SUPERALLOYS, THE MOST SUCCESSFUL ALLOY SYSTEM OF MODERN TIMES - PAST, PRESENT AND FUTURE

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Abstract

The deep roots of superalloys go back to 1907, although the term 'super-alloy' is believed to have first been used in the mid 1940s to refer to cobalt-base alloys such as Vitallium and nickel-base Waspaloy®. During the past 50 years, much alloy, hot working, heat treating and process development has occurred, enabling many of the end use technologies we know today.

This presentation will discuss some of the history of the superalloy industry related to the superalloys 718, Waspaloy and their derivatives, including ATI 718Plus® alloy. The presentation will then describe the wide range of manufacturing techniques used for the production of superalloys, available product forms and end-use applications. Concluding the presentation will be a discussion on what advancements we are likely to see in the future.

Introduction

Superalloys are successful today because they have solved pressing demands for durability and strength in machines and systems that were barely imaginable a hundred years ago. Superalloys have helped us conquer air and space, plumb the depths of the earth and ocean, and address many other challenges of modern life.

As such, they deserve to have their story told. The nature of this industry, however, makes the telling a challenging task. Its history is one of many small events and inventions that took place across the boundaries of nations, industries and countries. Many individuals contributed to the state of the art today, and only a few left their names in the scattered records.

This paper is an attempt by one of those individuals who has been witness to many of the industry's milestones to combine eyewitness history with industry research and begin to set the story down in print. It is hoped that we can begin the dialog needed to create a complete history, and set the stage for a view of the superalloy industry's bright and exciting future.

Because it is, to some extent, a first person account, I would like to state that this paper has a bias. It is written by an engineer who spent his career working for a superalloy mill; furthermore a mill that was a pioneer in the industry. With full disclosure out of the way let me close this introduction with the following: Alloy 718, Waspaloy and their derivatives are the most successful alloy systems of our time. Their success is due to a combination of factors that include the properties and performance of superalloys in service, the added value provided by vacuum melting, the success of gas turbines and the continuous development of superalloys and the products made from them. This success was and is driven by the dedicated professional engineers who work in the industry, to whom we owe a debt of gratitude and recognition.

A Working Definition

Superalloys have been defined many times by metallurgists for books and conferences, with reasonable consistency. A few of the most comprehensive definitions follow:

1. A superalloy, or high-performance alloy, is an alloy usually based on Group VIII A elements that exhibits excellent long-time strength, creep resistance, corrosion and erosion at temperatures above 1200°F, good surface stability, and corrosion and oxidation resistance. Superalloys typically have a matrix with an austenitic face-centered cubic crystal structure. A superalloy's base alloying element is usually nickel, cobalt, or iron. Superalloy development has relied heavily on both chemical and process innovations and has been driven primarily by the aerospace and power industries.
2. Superalloys were originally iron-based and cold wrought prior to the 1940s. In the 1940s investment casting of cobalt base alloys significantly raised operating temperatures. The development of vacuum melting in the 1950s allowed for very fine control of the chemical composition of superalloys and reduction in contamination and in turn led to a revolution in processing techniques such as directional solidification of alloys and single crystal superalloys.
3. A *superalloy* is a metallic alloy which can be used at high temperatures, often in excess of 0.7 of the absolute melting temperature. Creep and oxidation resistance are the prime design criteria. Superalloys can be based on iron, cobalt or nickel, the latter being best suited for aeroengine applications. The essential solutes in nickel based superalloys are aluminum and/or titanium, with a total concentration which is typically less than 10 atomic percent. This generates a two-phase equilibrium microstructure, consisting of gamma (γ) and gamma-prime (γ'). It is the γ' which is largely responsible for the elevated-temperature strength of the material and its incredible resistance to creep deformation. The amount of γ' depends on the chemical composition and temperature.

A good working definition, although less technically precise, is: superalloys are the nickel-, cobalt- and iron-based alloys used in the hottest, most demanding components in gas turbines and oil and gas equipment. Superalloys facilitate improved operating efficiency and reduce environmental emissions.

Why are Superalloys the Most Successful Alloy System of Modern Times?

This statement may be difficult to prove but it shouldn't be too controversial, considering that no one has or will likely try to disprove it. That being said I will make the case based upon the attributes of superalloys, where they are used, and the impact of those components.

Summary of Superalloy Properties

Superalloys are all of the following, and more:

- Suitable for applications at the highest fraction of their melting point of mechanically superior alloys
- Strong and ductile at cryogenic temperatures
- Excellent oxidation resistance

- Good corrosion and erosion resistance across a wide range temperature and environments
- Able to achieve elevated mechanical properties across thick sections
- Most cost effective metal solution where the above are required for the component to be successful in service

What is it about superalloys that allow them to be successful in torturous environments?
The following is a list of attributes that, although long and comprehensive, are by no means exhaustive:

Attributes of Superalloys
- Tight chemistry control
- Gamma prime and double prime
- The ability to be hot worked to have consistent and desirable grain structure
- Excellent mechanical properties
- Responds well to heat treating
- Able to achieve elevated mechanical properties across thick cross sections
- Weldability
- Cost effective
- Performs (strength and toughness) at elevated temperatures
- Oxidation and corrosion resistance
- Vacuum melted
- Multiple vacuum melted
- Electro-slag remelted
- Triple melted
- Cleanliness facilitated by raw material selection and vacuum melting
- Hot form- and forge-ability
- Able to be coated
- Enable products of significant value to society

Technologies Enabled by Superalloys
The above attributes provide design engineers great flexibility to customize superalloys, making them suitable for diverse applications, including:
- Jet engines to power commercial and military aircraft
- Gas and steam turbines for electrical power generation
- Hot spots on aircraft where strength is required
- Space exploration applications such as Space Shuttle components
- Oil and gas exploration and production at depth and in environments too severe for steels and other metals
- Cryogenic applications.
- Biomedical implants (cobalt-based alloys)
- Fasteners for many of the above applications
- Automotive turbochargers

Our lives are touched and the quality of life improved by these technologies, which are possible in part because of superalloys, that:

- Transport us across long distances
- Secure our National Defense
- Produce electricity that power our factories, businesses and homes
- Heat our homes
- Provide fuel to power our vehicles
- Improve our mobility as we age

If growth in demand of an alloy system is a measure of success, superalloys qualify. Superalloy demand has grown from essentially zero in the early 1950's to 120M pounds in 2008, the last market peak. Growth is cyclical due to the nature of the aircraft markets, the largest consumer of superalloys. But, with few exceptions, each new market peak is higher than previous.

If increasing technology of an alloy system is a measure of success, superalloys qualify. New alloys, finer and cleaner microstructures, improved processes and expanded sizes have been the rule. Demand from its end use applications pushes superalloy technology, and expanding superalloy technology further enables end use applications to reach new levels of performance and efficiency while often lowering its environmentally impact.

If being irreplaceable is a measure of success, superalloys qualify. Since their earliest use, the predominant replacement for a superalloy is another superalloy. The replacement is more highly alloyed, alloyed with a preferred blend of elements, or processed differently to outperform the original alloy in the specific application.

If you add it all up, there is no reason to dispute the claim that superalloys are the most successful alloy system of modern times. With that case made, let me proceed and talk about other interesting aspects of superalloys.

Where Did the Name Come From?

The term "superalloy" was first used in the mid-1940s to describe high temperature alloys that could not only be used at elevated temperatures but maintained their strength and toughness at elevated temperatures. The applications were the developing gas turbine engines for defense jet aircraft. Another alternative is that the nickel- and cobalt-alloys invented for aircraft engine turbochargers or superchargers was the origin of the name superalloys.

One speculation as to the origin of the name was that "super-alloys" of a stainless variety led to improved iron-based alloys, whose name became superalloys with the hyphen dropped. This explanation has merit but leaves unexplained why the word 'super' was used or where it came from. A metallurgical origin of the name superalloy is the alloys' special blend of elements and the resulting phases created alloys not believed to be possible therefore beyond our expectations or "super."

While the specific origin of the name is not definitively known, each of the alternatives is possible. It is the writer's view that the name is a combination of all possibilities. The logic is, nickel- and cobalt- based alloys have special or super properties (maintaining strength nearly to its melting point), and a target application for these alloys was superchargers for aircraft engines. When the name was first used it stuck in the culture, perhaps because of the popularity of the comic book character Superman.

Whatever the origin, by 1960 the name was here to stay. It is interesting to note this is before most of the advancements in composition, structure, and heat treating that make superalloys the metals they are today were invented.

If the name became part of the language in the late 50s, is that also when the era of superalloys began? How far back do the roots go? The answer is that there is not one path, but several.

For me, the era began with ATI Allvac, my employer since 1980. ATI Allvac was founded in 1957 as the 'Allvac Metals Company' by James D. Nisbet. Mr. Nisbet was also a published writer. His historical autobiography, The Entrepreneur, documents his starting of Allvac and his career. Along with the personal files of Jim's brother Oliver Nisbet, Allvac's long time Vice President, this narrative forms a good starting point.

A History of the Superalloy Industry

Where does the history of superalloys begin?

The story of superalloys is a tale of four technologies: alloy composition, vacuum melting, forging, and gas turbines for jet engines and power turbines. Which one was most important? Although the technologies are entangled, the driving force was gas turbines – or, more correctly, the aircraft they powered. Without aircraft, many of the superalloys' metallurgical developments would not have been needed.

The need for temperature resistant steels was driven by the industrial revolution and its outgrowth of products. Ni, Cr and Co were added to iron before becoming its substitute. These alloys were generally called high-temperature alloys. The high-temperature name was used into the 1940s before the term superalloys emerged. For a half-century, engineers and scientists in the U.S. and Europe invented various high-temperature alloys to meet existing and envisioned needs.

Around the same time (circa 1905), vacuum melting was invented to improve the reliability of the steels of the day. Vacuum melting permitted closer control of elemental chemistries. It also prevented the unintended alloying of nitrogen and oxygen from the air into the alloy and removed gases trapped in the metals. Vacuum melting also allowed the addition of refractory elementals such as niobium as well the ability to increase and control the amounts of aluminum and tantalum.

Vacuum melting was the breakthrough that tied it all together. Complex alloys of nickel, cobalt, chrome, molybdenum, aluminum and other elements could now be merged into an alloy with tightly controlled chemistries free of non-metallic impurities. High-temperature alloys stayed stagnant, and superalloys were born with a platform for their growth: vacuum melting, vacuum induction and vacuum arc remelting.

Before this topic is left it is important to name the third ingredient resulting in the birth of superalloys. On December 17, 1903 the Wright brothers made the first successful flight of a heavier-than-air craft. The race began to create machines that could fly higher and faster. It was fueled by both commercial and defense demand, and it eventually led to development of the jet engine. Jet engine construction required metals with a balance of strength and toughness. Alloys with extreme temperature resistance that were vacuum melted – superalloys – would become the answer.

To summarize, high-temperature steels gave way to nickel- and cobalt-based high-temperature alloys that were improved by vacuum melting, creating superalloys. Demand was driven by the application of gas turbine engines to power airplanes, advancing and expanding superalloy technology.

Early Years – Pre 1950

Early Alloy Development Leading to Superalloys

The seeds that grew into superalloys were planted in 1907 by Elwood Haynes and A.L. Marsh. Haynes was an automotive entrepreneur who also tinkered with alloy development. The alloys he experimented with were attempts to meet the emerging need to lower the cost of machining auto engine components. The growing problem was that as machining rates were increased, the cutting tools of the day would wear rapidly. What was needed was an alloy that would maintain its strength and hardness at elevated temperatures. Haynes found the answer in cobalt-chrome alloys which, through future development, would evolve into Vitallium. Vitallium has been said by some to be the first superalloy.

At the same time A.L Marsh was experimenting with nickel-chrome alloys for electrical resistance applications. Ni-Cr alloys have also been said to be the forerunner of superalloys.

The following list of patents is a small representation of early alloys that led to the development of superalloys. The selections show the evolution of alloy composition as applications changed. The driving forces for development were the automotive engine, followed by the steam turbine for electrical power generation.

Alloys, Patents and Applications Leading to Superalloys

- 1906 Ni-Cr binary alloy for electrical apparatus, Patent # 811,859 by Marsh
- 1907 Co-Cr binary alloy for cutting tools used to machining automotive engine components, Patent # 873,745 by Elwood Haynes
- 1907 Ni-Cr binary alloy for cutting tools used to machining automotive engine components, Patent # 873,746 by Haynes
- 1917 Fe (47%), Cr (23%), Ni (30%, Co may be substituted for Ni) alloy for heating elements. Patent # 1,211,943 by Hunter.
- 1924 Fe (bal), Ni (3.75 – 4.75%), Al (5.75 – 6.25%), Si (1.75 – 2.25%), C 2.4 – 2.8%) alloy for internal combustion engine parts, valve head and such. Patent # 1,680,007 by Boegehold.
- 1924 Fe (bal), Cr (10-15%), Ni (25 - 40%), Co (<10%), W (2 – 5%), Nb (1 – 3%), Ti (.1 - .2%), Mn (.5 – 1%), B (.2 – 1%), C (.3 – 1.0%) alloy for blades for steam turbines. Patent # 1,489,243 by Girin
- 1924 Fe (bal), Cr (5-9%), Ni (5%), W (.25 – 1%), Si (1 – 5%), C (.05 – .6%) alloy for turbine blades and electrical heating elements. Patent # 1,555,395 by Armstrong & De Vries.

- 1925 Fe (bal), B (.75 – 4%) alloy for pistons, piston rings and valves for internal combustion engines. Patent #1,562,043 by Pacz.
- 1925 Fe (bal), Cr (2.8 – 7%), Co (.2 – 5%), W (.2 – 7%), Si (<3%), C (.2 – 5%) alloy for forgeable engine valves. Motor parts and such. Patent # 1,545,095 by Giles.
- 1930 Fe (bal), Ni (33 – 48%) alloy for internal combustion engine valves. Patent #1,759,477 by Armstrong.
- 1931 Fe (bal), Cr (1 – 20%), Al (1.5 – 4.5%), Si (<4%) alloy for engine valves. Patent # 1,850,953 by Armstrong.

Breakthrough Events in Superalloy Processing

- 1905: W. von Bolton consumable electrode arc melted tantalum in a cooled copper crucible under a low pressure of argon.
- 1917: W. Rohn first melted nickel alloy in a vacuum resistance heated furnace.
- 1923: Heraeus Vacuumschmelze A.G. founded to operate vacuum furnaces.
- 1926: Two VIM furnaces in operation melting 80 Ni 20 Cr and 65 Ni 15Fe 20 Cr for thermocouples and denture alloys.
- 1950: Dr. Mohling melts first large heat, ten tons, vacuum induction melt of aluminum and titanium containing strengthened superalloy at Allegheny Ludlum Steel laboratory in Watervliet, NY.
- 1952: Special Metals Co., New Hartford, N.Y. produces the first production heat of Waspaloy in a 6-lb furnace for Pratt & Whitney J48 turbine engine blades
- 1953: First production vacuum arc remelting of superalloys by Allegheny Ludlum Steel in their Watervliet, NY laboratory.
- 1957: First vacuum melting conference was held in New York University
- Circa 1960: Allvac Metals Co., Monroe, N.C. exclusively produces double vacuum melt (VIM/VAR) superalloys
- 1962: World's largest vacuum induction furnace (12,000 lb) installed by Allvac Metals Co. in anticipation of market acceptance and growth of vacuum melted superalloys.

Early Cobalt Alloy Development

When was the first cobalt alloy developed? An answer to this question may not exist, but what is known is a U.S. patent was awarded for a cobalt alloy in 1907. The patent, No. 873,745, was for a cobalt-chrome binary alloy, awarded to Elwood Haynes. Haynes was the founder and namesake of The Haynes Stellite Company in Kokomo, Indiana, now called Haynes International Inc. Another patent was also awarded Mr. Haynes in 1907 for a nickel-chrome alloy for electrical resistance applications. Haynes choose not to develop nickel-chrome alloys however, leaving that task to A. L. Marsh, who owned U.S. patent No. 811, 859 for nickel-chrome alloys for electrical resistance applications.

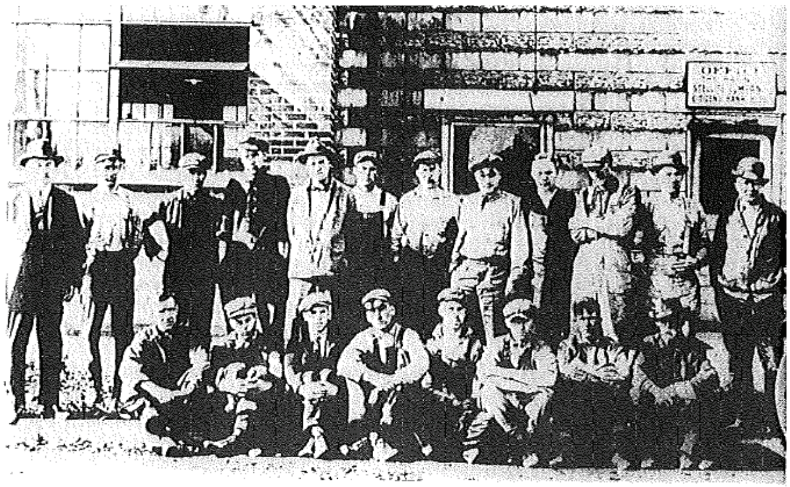


Figure 1. 1916 Photo of Haynes Stellite Employees

The first use for this cobalt-chrome alloy was knives that maintained their cutting edge and appearance because of the hardness and high luster the cobalt-chrome alloy provided, although this was not the intended application. The aim of the alloy development work, which was being done in the basement of Mr. Haynes's home, was to find an alloy suitable for contact points on spark plugs for the emerging automobile.

Automobile development was driving metalworking and machining. As automobile production volume grew and cost became a concern, improved cutting tools were needed that cut steel faster and lasted longer. Haynes' cobalt-chrome alloy proved to be the answer, and demand for it grew. The cobalt-chrome alloy's successes led to the construction of a dedicated melting plant. This plant was the first mini-mill, with a total size of 50 square feet. The business grew and in 1915 the Haynes Stellite Company was incorporated.

The success of cobalt alloys in improving the productivity of machining operations benefited many industries, including the infant aircraft industry. With the beginning of World War I, the demand for aircraft engines grew rapidly, and the demand for tooling made from Haynes's alloys grew along with it. But the leap from cobalt-alloy tooling to superalloy aircraft engine components would come later, as the aircraft industry sought to surpass the limits of the piston engine and adapt the gas turbine to powered flight.

Gas turbine development for jet aircraft in the U.S. began in 1941 when the U.S. learned that turbojet powered aircraft was being developed in England by Frank Whittle and in Germany by Hans von Ohain. A 'super-secret' facility was constructed on the site of General Electric Supercharger Division in West Lynn, MA. The facility had long worked on turbine technology to utilize the waste gases from turbochargers.

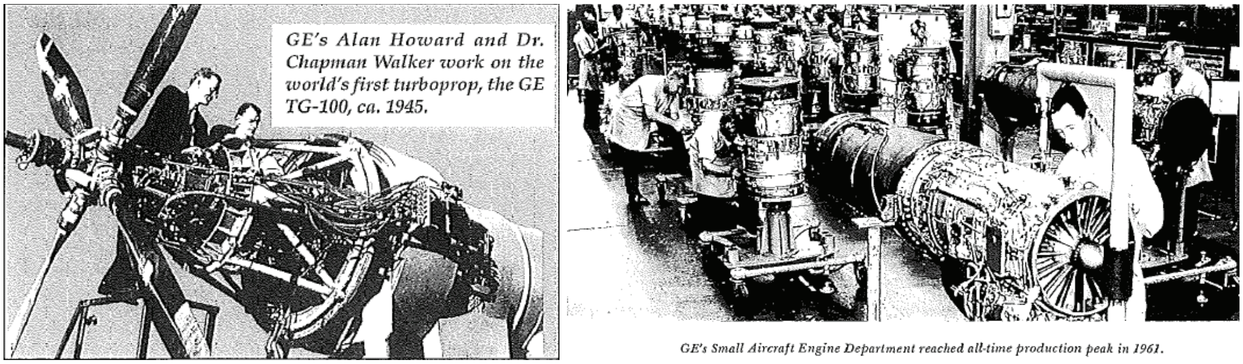


Figure 2. Early GE Jet Engine and Production facility

Meanwhile in Europe, England and Germany were flying experimental turbojet aircraft. England was reluctant to share their technology with the U.S. until the advent of war with Germany compelled them. In 1943 a British turbojet engine named W1X was delivered to the NACA laboratory in Cleveland, Ohio along with the plans for the improved W2X. The work being done in England was led by Air Commodore Frank Whittle, who became an important asset in advancing U.S. development.

The work that followed was downgraded from 'super-secret' to top secret. A modest test facility was built at the Cleveland laboratory where "spin pits" lined with wood to protect the workers from the dangers of blades flying off in all directions when engine compressors reached their limits during endurance testing.

Bell Aircraft, Buffalo, NY was tasked with concurrent development of a fighter aircraft. Prototypes failed, but development continued.

As it turned out, turbine engine performance favored flight. The low temperatures and forward motion of the aircraft created a ram effect that increased efficiency, and therefore energy, to power flight. It was also learned that a portion of the energy released by the turbine could be used for propulsive thrust in addition to powering the compressor.

German engineering prevailed and in 1944 Germany was mass-producing the Jumo 004, a turbojet with an axial-flow compressor, for the Messerschmitt 262. U.S. General Arnold was quoted as saying "The jet propelled airplane has one idea and mission in life and that is to get at the bombers, and he is going by our fighters so fast that they will barely see him, much less throw out a sky hook and slow him up." This aircraft provided super speed but came too late to change the outcome of the war.

It can be concluded from a review of historical events that the dawn of jet engines occurred between 1941 and 1943. Jet engines required better materials leading to the development of superalloys beginning around the same time, which required better chemistry and cleanliness control that led to rise of vacuum melting in the mid 1950s. It took three emerging technologies for the superalloy industry to become what it is today.

The Foundation is Laid

The products that the industrial revolution gave the world continued to be refined. Performance improvements led to the never-ending demand for metal solutions. And of course cost reduction was critical to grow market demand for the emerging products.

Electrical appliances, automobiles, more electricity to power the new appliances and higher performance engines for better performing automobiles provided an ever increasing spiral upward in demand for metal solutions and mass production. Mass production made improvements more important because they were leverages across big volumes of components and products.

History of Age Hardening

In November of 1919 at the International Nickel Company's research laboratory in Bayonne, NJ, as the story goes, a memo was placed on the desk of Paul Merica requesting development of a higher strength Monel® 400 alloy. The target application was steam turbine blades. The practice of the time was to melt a series of heats with differing chemistries to determine which had the desired effect. Aluminum levels were increased up to 5%. This work was the first of its kind on a nickel alloy to identify and take advantage of age hardening. U.S. Patent 1,572,744 was issued on February 9, 1926 for an alloy that became known as Monel K-500® alloy.

Other metallurgists, learning of the finding, began work to exploit this new technology. On April 2, 1930 U.S. Patent 1,755,554 was issued to the International Nickel Company protecting age hardening. Concurrent work in Europe was being done in Germany and France. Heraeus Vacuumscmelze of Germany patented a nickel-chrome alloy with a 6% aluminum addition in 1926 (UK Patent 286,376) and Society Anon. de Commentry of France received a patent in 1929 (UK 371,334).

The Stage is Set

The invention of turbojet engines for military aircraft in Germany by Hans von Ohain, (He-178) and Frank Whittle (W1X) in England led to the development of new age hardening alloys Tinidur (Fe-30Ni-15Cr-1.8Ti-0.08C) by Friedrich Krupp AG Hoesch-Krupp company in 1936 and Nimonic® 80 alloy by Mond Nickel Company, Ltd. in 1946 (UK Patent 583,162, December 11, 1946 respectively) Tinidur proved to not be weldable and was replaced with Cromadur (Fe-12Cr-18Mn) in circa 1944. Alloy 80 remains in use today.

High Temperature Alloys Become Superalloys in the 1940s

The automobile's internal combustion engine was adapted to power the airplane, adding demands for the alloys used for aeroengine parts. The power produced by engines grew, quickly increasing operating temperatures. New parts were also invented, such as the turbocharger and the supercharger. Flight added the aspects of risk, reliability, and strength to weight ratio to the performance of the internal combustion engine. In a car, if the engine failed, you were forced to walk. If an aircraft engine failed you would be lucky to be able to walk.

During the same time period the technology that had been developed for steam turbines began transforming, as gas turbines were developed. The need for alloys that performed at higher temperatures was similar to what was occurring in aircraft engines. These applications together provided the platforms for new high performance alloys.

The complexity of alloy composition advanced and we began to see the names of engineers we recognized and associate with superalloys on patents.

- 1945 Fe (bal), Cr (12-22), Ni (10 - 31%), Co (9 – 50%, W (2 – 6%), Mo (2 – 6%), Nb (2 – 6), C (.1 – .7%) alloy for gas turbines parts and such. Patent # 2,397,034 by Gunther Mohling.
- 1945 Fe (bal), Cr (18-23), Ni (8 - 20%), W (.75 – 2%), Mo (.75 – 2%), Nb (.15 – 1.5), Ti (.1 – 1%), Si (.4 – 2%), Mn (.4 – 3%), C (.2 – .35%), S (<.04%), P (<.04%) alloy for gas turbines and alike. Patent # 2,416,515 by Evans.
- 1945 Fe (bal), Cr (15 – 25%), Ni (2 - 25%), Co (10 – 40%), W (.5 – 15%), Mo (.5 – 5%), Al (>.5), Si (.<1%), B (<2%), C (<.35%), N (.25%), Total of .5 – 3% of one or more of Cb, Ta, Al, B alloy for gas turbines and such. Patent # 2,432,619 by Franks & Binder.
- 1946 Fe (bal), Ni (~55%), Co (5 – 15%), W (4 – 6%), Mo (13 – 18%), Al (2.5 – 3.5%), Si (.2 - 1%), Mn (.3 - 2%), C (<.15%) alloy for turbines, supercharger buckets, valves and such. Patent # 2,398,678 by Rudolf H. Thielemann.
- 1946 Fe (bal), Ni (50 - 70%), Mo (15 – 20%), Al (.5 – 5%), Mn (.5 - 4%), Si (.1 - .5%) alloy for superchargers, gas turbines and such; forgeable, machinable. Patent # 2,404,247 by Parker.
- 1947 Fe (bal), Ni (24-26%), Cr (14 – 16%), Mo (4 – 6%), Nb (1.5 – 2.5%), Si (.4 - .6%), Mn (.40 - .60%), C (.3 - .4%) forgeable, machinable, high temperature, high strength alloy exposed to airplane exhaust gases. Patent # 2,423,738 by Rudolf H. Thielemann

<u>Exploratory High-Temperature Alloy Research, 1946 – 1950</u>

In 1946 James D. Nisbet, a high temperature R&D engineer with GE Research Laboratory, Schenectady, NY, began a research project that would take four years to complete. This work, published in June 1946, proved to be more important than realized at the time in that it planted the idea in Mr. Nisbet that led to the founding of the company now known as ATI Allvac.

The foreword to *Exploratory High-Temperature Research*, written by W.E. Ruder of The Research Lab – The Knolls, does a good job of describing the environment in the gas turbine and high temperature alloy industries in 1950:

> "Early in World War II, with planes flying higher and faster, we were faced with the job of producing, quickly, alloys with high strength in a temperature range previously not seriously considered. From experience we knew that such alloys should probably contain chromium or aluminum, or both, for oxidation resistance; nickel or cobalt, or both, as bases: with wolfram or molybdenum, or both added to strengthen the matrix. We also hoped that metallic compounds, stable at high temperatures, might be found which would give us increased strength by a precipitation hardening treatment. By concentrating effort on the part of many laboratories and many trial and error experiments, some very good alloys were developed. During this period it was my constantly growing wish that someday, when we had time, a more logical and basic study of the effects of alloying might be undertaken. Early in 1946, Mr. Nisbet undertook to carry out just such a program. It was an ambitious and laborious project, involving most careful and detailed planning and close control of the many variables

encountered in melting, refining, casting, and testing. The field to be explored was almost limitless and had to be carefully surveyed before it was entered, if any new facts with broad applications were to be gleaned.

Physical metallurgy has made important advances during the past 40 years in its progress towards becoming an exact science. The effect of heat treatment and alloying on the structures of steels and in turn the effect of these structures on physical properties is now fairly well defined. Phase diagrams of the multitude of alloy combinations have been accurately determined. The mechanism of precipitation hardening is fairly well understood. The effect on physical properties of alloying pure metals except in certain limited fields, such as copper and aluminum alloys, has never been very thoroughly investigated. Our knowledge in this field is still quite empirical, and while many useful alloys have been produced, few basic principles of alloying have as yet emerged.

In the present work Mr. Nisbet and his associates have made a noteworthy contribution to the science of alloying and its effect on physical properties – broad conceived, carefully executed, and thoroughly analyzed in the light of existing knowledge. They have, through a basically experimental approach, evolved some interesting new concepts of alloying effects on physical properties, particularly in relation to temperature. Some 2000 alloys have been carefully prepared and tested for hardness, tensile strength, rupture strength at various temperatures allotropic changes, magnetic properties, and metallographic structure. The results are correlated and graphically presented. In the chapter on "Alloy Design" broad generalizations are presented - - admittedly too broad in some cases for the experimental evidence presented - - but challenging, nevertheless, and worthy of serious consideration by all who would prepare new alloys to meet new needs."

The experiment vacuum melted and centrifugal cast 6 pound heats at under 10 microns pressure and tested upward of a thousand compositions over the four years. Vacuum melting was chosen because it permitted tight control of chemistries and eliminated the random effect the atmosphere had on air melted compositions. The compositions tested were divided into four categories:

- Ternary: Fe-Cr-Co
- Quaternary: Fe-Cr-Co/Ni
- Quinary: Fe-Co/Ni-Mo/W
- Sextary: Fe-Cr-Co/Ni- Mo/W

A schematic and picture of the vacuum furnace used in the experiment are shown in Figure 3.

The results were separated and reported in two major categories. The first "Solid solutions and the effect of composition on the properties of solid solutions;" and the second, "Supersaturated solid solutions and the effect of precipitation on their properties."

The purpose of the work was to characterize alloys and the impact of alloying elements. No alloys were recommended to be put into service or patents applied for as a direct outcome of the research project. Raw materials of the highest purity were selected for the preparation of alloys and the vessel materials that would come into contact with the molten alloy were restricted to those which would not react and add impurities into the alloys.

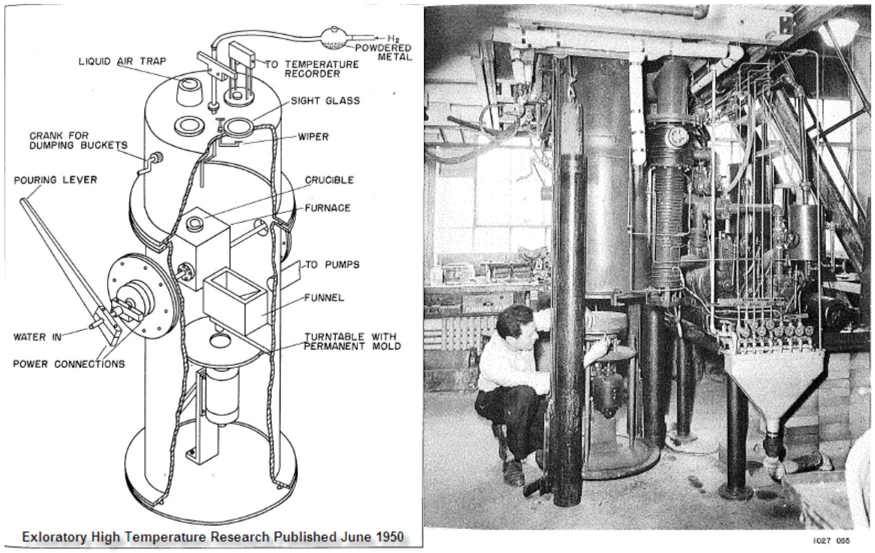


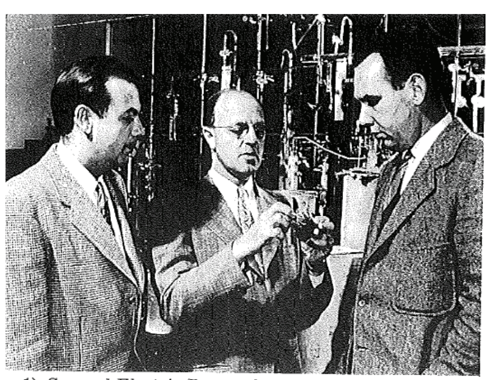
FIG. 6 VACUUM MELTING AND CASTING MACHINE

FIG. 11 VACUUM MELTING AND CASTING MACHINE - OPERATOR REMOVING CASTING FROM CENTRIFUGAL TABLE

Figure 3. 1950 VIM Schematic and Furnace

Mr. Nisbet made an interesting comment about the organization of the report, which can only be correctly stated in his original words. "Because engineers are primarily interested in the specific facts concerning specific materials, all of the data obtained on alloys tested are included in the appendix, tabulated in such a way that they may be quickly reviewed in a search for a material that will have certain desired characteristics. Because metallurgists are primarily interested in generalizations, these data are correlated and interpreted in the main body of the report." I wonder if this comment is believed true today or has the study of metallurgy advanced in the past 60 years to where metallurgists and engineers have a more common character?

The vacuum furnace and melting techniques were experimental and therefore many refinements were necessary. One of the more significant challenges was "carbon boil." Carbon was added as an aid in the removal of oxygen. The resultant "evolution of carbon monoxide from the molten metal caused during the carbon-oxygen reaction is enormous." Work to improve the process had limited success. Carbon boil caused the molten metal to splatter and therefore loss of metal was common. In addition, carbon could not be fully removed and became a variable in the experiment.



1) General Electric Research
Dr. Holloman, Dr. Suits and Nisbet

Figure 4. Drs. Holloman and Suits, GE with James Nisbet, founder of Allvac Metals Company

Superalloys in the 1950s – Emergence of Vacuum Melting

A Brief History of Vacuum Melting

Vacuum melting was first performed in 1916 in Hanau, Germany by Dr. Wilhelm Rohn and W. C. Heraeus in a vacuum induction furnace of their design. Their work, focused on steels, led to the development of clean steels that enabled aircraft engine technology including the development of turbine engines for military aircraft used in WWII Ref.22. "

In 1945 a small vacuum furnace was built at NACA to melt high temperature alloy samples for evaluation. The furnace was built using two Curtiss-Wright air-cooled engine cylinder barrels welded end to end as the shell. Crucibles with a capacity of about 150 grams were slip cast from beryllium oxide and resistance heated by a wound coil of molybdenum wire. There was no way to pour the melt into a mold, and after a heat was made, it was frozen in the crucible, which had to be destroyed to reclaim the solidified casting.

The engineer on the program, Dr. Darmara, left NACA in 1946 to return to his former employer Utica Drop Forge and Tool Company as Chief Metallurgist. The work performed at NACA was the foundation that resulted in the development of vacuum induction melting in 1952. The Metal Division of UDF later became Special Metals.

In 1946 a designed experiment was started in Schenectady by James D. Nisbet "to satisfy the basic need for a systematic study of high-temperature alloy properties to obtain fundamental relationships, It was anticipated that this would result in principles which would form the basis for design of high-temperature properties and for the empirical design of high-temperature alloys." To reduce the variability of the results, melting in a vacuum was chosen. This work was not intended to prove the benefits of vacuum melting but to simply minimize the "effects of such impurities as oxygen, nitrogen, and carbon."

The result, however, was to plant a seed in the mind of a metallurgical researcher that the future of high-temperature alloys, not yet widely known as superalloys, depended upon the benefits only vacuum melting could provide. This seed was evident by a comment in the report saying "These vacuum melting techniques have been highly successful in permitting consistent production of high-purity materials, even those containing high percentages of chromium and titanium. It should not be difficult to adapt these techniques to full-scale commercial processes where high purity is required." Based upon this body of work investigating alloy compositions and vacuum melting that conclude in 1950, the stage was set for the development of superalloys, including alloy 718 and its derivatives, to meet the demands of rotating components in jet engines and eventually land-based turbines and oil and gas production.

Benefits of Vacuum Melting

The benefits of vacuum melting can be stated as follows: "There are several excellent reasons for the adoption of vacuum melting and casting procedures. The removal of atmospheric gases from the furnace prevents contamination of the melt by those gases and minimizes oxidation. The maintenance of a high vacuum, together with the introduction of the reducing agent into the system, permits removal of oxygen already in chemical composition with the metal. As a matter of fact, hydrogen tends to reduce nitrides as well as oxides. Gases already in solution tend to come out of solution as the pressure decreases. Finally, the combination of vacuum melting and degassing techniques permits the use of such highly active additions as titanium. It must be reiterated that even though these techniques are the best available and permit clean melting of materials far richer in active elements (such as chromium and titanium) than is possible with ordinary commercial methods, absolute purity was not attained."

"By 1950 – 1951 the demands of the jet engine age and the newer high thrust engine strained the possibilities of conventional air-melting method to the limit. Vacuum induction melting was tried again to resolve the difficulties in melting requirements. This time the seed fell on fertile ground."

"While many of these titanium- and aluminum-containing alloys were developed by the more conventional air-melting techniques, it was vacuum melting which served to accelerate alloy development and gave alloys creep-strength heretofore regarded as practically unattainable. The advantages of vacuum induction melting – the prevention of contamination of the metal bath and the hardening of elements by the interstitials, the precision with which chemistry could be controlled, the distilling off of "tramp" or low melting elements, and the overall cleanliness, gave to the aircraft engine consistency and strength that were critically needed. Vacuum induction melting became such a popular solution that there was a concentrated effort to put everything in a vacuum furnace."

The following comment made by Rudolph Thielemann in 1967 in a presentation to the European Investment Casters Federation is a testimonial to the role vacuum melting played in the success of superalloys and their role in gas turbines. "Since the early work on the exhaust gas driven turbosuperchargers, a great deal of progress has been made in developing high temperature alloys for critical gas turbine applications. In this effort, the development of new processes and techniques for melting, consolidating and casting the alloys has been very important. The introduction of the (vacuum) melting furnace has furthered the metallurgical progress in the alloy development more than any other single factor."

<u>Superalloy Producers and Trademark Names of the 1950s</u>
Allvac Metals Company, Monroe, NC
Allvac used two trade names. When the alloy was double vacuum melted (VIM/VAR) it was called "Allvac," as in "Allvac 718." When the alloy did not require VIM as its primary melt practice but was remelted using either a VAR or electro-slag remelt (ESR) practice, the trade name used was "Nickelvac," as in "Nickelvac X".

Other industry trade names are:

Hastelloy and Stellite – Haynes Stellite Company, Kokomo, IN
Inconel and Incoloy – Huntington Alloys, division of International Nickel Company
Nimonic – Mond Nickel Company, Ltd
Unitemp and Udimet – Special Metals Company, division of Utica Drop Forge

Trademarked names of alloys of the era still used today are:

Astroloy – Pratt and Whitney
René– General Electric Company Waspaloy – Pratt and Whitney

In the 1950s, superalloys comprised approximately 10% of a jet engine. This proportion grew to 50% by 1990 and has maintained this position in spite of the growth of competitive materials such as titanium, steels, ceramics and composites. The following is a list of producers of gas turbine, the engine model number and aircraft that were in production in 1959. Evolution and revolution occur in an industry over fifty years. This list shows some of the changes.

<u>Gas Turbines for Aircraft in 1959</u>

- Allison Division of General Motors, Indianapolis, IN
  - 501 turboprop, 726-740 lbs. thrust, for the C130
- Armstrong Siddeley Motors Ltd., Parkside, Coventry, England
  - Sapphire turbojet, 11,000 lbs. thrust, for the Hunter and Javelin
- Bristol Aero-Engines Ltd., Filton House, Bristol England
  - MK200 turbojet, 16,000 lbs. thrust, for the Vulcan
- Continental Aviation & Engineering, Detroit, MI
  - 356 turbojet, thrust not determined at the time
- Fairchild Engine Division, Deer Park, NY
  - J83 turbojet, 2,000 lbs. thrust, for a classified aircraft
- Pratt & Whitney Division of United Aircraft, East Hartford, CT
  - JT 3 and J57 turbojets, 9,700-16,900 lbs. thrust, for the B-52, F-100 (in 1959??), KC-135, DC-8, B707, B720
- SNECMA, Paris, FR
  - Atar 9 turbojet, 13,227 lbs. thrust, for the Mirage
- Westinghouse Electric Corp., Aviation Gas Turbines, Kansas City, MO
  - J34-WE46 turbojet, 3,400 lbs. thrust, for the T2J
- GE Aviation
  - J47, J79, J85, J93 turbojets

<u>ATI Allvac's Beginning Years</u>

James D. Nisbet, after working in research for GE, joined Universal Cyclops. His role was to build a research center for vacuum melting. Mr. Nisbet's interest was in high temperature metals. However, the work in the facility was by no means restricted to cobalt- and nickel-based alloys. As was the case in the industry at the time most vacuum melting was done on specialty steels. Jim became restless before long and asked for the resources to build a greenfield production plant for vacuum melting. Universal's leadership at the time is said to have believed vacuum induction melting to be a good laboratory process, but would not make a profitable business venture. As was often the case, Jim's convictions were strong. He left Universal Cyclops and went on the road, literally driving to visit his friends in the industry to sell shares in his future company, the Allvac Metals Company (short for "All Vacuum Melted.")

Jim chose Monroe, NC as the site for his company. Why Monroe? Monroe was certainly not a metals center. In fact it was the opposite: a small southern agricultural community. But Monroe had a train station so visitors could get there and natural gas was available to power the planned heating furnaces. It was close to Charlotte so it could be found on a map. And it was close to Jim's home, a farm just across the state line in Van Wyck, SC. Finally, the location was close to the home of Jim's brother Oliver, who would be a significant source of funding for the new company and its initial sales executive.

To raise money, additional shares were sold to the public. The underwriter was Interstate Securities Corporation, Charlotte, NC. The purchases of shares were over-subscribed. The capital was used to "set up a budget to include the purchase of equipment, inventory and to reserve sufficient working capital for initial production." Comments from Allvac's early employees say this may have been the last time that the Allvac Metals Company had excess working capital considering the rapid growth that followed.

In September 1957 Allvac began business with groundbreaking for the installation of a 500 lb. vacuum induction melting furnace. On September 16, 1958 the first VIM heat, Waspaloy, was melted. While this was being accomplished the company's rolling mills were being installed and plans were in place to ship its first order by year end. Market conditions were changing, with stretch-outs in defense aircraft build rates, but the emerging market for commercial aircraft helped buoy the market for superalloys. It is interesting to note that at this time another market was exploring the use of gas turbine…the automotive industry. This led to a handful of cars powered by turbine engines but of course this application for superalloys never materialized.

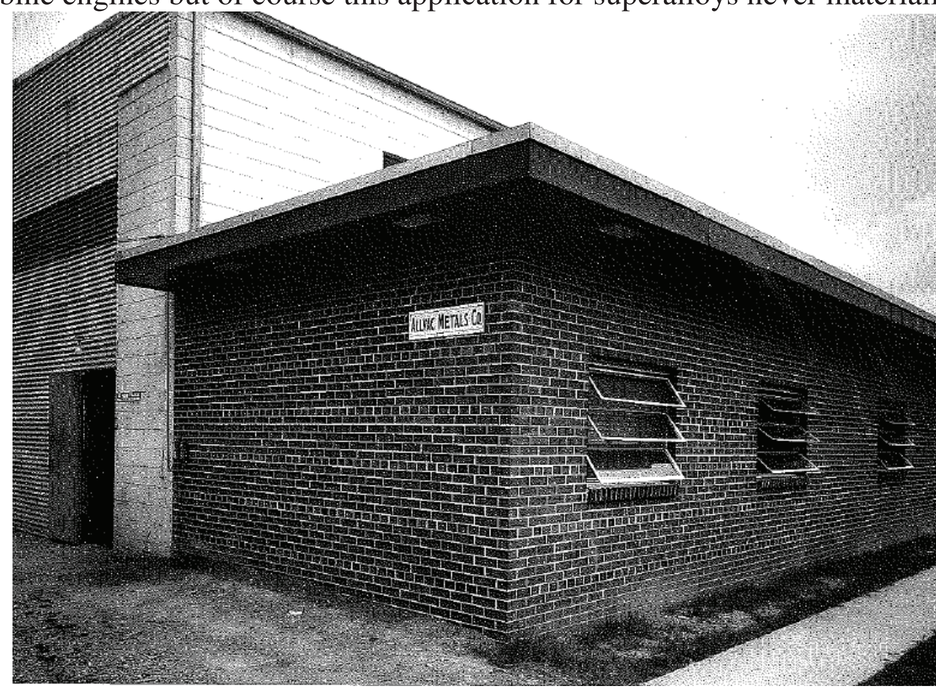


Figure 5. Allvac Metals Company, Monroe NC, 1958

Figure 6. Boeing 707 Maiden Flight December 20, 1957, powered by 4 – P&W JT4s or Rolls-Royce Conway Turbojets. First Passenger Flight October 26, 1958 by Pan American World Airways

In 1958 the company's primary alloys were Waspaloy and René41. The products produced were: ingots from 150 lbs. to 1500 lb, billets from 3″– 8″ diameter weighing up to 1000 lb, bars from .5″– 3″ diameter, plate .187″– 2″ thick x 20″ wide, and strip .060″ x 12″ wide. These products were made internally using the following equipment: 17″ x 35″ breakdown mill, 10″ x 20″ bar mill, centerless grinding and lathes for bar finishing, and swing grinders for conditioning

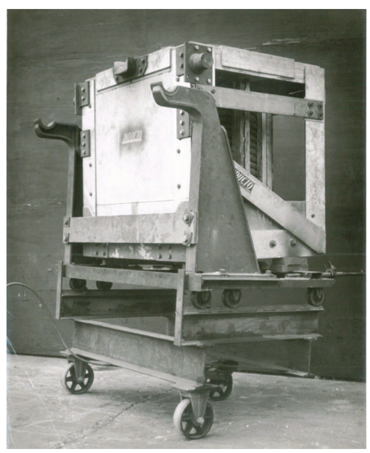
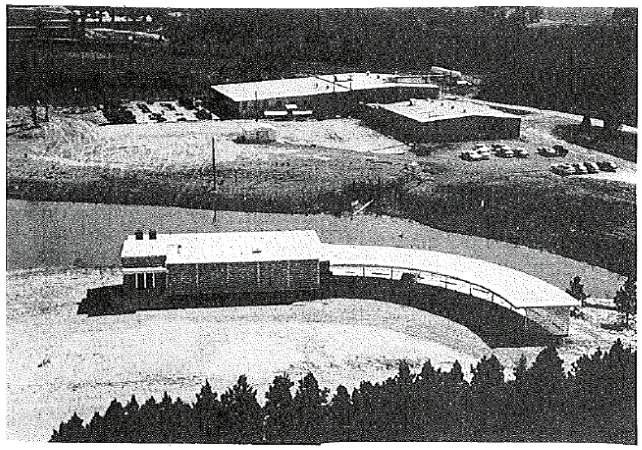


Figure 7. Allvac's 500-lb VIM Furnace

1959 was Allvac's second full year of operations and its first year of profitability, with total net income of $55. The story goes that this was a surprise to Jim so he went to discuss the issue with his finance executive. When asked what he had to do to show a profit, the financial chief simply said "that's the way it worked out." This level of integrity was a core characteristic of the company that still exists today.

VIM capacity was expanded to 3500 pounds and billet capability increased to include 12″ – 14″ billet weighing up to 2500 lb. By September 30, 1960, year-to date sales for three quarters were $493.393.53. This was respectable growth, considering the value of money in 1960 and that the company was just three years old.

Around 1961 Allvac took the position that it would only make and sell double vacuum alloys, regardless of specification. This position separated the company in the marketplace from other producers and set the stage for the consumers of superalloys to see the benefits of vacuum melting. The difference was, and still is, improved cleanliness that resulted in improved forgeability and superior properties for the end user.



The new laboratory office building containing 5,600 square feet was completed and occupied in September, 1961.

Figure 8. Allvac Metals Company 1961

In 1962 a 16,000-lb VIM furnace was added, giving Allvac the world's largest VIM furnace. VIM furnaces were also being operated by Universal Cyclops (2000 lb.), GE (500 lb.), Carpenter Steel, Allegheny Ludlum, Firth Sterling and Special Metals. By comparison ATI Allvac today operates many VIM furnaces in three facilities, with the largest pouring 50,000-lb ingots. Internal ingot breakdown capability was also added with the addition of a 2200 hp reversing blooming mill began rolling superalloys in 1963. To make ends meet, Allvac also melted and produced magnets. With the growing success of superalloy sales the Allvac Magnet Co. was discontinued.

By 1963 the superalloy industry, still referred to as high temperature alloys by many, was in a full growth mode. Pilot plant production methods were replaced by high volume production operations. Allvac operated its new 16,000-lb VIM feeding two VARs, one 12″ and the other 24″ in diameter. Vacuum melting had taken hold in a big way. The Allvac Metals Company's 1963 Annual Report described the state of the industry:

> "The plan is an optimistic one in which management has confidence. Like in all projected plans, "ifs" are important factors. If our share of the market is obtained; if prices become stable; if manufacturing costs continue to improve; if technical can meet the rigid specification requirements; and, if needed operating funds can be obtained, the plan can be achieved. Innovation is the answer to these "ifs" and in this department, Allvac leads the industry."

This statement is still true today at companies across the gas turbine and superalloy industries.

As of 2010, the Allvac Metals Company, now named ATI Allvac continuously produced superalloys for 53 years.

The 1960s and Beyond – Growth of the Superalloy Industry

By 1960 the melters of superalloys were a mixture of steel companies, forging companies with their own melt shops and one entrepreneurial company established in 1957 to specialize in superalloys. Between 1960 and 1965, vacuum induction melting became the standard for producing high temperature alloys, with the specialty steel companies, who were slow to accept the technology, being the large customers. Firth Sterling and Carpenter Steel soon installed VIMs.

The size of VIM furnaces expanded significantly as 'steel' mentality was superimposed on the emerging vacuum melting industry. In a 1963 AMM press release it was announced that a 60,000-pound vacuum furnace called Therm-I-Vac would be installed in Latrobe, PA. The company president was paraphrased as saying "Sooner or later all quality steels will be produced by vacuum melting techniques to eliminate gases and other impurities from the molten metal."

The Therm-I-Vac process was not a VIM but instead "steel made in electric furnaces, in the usual way, is poured from a ladle into an electric induction furnace housed inside a vacuum chamber. As the molten metal enters the vacuum, it literally explodes into thousands of tiny droplets as the vacuum sucks undesirable gases out of the steel." This furnace along with consumable vacuum remelt furnaces started production in 1964. It is concluded that the Therm-I-Vac furnace later was converted into a 30,000 pound VIM furnace still operated today.

This technological wave was unstoppable. Steel companies and steel forgings companies entered the vacuum melting business. The race was on to see which companies could capitalize on the trend to vacuum melt and who would operate the best, largest vacuum furnace.

The trend peaked in 1968 when Cameron Iron Works in Katy, Texas installed what was then the world's largest VIM furnace, at 120,000 lb capacity. It was built in a 120,000 square-feet facility housing the VIM furnace, a 50-ton 18,000 KVA electric arc furnace, a degassing chamber, and associated equipment. An article announcing the expansion quoted CIW as saying:

> "At the present aerospace is the biggest consumer, but oceanography may be just as big in the future. As man advances into space, metal requirements become more complicated because of heat and pressure, and the same is true in the ocean. As man presses his search for minerals and oil on the ocean floor, our research will have to keep pace."

CIW's strategy appeared to be based on a belief that the melting of specialty steels was moving from air melting to VIM. This transition didn't fully materialize, however; and in the early through the mid-1980s this furnace was melting 60,000-lb VIM heats, primarily of superalloys, and was dismantled in the late 1980s. CIW's comment, made over 40 years ago, has been proven nevertheless to be largely correct, although it did not anticipate the dramatic growth of commercial aerospace, keeping the aerospace industry the largest consumer of superalloys.

<u>Alloy 718: The Most Widely Used Superalloy</u>

In the world of superalloys, Alloy 718 is considered by many as the most successful and versatile nickel-based alloy ever invented. It is used extensively in the aerospace, power generation and oil & gas markets for highly engineered critical components in hot corrosive environments.

Additionally, its derivatives, such as alloys 706, 925 and ATI 718Plus® are also used in substantial quantities.

Alloy 718 was patented on July 24, 1962 by Herb Eiselstein to meet the demands of emerging jet engine technology. The patent was applied for in 1958. After nearly four years and two amendments, the patent was issued. Alloy 718 replaced highly alloyed steels and nickel-based superalloys.

The versatility of Alloy 718 is seen in the number of individual chemistries, melt regimes and forging (billetizing) practices. The permutations of these characteristics are greater than 2000! While every discrete permutation is not used, the number that are used is substantial. It is easy to conclude that Alloy 718 is versatile.

- Over 20 different chemistries of Alloy 718 are melted.
- 7 melt schemes are employed to melt Alloy 718 with many having multiple practices. (i.e. different melt rates)
- The hot working practices using presses, radial forges and large and small rolling mills, to meet end use mechanical and structural requirements, are too numerous to accurately estimate.

In addition to mill products, Alloy 718 and its derivatives are cast into parts. Some of the alloys such as Alloy 720 are vacuum atomized into powder that are HIPed into mill products and near net shape components for critical applications.

Alloy 718 has been in use for nearly 50 years. Will it be King forever? It is securing its place on the newest commercial engines (GEnX, Trents 1000 & XWB) for next generation aircraft (Boeing 787, Airbus XWB) as well as the latest gas turbine engine derivatives (F136) for the next generation of defense fighter aircraft (JSF).

The 718 family of alloys will have a dominant place in gas turbine engines for commercial and defense aircraft, gas turbine engines for municipal, industrial and marine power generation and downhole and above ground control devices for oil & gas exploration and production for many years to come. It is safe to say that its life span could approach 100 years.

<u>The Early Growth Years</u>

Brochures from companies producing superalloy in 1960 advertised the grades shown below. The predominant practice for melting ingots, air melt, was followed by remelt in a vacuum arc remelting furnace (VAR). The least used but the fastest growing approach was double vacuum melted ingots produced using vacuum induction melted (VIM) electrodes followed by VAR.

Grades produced in 1960 included:

- Astroloy
- Alloys B, C, D, N, W, X
- Nimonic 75, 80, 80A, 90, 95, 100, 105
- Alloy M-252
- Inconel 713C
- Alloy 700

- Alloy 718
- Waspaloy (trademark of Pratt & Whitney Aircraft, 1946)
- Rene 41
- Udimet 500ZB
- Alloy 901
- IN-100
- Vitallium
- Alloy L-605
- Alloy A 286 (iron-based superalloy)

Trade Names

A practice in 1960 was for mill producers to modify the chemistry of an existing nickel-base alloy and give it their own trade name. Often the alloy's number was not changed. The confusion this entered into the marketplace was significant considering the substantial difference in competing alloys of the same name except for the trade name. Examples of this include:

Hastelloy W	Ni 60%, Mo 25%, Cr 5%, Co 1%, V .3%, C .08%
Inconel W	Ni 74%, Mo 0%, Cr 15%, Co 0%, V 0%, C .04%, Ti 2.4%, Al .6%
Inconel 700	Ni 44%, Mo 3%, Cr 14%, Co 29.5%, C .1%, Ti 2.5%, Al 3.0%
Udimet 700	Ni 53%, Mo 5%, Cr 15%, Co 18.5%, C .12%,Ti 3.5%, Al 4.25, B .08%

Key Events

The following excerpts were taken from articles, press releases and company annual reports from their respective years. The size of VIMs built is surprising. Some of the actual period information contradicts what was operated in the 1980's and beyond.

1963

- Latrobe Steel Company "…installation of the most complete and flexible vacuum melting facility in the industry…" VIM "Therm-I-Vac and VAR
  - "After steel is made in an electric furnace in the usual way, it is poured from a ladle into an electric induction furnace housed inside a vacuum chamber. As the molten metal enters the vacuum, it literally explodes into thousands of tiny droplets as the vacuum sucks undesirable gases out of the steel." J.E. Workman, President Latrobe Steel Co. in a Metal Market Article in 1963.
- The Vanadium Alloy Steel Company or VASCO operated CVM, consumable vacuum melting, furnaces producing from 3,000 to 26,000 lbs. heats. The ingots were for research and production.

1964

- Superalloy market reported to be $20M
- Union Carbide's Stellite Division, Kokomo, IN producing vacuum melted alloys (VAR) went into full production
  - "Improved ingot surface"
  - "Carbide segregation and "freckling" (undesirable intermetallic compounds) have been eliminated."
  - 30″ dia. 15-ton ingots

- Eastern Stainless Steel Corp., Baltimore MD, formed Kastalloy Metals Co. to produce and distribute remelted alloys for the casting industry.
    - 718 cryogenic fuel lines for the Saturn C booster rocket, Waspaloy engine components for the new A11 supersonic fighter, A286, Rene 41, Astroloy, N-155, L605, and Hastelloy all for jet engines.
  - Special Metals, Inc. (recently separated from Kelsey-Hayes and prior to being purchased by Allegheny Ludlum) begins operating an 11,000-lb VIM.
  - Mill product pricing by the piece instead of by the pound is encouraged by the aerospace industry. An executive of the time was said to have found piece pricing a new concept and was quoted as saying he "would have to sleep on it." The change was considered another way of negotiating lower pricing.
- 1965
  - Allvac was purchased by Vanadium Alloy Steel Company Cameron Iron Works, Houston, TX is world's largest vacuum melter
    - Integrated company operating VIM and VAR (34″diameter), billetizing and forging.
    - Operated a 10ton VIM in Livingston, Scotland and two VARs
    - "Vacuum melted high density nickel based alloys in billets, bars, slabs, sheet and plate."
    - Discs, engine shafts, turbine wheels of 901, Waspaloy, Astroloy, 718, A286
  - Universal-Cyclops Steel Corp. renamed to Cyclops Corp.
- 1966
  - Special Metals Corporation, New Hartford, NY, a subsidiary of Allegheny Ludlum, began construction of a 30,000-lb VIM. Operation began in 1967
    - Doubled VAR capacity by adding 2 additional VARs
  - Latrobe Steel Company, Latrobe PA, operates VARs
- 1967
  - Cameron Iron Works installs a 60ton VIM at its new facility In Cypress, TX. Also installed were hot and cold rolling mills roll gauges down to .008″. This expansion targeted superalloys for rotating parts for the growing aerospace industry.
  - Superalloy Capacity (believed to be VIM capacity not mill product capacity)
    - 1957: 750 tons
    - 1967: 90,000tons
- 1968
  - U.S. produced 80% of jet engines for the "free world market."
  - The buildup of engine production due to the Vietnam War was projected to end by 1971.
  - The military accounted for 80% of turbine and turboprop engines through the middle of the 1960s. Production peaked at over 14,000 engines.
  - Commercial engine production was forecast to reach 5000 engines annually by the end of 1970
  - Key military programs included F-111, A-7, Air Force FX and Navy VFAX

Alloys and Applications

The following charts were presented by Rudolph Thielemann, at the European Investment Cast Federation Conference in 1967, showing primary alloys used for turbine components of the day.

High Temperature Alloys Used For Turbosupercharger Blades and Discs

17W alloy wrought blades/discs Ni 19%, Cr 12%, W 2.2%, Mo 1%, C .5%, Fe bal
16-26-6 wrought discs Ni 25%, Cr 16%, Mo 6%, C .1%, Fe bal
Vitallium cast blades Cr 27%, Mo 6%, Ni 2%, C .25%, Fr bal
6059 cast blades Ni 32%, Cr 23%, Mo 6%, C .4%, Fe bal

Air Melted Cobalt Base Alloys for Turbine Blades and Vanes

X-40 cast turbine blades/vanes Cr 25%, Ni 10%, W 8%, C .4%, Co bal
WI-52 cast turbine vanes Cr 20%, Ni 3%, W 11%, Nb 1.5%, C .4%, Co bal
S-590 wrought turbine blades Cr 20.5%, Ni 20%, W 4%, Mo 4%, Nb 4%, Co bal
S-816 wrought turbine blades Cr 20 %, Ni 20%, W 4%, Mo 4%, Nb 4%, Co bal

Gas Turbine Disc Alloys

Discaloy wrought turbine disc Cr 13.5%, Ni 26%, Mo 2.7%, Ti 1.7%, B .005%, Fe bal
A-286 wrought turbine disc Cr 15%, Ni 26%, Ti 1.7%, B .005%, Fe bal
Rene 41 Cr 19%, Mo 10%, Co 10%, Ti 3.1%, Al 1.5%, B .005%, Ni bal
Waspaloy Cr 19.5%, Mo 4.3%, Co 13.5%, Ti 3%, Al 1.3%, B .006%, Zr .06%, Ni bal
U-500 Cr 18%, Mo 4%, Co 18.5%, Ti 2.9%, Al 2.9%, B .006%, Zr .05%, Ni bal
U-700 Cr 15%, Mo 5.2%, Co 18.5%, Ti 3.5%, Al 4.3%, B .03%, Ni bal

Vacuum Melted Wrought Nickel Base Alloys

Alloy 901 wrought turbine disc Cr 12.5%, Ni 42%, Mo 6%, Ti 2%, B .005%, Fe bal

Was there ever an 'Inconel' alloy?

Today, the term 'inconel' is improperly used to describe alloys 600, 718, X750 and their derivatives. This common mistake is made in discussions, formal papers and patents by technical and non-technical people employed by companies ranging from independently owned machine shops to multinational engine primes worldwide.

The original Inconel was a trademarked alloy family developed and marketed by Huntington Alloys in the formative years of the superalloy industry. The original Inconel's chemistry was Ni 78%, Cr 14.5%, Fe 7%, C .05%, and closely resembles alloy 600☹ Ni 72%, Cr 15.5%, Fe 8%, C .075%). Huntington's development was funded by the International Nickel Company as an outlet for the nickel they mined. The alloys developed include alloy 718 and its derivatives, the namesake of the conference for which this paper was written. Early success and strong marketing helped transform the Inconel brand into the industry ubiquity that it is today, similar to Kleenex, Jell-o and other trademarks that have become generic through common misuse.

The Story of Boron

Boron plays an important role in helping refine the structure of superalloys. Did the innovation of boron control come from research or chance? Here is what happened.

All-prime raw materials were used to make superalloy heats until volume grew. When volume grew, so did the need to cut costs. One step taken to reduce cost was to use scrap as part of the charge design. Before long, it was noticed that heats melted using scrap had improved properties. The investigation that followed found the significant difference in heats with and without scrap was the boron level. Studies confirmed this, and boron's role in alloy 718 and other superalloys was solidified forever.

Where did the boron come from? Boron was a residual in scrap from ingots that were air melted only by companies whose primary products were specialty steels. The revert (internal scrap) streams in these companies contained boron passed on from prior heats. Therefore, when revert was used in the charge makeup, boron was inadvertently added though not specified.

A Brief History of Superalloy Powder

Powder Metallurgy (PM) superalloys have been used in aircraft turbines for approximately 40 years. They originated from the contributions of many scientists and engineers in both government and private industry. The first commercial development began with vacuum induction atomization at the Federal-Mogul laboratory in Ann Arbor, Michigan. Although a request for quotation for high purity superalloy powder was released by Wright-Patterson Air Force base in 1965, subsequently produced by Hoganaes, early development was primarily driven by Pratt & Whitney Aircraft. They believed that powder metallurgy would be an improved method for making superalloys for highest temperature, highly stressed parts for a new generation of fighter aircraft engines. The time frame was the late 1960s.

The earliest development involved PM Astroloy, an alloy similar to cast/wrought 700. Pratt & Whitney then selected a vanadium bearing, higher cobalt, lower molybdenum alloy named IN-100, originally developed as a cast/wrought alloy by the International Nickel Corporation. Pratt & Whitney experimented with as-HIP compacts that were isothermally forged, but chose to move to HIP and extrude, or direct extrusion. Full scale consolidation was performed by hot extrusion at Cameron Iron Works in Texas who had been using hot extrusion for manufacture of oil field equipment. The superalloy extrusions were cut into sections and isothermally forged into disc preforms for high pressure turbine disks for the F-100 engine to power the F-15 fighter.

During the early 1970s, General Electric was developing Rene 95 using cast/wrought methods before cross rolling to heavy plate. This proved to be a difficult task. GE approached the Crucible Steel Company, Pittsburgh, PA, owned by Colt Industries, to manufacture Rene 95 in their 600 pound atomizer. Under construction was a new facility in Oakdale, PA which would house a 5000-pound vacuum induction atomization unit and a 45″ diameter HIP unit purchased from Battelle Laboratories. This facility is now ATI Powder Metals.

The first Rene 95 qualification heats were produced in the 600 pound research unit and the powder transferred to the Oakdale facility for screening, canning, evacuation, and hot isostatic pressing. Rene 95 was initially applied in the T-700 engine for the U.S. Army's Blackhawk helicopter. GE also used the alloy in the as-HIP and heat treated condition for the turbine spool of the F-404 engine for the F-18, the F-110 engine for the F-16 and eventually the B-1 bomber.

Federal-Mogul was acquired by Special Metals Corporation and became qualified for Rene 95. Rene 95 powder was also purchased from Carpenter Steel.

In 1980, at the Farnborough Air Show, an F-18 experienced engine failure attributed to an as-HIP René95 turbine disc. GE Aircraft elected to remove PM superalloys from all parts where it was not absolutely necessary and inserted direct age 718 alloy process by cast/wrought methods. The remaining PM parts were processed using extrusion and isoforging. As-Hip material remained in military versions of the T-700 Blackhawk engine until 1987 and is still used today as an alternative for high pressure turbine blade retainers where fatigue was a secondary failure mechanism. René88 DT eventually replaced almost all Rene 95 extrude and isoforged material.

During the early 1980s Snecma, the French turbine manufacturer, began utilizing as-HIP low carbon Astroloy for military fighter engines and eventually developed N-18, a lower cobalt, higher molybdenum alloy similar to IN-100 without vanadium but with a small hafnium addition.

By the mid-1980s the aircraft turbine industry had moved to a unified philosophy of one alloy in finer powder forms, extruded to full density and isothermally forged into near-net preforms or mults from which individual parts were produced. At the same time Garrett AiResearch, who became Allied Signal Inc. before becoming Honeywell, adopted the as-HIP philosophy for auxiliary power unit turbine discs. While propulsion engines, particularly fighter jet engines, experience many throttle changes during flight, requiring extended low cycle fatigue life as engine loads rise and fall, auxiliary power units run more like diesel engines, rising to full load after startup and running steadily in this range for nearly entire flights. This design philosophy must recognize creep and high temperature strength as primary failure modes with low cycle fatigue as a secondary failure mode, much like the role of a high pressure turbine blade retainer ring in a propulsion engine. As-HIP material filled this role very well. In addition to costing less than an extruded + isothermally forged part, as-HIP material could still withstand a higher sensitivity and more rigorous non-destructive ultrasonic inspection than cast and wrought materials, and was typically easier to machine. The nearly isotropic properties enjoyed in an as-HIP disc also simplified design criteria across the hub, web, and outer rim of a small disc. Garrett utilized PM low carbon Astroloy, a slightly lower carbon variant of the original material created in Ann Arbor Michigan at Federal Mogul. Special Metals Corporation and Crucible Compaction Metals became qualified sources. It is still in widespread use today along with PM alloy 720, chemically similar to the original cast and wrought Udimet 720.

While the large engine manufacturers in the United States were developing their PM superalloy processes, Rolls-Royce engineers utilized cast and wrought alloys including 718 and 720 alloys as their disc materials. Rolls-Royce recently introduced RR1000, a superalloy containing tantalum and hafnium, in the Trent 1000.

This brief history of the development, primarily in United States, of PM superalloys, cannot give proper credit to the many engineers at industry laboratories and government installations, including NASA and the US Air Force. It is merely an attempt to provide an overview of the timeline that moved superalloy powder from a laboratory experiment to a core technology of military and commercial aircraft turbines.

Specification Evolution

Alloy 718 Specifications

The first issue of AMS 5662 was dated 9-1-65. It has been revised a dozen times with the current revision being ‘M’. Through the years and specification revisions the properties of metal produced to the specification is essentially unchanged. Major element percentages and their ranges have not changed although a few additional elements are now controlled that were not listed in 1965. Tensile and yield strength, heat treat parameters and grain size requirements are the same with only transverse elongation and reduction of area properties having been reduced.

The first end user specification identified for alloy 718 was issued on 3/20/62. Revisions have exceeded AMS revisions up to three times. Chemistry percentages and ranges of major elements are largely unchanged but most minor elements are more tightly controlled. As with the AMS 5662, elements are now controlled that were not initially specified. In 1962 single vacuum melting (VIM) was permitted where double melting is now required (VIM + consumable remelt). Grain size, not specified, in 1962, is typically controlled to requirement finer than the AMS specification. The 1962 four page specification has grown to as many as nine pages.

Waspaloy Specifications

The new issue of AMS 5708 was dated 7-15-63. It has been revised ten times and has grown from three to ten pages. Single melting in a VIM or double melting with the second melt being a consumable remelt is unchanged over the forty-six years that have passed since the initial specification was issued. While the specification is unchanged, industry melt practice is changed to VIM followed by a consumable remelt. Like alloy 718, the major element percentages and their ranges have not changed although the same few additional elements are now controlled that were not listed in 1963. Stress rupture requirements and heat treat parameters are the same.

The first end user specification for Waspaloy was issued on 7/15/60. Specification changes are similar to those described above for AMS Waspaloy and end user alloy 718. Chemistry percentages and ranges of major elements are largely unchanged but most minor elements are more tightly controlled. As with the AMS 5708, elements are now controlled that were not initially specified. In 1960 single vacuum melting (VIM) was permitted where double melting is now required (VIM + consumable remelt). Mechanical properties are unchanged.

To summarize the evolution of specifications for alloy 718 and Waspaloy, the changes in the specification, and the quality of the metal produced, reflect changes that vacuum induction melting and remelting brought to the superalloy industry. Among vacuum induction melting's value-added benefits, are dramatically improved chemistry control and cleanliness and the ability to control minor elements to tighter limits.

Superalloys Today

Over the years superalloy producers have come and gone. Today there are three major U.S. based producers and a similar number based outside the U.S.

Available Product Forms

Superalloys are available in every mill product form including:

- Ingots and billet for open and closed die forgings and extrusions
- Slabs for rolling into plate and sheet
- Forged round and rectangular billet and bar
- Forged cylindrical, tapered and stepped shafts
- Rolled round, rectangular, shaped bar and coil
- Hot rolled plate and sheet

- Cold drawn bar, rod, coil and wire
- Cold rolled sheet and strip in standard and precision gauge tolerance
- Hot extruded and cold pilgered tubing

Ingot and mill products are produced using a variety of single, double and triple melt techniques including the following.
- Electric arc furnace (EAF)
- EAF and argon oxygen refined (AOD)
- EAF or EAF/AOD followed by electro-slag (ESR) or vacuum arc (VAR) remelted
- EAF/VAR/VAR
- Vacuum induction (VIM) followed by ESR or VAR
- VIM/ESR/VAR

Mechanical properties and grain structures differ based upon needs of downstream processing and end use applications. Alloy 718 and superalloys have excellent versatility as seen in the applications and components they enable.

Applications
- Commercial and military jet engines
- Rocket motor components
- Auxiliary power units (APUs)
- Power turbines for municipal, industrial and marine applications
- Oil and gas exploration, production and flow lines
- Defense systems
- Locomotive engines
- Heavy vehicles and selective light vehicles
- Tooling for extrusion and forging

Components
- Components in jet engines, APUs, industrial and marine gas turbines include rotating and static parts such as turbine and compressor cases, disks, shafts, blades and vanes, and fasteners.
- Components in municipal gas turbines include turbine wheels, spacers, stub shafts, compressor rotor bolts and fasteners.
- Oil and gas industry in downhole, subsea and above ground components including pup joints, safety valves, side pocket mandrills, packers, gate and ball valve parts and blowout preventers.
- Diesel engine valves and other engine parts
- Extrusion and forging dies where temperatures exceed the limits for tool steels.
- Superalloys facilitate commercial applications essential and irreplaceable in defense systems such as aircraft and weapon systems for national security.

The Superalloy Committee of The Specialty Steel Industry of North America
In 1988 the U.S. producers of superalloys formed an association to represent the industry's interests in Washington D.C. and develop statistics on the size of the superalloy market. The

Superalloy Committee (SAC) formed within an existing association for specialty steel companies. The organization is currently called SSINA, the Specialty Steel Industry of North America. Looking back at the history of the superalloy industry it is not surprising that the industry leveraged its relationship with specialty steel to form its industry association. It's also interesting to note that the symbiotic relation between superalloys and specialty steel is as important today as it was in the dawning and during the growth of the superalloy industry.

The SAC's impact on the superalloy industry has been, and continues to be significant, thanks to the works of industry executives from the superalloy companies and the team of attorneys and economists who helped manage the SAC. A topic addressed earlier in this paper is "What's the definition of a Superalloy?" The development history is complex and sometimes unclear. One of the early tasks of the SAC was to clearly define which nickel-, cobalt- and iron-based alloys are superalloys. The Committee categorized these alloys, removing the confusion. The categories are:

1. Heat Resisting Alloys
2. Corrosion Resistant Alloys
3. Nickel-base Superalloys
4. Electrical Alloys
5. Iron-based Superalloys
6. Cobalt-based Superalloys

This categorization accomplished two important distinctions. First it recognizes the differences in nickel-, cobalt- and iron-based superalloys, and secondly it recognizes the importance of other nickel alloys without confusing them with superalloys. If you would like to learn more about the Superalloy Committee please visit the Committee's website at www.ussuperalloys.com.

The Superalloy Committee is active today, carrying out the mission set forth by its founders, appraises the needs of the industry to determine how the SAC can aid in the growth of the Superalloy Industry and works closely with Congress and governmental agencies to assure the interest of National Security are met by the superalloy industry.

Superalloys Tomorrow

What does the Future of the Superalloy Industry Look Like?

Three factors gave life to and nurtured the superalloy industry: new alloys enabling performance at higher temperature; vacuum melting, providing consistent repeatable processing for cleanliness; and the growing jet engine market, driving superalloy technology.

The invention of new alloys led to the need for vacuum melting to provide cleanliness required for consistent performance demanded by jet engines. Single vacuum induction melting led to double vacuum melting with vacuum arc remelting following the vacuum induction primary melt. To move alloy cleanliness to new levels, a third melt, electro slag remelting, was added between VIM primary melting and the VAR final melt.
But technology demands continued to evolve requiring powder technology and isothermal forging to producing hardware from alloy chemistries too segregation-prone for VIM/VAR melting. While new and improved chemistry was being developed and alloy cleanliness was

improving, hot working of the ingots became the next area of focus. Billetizing techniques became highly engineered processes providing fine grained, equi-axed superalloy billet to the closed-die and ring rolled forgings operations that followed. These refined structures' finer, more consistent grain size allowed jet engine design engineers to raise the bar for component performance and design to tighter standards without lowering safety margins. So a fourth element: highly engineered billet was added to the three cornerstones supporting the superalloy industry.

In summary, today's superalloy industry is the product of elements:

- Alloy development
- Vacuum melting
- Engineered billetizing
- Deformation Processing
- The technological demands of jet engines.

What comes next? The future cannot be seen with certainty, but there is a way to look ahead. If recent trends are carefully appraised and designers of products made from superalloy are consulted as to their needs, the future starts to clarify. Today superalloys are an enabling technology for highly efficient gas turbines for aircraft and municipal electrical power generation and the safe recovery of oil and natural gas buried miles beneath the earth's surface and sea beds. The needs of these end uses critical to our way of life will push superalloys to new levels of quality, reliability and in-service performance.

Forecast for Cast/Wrought Processed Superalloy Products

<u>More powder alloys converted to cast/wrought</u>

Reasons for this trend:

1. pressure to reduce the cost of making the ingot.
2. cost advantage of hot working ingot to billet using press and radial forging techniques compared to extrusion
3. forging offers greater flexibility in billet diameter without adding the cost of extrusion tooling
4. cost-effective forging campaigns require fewer ingots to be forged at one time than extrusion.
5. lack of powder and isothermal forge capacity to fulfill industry needs

<u>New alloys</u>

The need for cost-effective alloy alternatives that offer improved performance at elevated temperatures is a constant. A recent example is ATI 718Plus® alloy.

<u>Existing alloys improved through chemistry refinements and tighter elemental control</u>

Little changes can have big returns in the performance of a superalloy during forging as well as in the final part.

<u>Cleaner microstructures</u>

The superalloy industry exists today because cleanliness delivers better performance in the end product. The future will likely include breakthroughs in this area.

Ingot diameter increases

36-inch 718 alloy triple melted premium quality ingots are available today for use in industrial turbines. Approval of 24-inch 718 ingots for jet engine applications cannot be far behind.

Billet diameter increases

A barrier to larger diameter superalloy billet has been removed: a 10,000 ton billetizing press coupled with a 700mm radial forge began operating in late 2009 at ATI Allvac. The facility is approved to produce premium rotating quality billet including alloys 718, 720 and Waspaloy. Fine grain billet up to 16-inch diameter will be developed. Larger diameters may follow as the capabilities of the facility are fully developed.

Forged billet and bar with engineered structures availability

Finer grain will be available, offering closed-die forgers greater flexibility in processing, and engine designers an additional parameter to consider if desirable in their application. Binary grain structures: i.e., coarser or finer grain in the center of the billet and finer or coarser grain from mid-radius to surface in a predetermined, predictable, engineered pattern will become available. This forecast is undoubtedly further in the future than others discussed. It will also require significant development as well as a compelling business case.

Engineered mechanical properties

The new forging capability discussed above changes the game in superalloy forging. Superalloy strength at elevated temperatures often makes the billetizing press subservient to the alloy being forged. With the 10,000 ton press, this is no longer the case. Superalloy billet forged on the 10,000 ton press will be subservient to the press. Since this process is highly automated, variability is reduced and repeatability increased. Such precision control opens the door to developing forging billet and bar with optimized properties and structures specifically matched to the component design.

Forecast for Superalloy Powder Products

Heat size increases

Significantly larger heat sizes for powder atomization will become approved for premium rotating quality applications.

New alloys

Higher turbine operating temperature gave birth to and nurtured the superalloy industry. This need will continue to drive the development of new powder superalloys. ATI Powder Metals, located near Pittsburgh, operates an R&D laboratory with extensive sub-scale capabilities that will be a platform for new alloys that solve today's problems and remove barriers to the next generation of gas turbines.

Multi-alloy compacts and billets

If one superalloy is good, two may be better. Powder compacts will be designed with multiple chemistries of a single alloy or multiple alloys. Processing will be engineered to create preforms that can be closed-die forged and heat treated into components with highly engineered multiple properties.

Multi-alloy cast–wrought/powder billets

Improved efficiency, low emissions and cost effectiveness will drive development of disks made from hybrid billets comprised of cast–wrought/powder superalloys. These highly engineered superalloys components will enable dramatically advanced future generation gas turbines.

Some Things Change with Time, Some Things Don't

This paper addresses the past, present and future of the Superalloy industry. The following collection of contemporary references shows that while some things change with time, some things remain the same. These are presented for your perspective and entertainment. Many of these words will ring with irony in the ears of today's engineers.

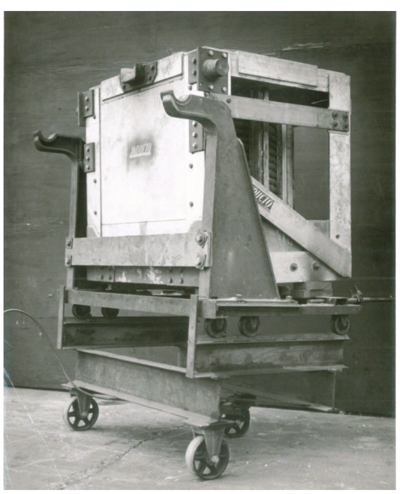
Some Things Change with Time

Throughout the 1940s and well into the 1950s it was said that the qualification of a new superalloy for gas turbine applications, jet and municipal power took one to two years. Today that time is extended often a decade or more. The reasons for this is the existing materials are working; therefore advancements can be made in a slow, conservative, risk averse manner emphasizing reliability.

"As the alloy has high strength at very high temperatures, it is somewhat difficult to forge. The most satisfactory results are obtained with small ingots having a cross section not greater than about four inches square" Rudolf H. Thielemann, Ni-Mo-co-W-Ti alloy patent #2,398,678, March 1, 1941 (predecessor to Waspaloy)

Process Capabilities Have Changed

- The typical VIM heat size was 500 pounds in 1957. Today 45,000 pounds is common.




Products Have Changed

- In the early days of superalloys mill products were offered as rounds from .25″ up to 4″ diameters and rectangles with up to a 4″ cross section. Today mill products are produced as rounds from fine wire to 14″ diameter and larger.

Superalloys Produced Have Changed

- In the 1960s approximately 15 to 20 high-temperature alloys were melted. Today there are more than 20 alloy 718 chemistries melted with most meeting the ASTM B 637 specification.
- New alloys have been invented but only a few have found sizable applications. Included in the list of successful new alloys are alloy 720, alloy 925, RR1000, and ATI 718Plus® alloy.
- In the nickel chapter of the 1948 Metals Handbook nickel alloys such as alloy 600 were typically melted in 6000-lb coreless induction furnaces or 10,000-lb electric-arc furnaces. The charge, typically about 4650 lb and 9200 lb respectively, produced an 18″ x 18″ x 40″ ingot. Air melting was the production process of the day. Today nickel alloys such as alloy 600 are melted in electric furnaces, typically 20 to 30 tons, and then refined in AOD vessels. The product of this melt could be an ingot or an electrode. Electrodes are remelted using ESR or VAR techniques into ingots up to 40″ diameter. More complex precipitation hardening nickel alloys such as alloy 718 receive primary melting in VIM furnaces up to 45,000 pounds, where one or more electrodes are poured, before remelting once or twice in ESR and VAR furnaces.

Some Things Don't Change With Time

"*Since the inception of Allvac Metals Company some months ago*, the market for high temperature metals has changed from a "seller's" market to a "buyer's" market. Many of the potential customers are associated with the defense business. Recent economy measures in Congress and drastic cut-backs in the Defense Department have caused the customers to adjust their plans and inventories accordingly." January 1958

"Cermets and ceramics continue to be prime hopes for overcoming high temperature problems. The feeling in the industry is that a breakthrough in ductility isn't too many years away." *Aviation Age* 1958-1959

"Machining the 'UNMACHINABLE' is perhaps the number one problem …nickel-base and cobalt-base alloys…this could mean an increase in machining cost …" *Aviation Age* 1958-1959

"The *new engine* boosts the speed of a conventional jet by 40 miles an hour, increases thrust by at least 25 per cent and yet offers from 20 to 25 per cent less fuel consumption at cruise level."
JT3D engine in 1962 (4 engines powered the Boeing 707 at 640 miles per hour)

"The plan is an optimistic one in which management has confidence. Like in all projected plans, 'ifs' are important factors. If our share of the market is obtained; if prices become stable; if manufacturing cost continue to improve; if technical can meet the rigid specification requirements; and, if needed operating funds can be obtained, the plan can be achieved. Innovation is the answer to these 'ifs' and in this department, Allvac leads the industry." 1963 Allvac Annual Report

"…the routine metal manufacturers were skeptical of the future economics of vacuum melting; whereas, the technical people closely associated with the process were making a strong technical case for its value used in melting nickel-based superalloys." 1967 -- Jim Nisbet, International Vacuum Metallurgy Conference

"…the insatiable demands of the turbine engines that power our high performance military and commercial engines, as well as our industrial turbines, have motivated a search for new materials. These materials are for use at high temperatures in one of the most complex and difficult environments ever encountered. During this entire period, the materials technologists have met these demands with ever-improving superalloys, which, in addition to their increased use in engines as temperatures are pushed further upward, have become important to many other applications." G. Mervin Ault, Director of Space Technology and Materials, NASA Lewis Research Center. 1972 Foreword in the book The Superalloys.

A Few of the Pioneers of the Superalloy Industry

The Hall of Frame of superalloy pioneers in alloy development and processing and the many iconic engineers who have and continue to grace the industry exists only in the Conference proceedings and papers written on the subject and the minds of those in the industry. The information is widely disbursed and forgotten as time passes. The list below, admittedly incomplete, is an attempt to list some of the people who helped form the Superalloy industry and describes their contributions.

Rudolf Thielemann

- Started his career with General Electric, Schenectady, NY
- First to recognize Vitallium as an alloy for gas turbine blades
- In 1945 joined Pratt & Whitney Aircraft
- Patent holder of cobalt-base alloys (1941-1966) that led to the invention of Waspaloy® in 1946, named after P&W's popular radial internal combustion engine, the Wasp engine.

Dr. Gunther Mohling, Allegheny Ludlum Steel Company

- The 1984 Superalloy Conference was dedicated to Dr. Mohling for his extensive body of work on superalloys starting in the late 1930's when advancements required individual creativity and were largely novel.
- First to vacuum induction melt a large heat, ten tons, of aluminum and titanium containing strengthened superalloy. This accomplishment was achieved at the laboratory he founded in Watervliet, NY in 1950. Alloys melted included Waspaloy, A-286 (co-inventor) and M252.
- Produced the first production electric vacuum arc remelting of superalloys in 1953.

James D. Nisbet

- Graduate Clemson University, SC in 1937 and was hired by General Electric, Schenectady, NY. He brought with him little but his ambition and a love for flying.
- After initial engineering positions he settled into the research center and began working on high-temperature alloys for power turbines.

- Performed extensive research on high temperature alloys melted in a vacuum to eliminate variation caused by the reaction of the alloys with air.
- In 1946 he embarked on a research project that lasted four years.
- In June of 1950 the project was complete and a 316-page report titled Exploratory High-temperature Alloy Research and 288-page volume of data and reference materials were published. The report's abstract describes the work well: "A high-temperature exploratory metallurgical research report covering four years of experimental work and the evaluation and interpretation of test results on several hundred alloys involving combinations of seventeen different elements."
- Hired by Universal-Cyclops in 1954 to build a research facility to perfect vacuum melting as a production process.
- Founder of Allvac Metals Company, Monroe, NC in 1957, dedicated to the production of superalloys.
- First to exclusively produce superalloy using double vacuum melting (VIM/VAR)
- Holder of several patents on processing and control of vacuum induction melting.
- The Allvac Metals Company merged with the Vanadium Alloy Steel Company that later merged with Teledyne, Inc., which merged with the Allegheny Ludlum Steel Company in 1998, later becoming Allegheny Technologies Inc. (ATI) and giving the name ATI Allvac to the company Mr. Nisbet founded.

Clarence G. Bieber, International Nickel Company

- Inventor of numerous nickel-base alloys
- Credited with doing the research that led to the development of numerous nickel-base alloys including Inconel and Maraging steels
- Holder of numerous superalloy patents

Dr. Falih N. "Doc" Darmara, Specials Metals, division of Utica Drop Forge & Tool Corp

- Born in Izmir, Turkey, received his Ph.D. from Harvard in 1938 and did advanced study at MIT in the late 1930s.
- Hired as chief metallurgist at Utica Drop Forge & Tool Co. in 1941
- Joined The Lewis Flight Propulsion Laboratory of NACA (The National Advisory Committee for Aeronautics – now NASA) in 1944 to perform alloy development.
- Designed and built the first commercially successful small (6 lb) vacuum induction furnace, leading to the birth of a new industry.
- Became the first President of Special Metals Corporation in 1961.
- Patented several vacuum melting processing techniques and a process for making superalloy powder in August 1974 (US Patent 3829538).
- Dr. Darmara retired from Special Metals in 1976 and passed away on July 15, 2009 at the age of 98

Elwood Haynes

- Automotive entrepreneur in Kokomo, Indiana, whose first love was tinkering with alloys in his basement.

- 1907 patent for a binary cobalt-chrome alloy to improve the productivity of metal cutting tools in automotive applications. The alloy could be considered the father of Vitallium, identified by some to be the first superalloy.
- 1907 patent for a binary nickel-chrome alloy for emerging electrical resistance applications such as toasters.
- 1915 founded The Haynes Stellite Company in a 50 square foot cement block building.

Herbert L. Eiselstein

- Inventor and patent holder of Alloy 718 in filed in 1959 and awarded in 1962.
    - Licenses were given royalty free
- Native of Huntington, WV
- VP of Technology and R&D, Inco Alloys International

Conclusion

The story of superalloys, their development, and of the engineers who made innovation happen, parallels the story of the great industrial force of the last century: power by internal combustion. It enabled great leaps in transportation and power systems to improve the quality of life for billions of people on earth. Superalloy technology was one of the catalysts that transformed this evolving force, giving it speed and power, wings and thrust, enabling us to reach for new worlds of possibility. Superalloy technology has been one of the definitive innovations of recent history, literally doing more while costing less.

Today, as we contemplate the limits and impact of many of our technologies, we are looking to many sources for ways to gain more value at less cost, to mitigate and minimize, to remedy and repair. Superalloys are among the solutions that will open new doors, delivering more efficiency to existing systems and enabling new solutions that haven't yet been imagined.

Innovation created the superalloy industry. Innovation has kept it vital and relevant. Innovation will be its future.

Acknowledgements

The author expresses his appreciation to the many employees at ATI Allvac who shared information and helped point the way for this paper. A special thanks to Brian McTiernan, ATI Powder Metals for writing the section on the history of superalloy powder.

I would also like to thank the many engineers who worked in the superalloy and turbine engine industries over decades building the technologies practiced today. In particular, I thank Mr. James D. Nisbet for his vision for vacuum melting and the founding of the Allvac Metals Company, Monroe, NC, and the men and women of ATI Allvac for their dedication to our company and industry.

A debt of gratitude is owed to all authors and presenters at conferences for the past four decades who discussed the history of high-temperature/superalloys and vacuum melting within their company or the industry. The information allowed me to weave the story of our industry more

accurately and in greater depth. It is to these same individuals I certainly owe apologies for having certainly missed one or more footnotes.

Lastly, my thanks go out to Phil Morton and Brad Fisher for their help in reviewing and editing this paper. Without their assistance this work would not have proceeded beyond a rough draft.

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EXHIBIT 7

It's Elemental

Previous Element (Titanium) The Periodic Table of Elements Next Element (Chromium)

The Element Vanadium

[Click for Isotope Data]

23
V
Vanadium
50.9415

Atomic Number: 23
Atomic Weight: 50.9415
Melting Point: 2183 K (1910°C or 3470°F)
Boiling Point: 3680 K (3407°C or 6165°F)
Density: 6.0 grams per cubic centimeter
Phase at Room Temperature: Solid
Element Classification: Metal
Period Number: 4 **Group Number:** 5 **Group Name:** none

What's in a name? Named for the Scandinavian goddess **Vanadis**.

Say what? Vanadium is pronounced as **veh-NAY-dee-em**.

History and Uses:

Vanadium was discovered by Andrés Manuel del Rio, a Spanish chemist, in 1801. Rio sent samples of vanadium ore and a letter describing his methods to the Institute de France in Paris, France, for analysis and confirmation. Unfortunately for Rio, his letter was lost in a shipwreck and the Institute only received his samples, which contained a brief note describing how much this new element, which Rio had named erythronium, resembled chromium. Rio withdrew his claim when he received a letter from Paris disputing his discovery. Vanadium was rediscovered by Nils Gabriel Sefstrôm, a Swedish chemist, in 1830 while analyzing samples of iron from a mine in Sweden. Vanadium was isolated by Sir Henry Enfield Roscoe, an English chemist, in 1867 by combining vanadium trichloride (VCl_3) with hydrogen gas (H_2). Today, vanadium is primarily obtained from the minerals vanadinite ($Pb_5(VO)_3Cl$) and carnotite ($K_2(UO_2)_2VO_4 \cdot 1\text{-}3H_2O$) by heating crushed ore in the presence of carbon and chlorine to produce vanadium trichloride. The vanadium trichloride is then heated with magnesium in an argon atmosphere.

Vanadium is corrosion resistant and is sometimes used to make special tubes and pipes for the chemical industry. Vanadium also does not easily absorb neutrons and has some applications in the nuclear power industry. A thin layer of vanadium is used to bond titanium to steel.

Nearly 80% of the vanadium produced is used to make ferrovanadium or as an additive to steel. Ferrovanadium is a strong, shock resistant and corrosion resistant alloy of iron containing between 1% and 6% vanadium. Ferrovanadium and vanadium-steel alloys are used to make such things as axles, crankshafts and gears for cars, parts of jet engines, springs and cutting tools.

Vanadium pentoxide (V_2O_5) is perhaps vanadium's most useful compound. It is used as a mordant, a material which permanently fixes dyes to fabrics. Vanadium pentoxide is also used as a catalyst in certain chemical reactions and in the manufacture of ceramics. Vanadium pentoxide can also be mixed with gallium to form superconductive magnets.

Estimated Crustal Abundance: 1.20×10^2 milligrams per kilogram

Estimated Oceanic Abundance: 2.5×10^{-3} milligrams per liter

Number of Stable Isotopes: 1 (View all isotope data)

Ionization Energy: 6.746 eV

Oxidation States: +5, +4, +3, +2

Electron Shell Configuration: $1s^2$
$2s^2$ $2p^6$
$3s^2$ $3p^6$ $3d^3$
$4s^2$

EXHIBIT 8

Vanadium: The World's Critical Element Fueling a Major Trade War

NEWS PROVIDED BY
NetworkNewsWire →
Oct 30, 2018, 08:30 ET

NEW YORK, October 30, 2018 /PRNewswire/ --

NetworkNewsWire Editorial Coverage

The move towards the adoption of electric vehicles (EV's) along with solar and wind power generation has sparked interest in what could become the next super metal: vanadium. The United States doesn't currently produce vanadium; however, **United Battery Metals** (OTC:UBMCF) (CSE:UBM) (FWB:0UL) **(Profile)** is in development of a world-class vanadium resource in Colorado. The vanadium redox battery (VRB) is a potentially revolutionary way to store energy, and major miners such as **Largo Resources** (TSX:LGO) (OTC:LGORF) may not be able to react quickly enough to offset the potential spike in vanadium demand. The adoption of VRB technology could provide a catalyst for the vanadium industry, a positive for companies such as **Prophecy Development Corp.** (TSX:PCY) (OTC:PRPCF), **Vanadium One Energy Corp.** (TSX.V:VONE), and **First Vanadium Corp.** (TSX.V:FVAN) (OTC:CCCCF), which are eager to serve this growing marketplace.

To view an infographic of this editorial, click here.

Critical to Security

The Department of the Interior deemed vanadium as one of the commodities considered critical to the economic and national security of the United States. This recognition is a result of President Donald J. Trump's executive order to break America's dependence on foreign minerals

President Trump has moved relentlessly against China on trade policy, a country that happens to be the global leader in vanadium production by a wide margin. Without Chinese vanadium to depend on, the **United Battery Metals' (OTC:UBMCF) (CSE:UBM)** Wray Mesa, Colorado, project could help the US develop its own domestic vanadium supply. The price of V2O5 vanadium pentoxide flake 98 percent, a common form of vanadium, has increased significantly over the last three years.

The global shift toward EVs is growing stronger. According to Forbes, China is subsidizing the purchase price of an EV by as much as $10,000 per vehicle. Beijing wants to curb its dependency on dirty fuel sources, which has required the government to slash the number of new vehicle registrations allowed in Beijing this year from 150,000 to just 100,000. Of those 100,000, 60 percent must be an EV.

Vanadium redox batteries offer a potentially game-changing solution for stationary storage units and charging stations. Unlike lithium-ion batteries, VRBs can be charged and discharged simultaneously, allowing up to 50 vehicles to connect to VRB charging stations at the same time. This means the trend towards EVs could require significant amounts of vanadium in the form of charging infrastructure to provide energy to these new vehicles.

Until recently the steel industry used the majority of the vanadium supply as an additive to strengthen steel. Demand in the steel industry continues to grow, thanks in part to the current administration's support of domestic steel production, which has caused companies such as US Steel to open new facilities and cancel plant closures nationwide. Now it looks like vanadium could be vital for cutting-edge battery technology in addition to being a steel additive. There are currently no active vanadium producers in the United States, meaning United Battery Metals could have a head start in development, thanks to its 3,000-acre land package in Wray Mesa.

In addition to the steel industry and car charging stations, VRB's could play a critical role in grid power storage. Solar and wind power nationwide is a burgeoning industry that is growing exponentially with a shift to clean energy solutions. California has recently announced that by 2020 all homes and mid-rises will be required to install solar panels. It is here that VRBs can play a part. The ability to store power from low-usage periods and spill it back into the grid during peak demand periods makes VRB's a far superior choice for large-scale energy storage than lithium-ion batteries. Experts predict that it is just a matter of time before this law will be adopted nationwide. Regulations such as these could become a big driver for vanadium demand in the United States, a country in desperate need of a domestic resource.

Growing Pressure on Battery Infrastructure

EV's offer society an incredible transportation option that could drastically reduce carbon emissions. As the shift towards EV's continues, a new network of charging stations could be necessary to provide the vehicles with electricity. With multiple governments already moving to regulate internal combustion engine vehicles, the move towards electric transportation has already begun, meaning the race is on to create the energy infrastructure necessary to support these new electric vehicles.

The electric vehicle revolution has required massive amounts of lithium to produce the lithium-ion batteries found in EV's such as the Tesla. However, the next battery revolution could be built on a different resource altogether. As energy demands grow and the lithium-ion battery becomes as common as the lightbulb, new sources of energy have the potential to become the backbone of the next battery industry. In the case of vanadium, the unique properties of the metal have enabled new means of electric storage, which could greatly benefit vanadium miners such as UBM.

Vanadium: Enabling the Energy Storage Revolution

Vanadium redox batteries offer unique advantages that no other battery can match. Unlike lithium-ion batteries, VRB's don't heat up when in use, and they can be charged and discharged at the same time. Today VRB's are being developed to work in conjunction with renewable power sources and EV's.

Unfortunately, there isn't currently enough vanadium in production to meet growing demand. For United Battery Metals, the vanadium supply crunch in the United States offers a potentially lucrative opportunity. The company has a large land package in a politically stable jurisdiction, and its Wray Mesa project has the potential to become the lone vanadium producer in the country.

VRB's also solve a common problem for sustainable power sources, offering an almost perfect solution for storing power at stationary power stations. They offer a long service life and can be recycled when they need to be replaced. VRB's can also charge and discharge simultaneously, meaning a VRB-based power station could be capable of charging itself through the grid while also providing energy to vehicles or other devices.

According to Forbes, the number of EV's sold globally is expected to increase from 1.2 million in 2017 to 2 million in 2019. This trend could also greatly benefit vanadium miners such as United Battery Metals, which are capable of providing enough of the super metal necessary to jumpstart the next battery revolution.

A Head Start in the Race to Vanadium Production

United Battery Metals could be in a prime position to meet US demand with its wholly controlled Wray Mesa project in the UraVan district of Colorado. This year the USGS added vanadium to its list of strategic elements, meaning the Wray Mesa project could become incredibly important to the United States and its national interests as the country focuses on developing its own domestic resources.

Wray Mesa has a chance to become the next major source of vanadium in the United States. According to a 43-101 prepared in 2013, Wray Mesa is sitting on an estimated resource of 2,640,000 pounds of vanadium. The property is also close to the town of La Salle, which has access to established roads, and municipal water only six miles away.

With a global scramble to lock down large amounts of high-grade vanadium taking place, UBM could be in an optimal position to capitalize on the trend. The UruVan district has a history of producing both uranium and vanadium, with a number of small mom-and-pop mines populating the area. Colorado is also a mining-friendly jurisdiction with a solid track record of protecting resource investments.

United Battery Metals has put together a land package that has an estimated resource of more than 2.6 million pounds of vanadium; However, the resource model the company used is based on exploration results that likely understated the resource. Very little modern drill work has been undertaken in the UruVan district, meaning there could be a lot more vanadium waiting to be found during exploration.

Most of the elements that will drive the shift away from carbon-heavy power are in short supply. Metals such as vanadium and cobalt have been an afterthought to industry for decades; however, lately the price of these vital elements has been exploding.

Others in the Vanadium Space

Prophecy Development Corp. (TSX:PCY) (OTC:PRPCF) owns the Gibellini project in Nevada, which is one of the only large-scale, open-pit vanadium projects of its kind in North America. The project is currently undergoing EPCM and EIS preparation and could be the right project at the right time.

Vanadium One Energy Corp. (TSX.V:VONE) is a mineral exploration company whose mandate is to acquire vanadium and manganese mineral projects within North America. The company plans to define the economic potential of its properties, define end markets, and process and refine raw materials onsite to create a closed-loop supply chain with end users.

Largo Resources (TSX:LGO) (OTC:LGORF) is a strategic mineral company focused on the product of vanadium flake, high-purity vanadium flake, and high-purity vanadium powder. One of the lowest cost producers of V205, the company currently operates the Maracás Menchen Mine in Brazil, an open pit mine that boasts consistent, robust production rates.

First Vanadium Corp. (TSX.V:FVAN) (OTC:CCCCF) is another mining company developing projects in North America. The company is working to catch up with vanadium demand through its Carlin project in Nevada. The Carlin project was originally discovered by Union Carbide Corp. in the 1960s, including 127 rotary drill holes that have systematically defined near surface shallow dipping deposits. First Vanadium is also exploring a copper project just outside of Jerome, Arizona.

For more information on UBM, please visit **United Battery Metals (OTC:UBMCF) (CSE:UBM).**

Please also **read and review and the following article: Why Every Investor Should Learn the Word 'Vanadium' Before It's Too Late**

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EXHIBIT 9

VANADIUM

Vanadium Industry In The News

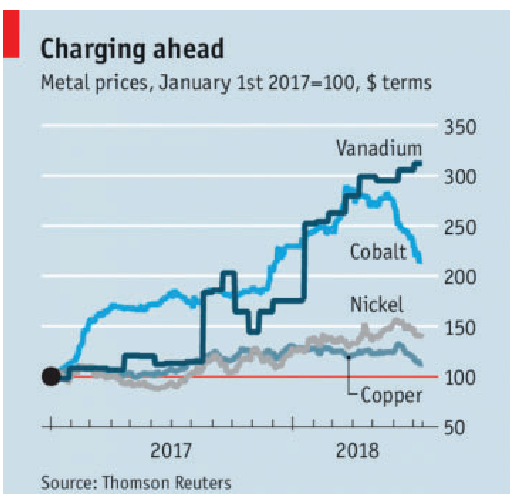
Vanadium is the latest beneficiary of the battery craze

21st July 2018 Vanadium Industry In The News

A metal used to harden steel could also help prevent global warming

July 21st 2018, Going with the flow, Beauty and long lifeOPEN a toolbox, pull out a spanner and you may be holding a bit of the answer to global warming: vanadium, a metal named after Vanadis, the Scandinavian goddess of beauty. Used mostly in alloys to strengthen steel, its appearance may not live up to the romance of its name. Yet vanadium could become a vital ingredient in large clean-energy batteries, in which case it will shine a lot brighter.

Its price has already been rising faster than cobalt, copper and nickel, all of which are used in lithium-ion batteries (see chart). The main reason for the run-up is prosaic. About nine-tenths of the world's vanadium is used to harden steel; China has tightened standards on the strength of rebar to make buildings more earthquake-proof. Mark Smith, boss of Largo Resources, which mines high-purity vanadium in Brazil, says this alone should increase demand for the metal by up to 15,000 tonnes in 2018-19. Last year total production was 83,000 tonnes.



Economist.com

But adding oomph is the incipient demand for vanadium pentoxide, a compound that is used as an electrolyte in vanadium redox flow batteries (VRBs). These batteries are as big as shipping containers and may be better at storing large amounts of wind and solar energy than stacks of lithium-ion batteries. VRBs house the electrolyte in tanks separate from the battery cell and can be charged and discharged almost inexhaustibly over 20 years (indeed, this gives the electrolyte enough residual value that it can be leased). Some analysts reckon that could make them cost-competitive with their lithium equivalents, and safer and more scalable to boot.

They currently use only 1-2% of the global vanadium supply, but the potential growth is producing a halo effect on vanadium prices. "The market just thinks VRBs are sexy," Mr Smith says. Although the flow batteries are too bulky for use in electric vehicles, they may be ideal for stationary storage. China's National Development and Reform Commission, a state planner, has called for lots of 100 megawatt (MW) VRBs to be built to help manage the fluctuations of wind and solar energy. A

200MW one billed as the world's most powerful battery is being built in northeastern China—it is twice the size of a lithium-ion one installed in Australia with much fanfare by Tesla in December.

Some worry that the run-up in vanadium prices will kill VRBs in their infancy. But the metal is abundant; resources total about 63m tonnes. Most of it comes as a by-product from the use of iron in steelmaking, especially in China; some of it is mined in South Africa and Brazil.

The main bottleneck, says Fortune Mojapelo, boss of Bushveld Minerals, a South African vanadium miner, is processing capacity. His firm plans to produce vanadium pentoxide in South Africa to be used in VRBs that Bushveld hopes to erect across Africa. A trend toward vertical integration—from raw material to battery—is also evident in news that VRB Energy, a Beijing-based flow-battery manufacturer, has set up a long-term agreement with a Chinese electrolyte supplier, Pangang Group Vanadium and Titanium Resources, which may also buy a stake in VRB Energy.

If VRBs are as yet little known, that may be because they lack a flashy promoter, such as Tesla's Elon Musk. But vanadium has at least two backers with considerable clout. One is Glencore, the world's biggest commodities trader, which mines it in South Africa. The other is Robert Friedland, a canny billionaire who controls VRB Energy. Both are also leading developers of cobalt. They are betting big on the beauty of batteries.

Correction (July 20th, 2018): *This article previously stated that VRB Energy was Canadian. To clarify, the company is based in Beijing.*

Source: www.economist.com, this article appeared under the Business section of the print edition of "The Economist" magazine under the headline "Beauty and long life"

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EXHIBIT 10

Selected Vanadium Applications in Critical Infrastructure Sectors

Commercial Facilities Sector	Critical Manufacturing Sector	Defense Industrial Base Sector	Energy Sector	Transportation Systems Sector
• Vanadium microalloyed high strength Grade III rebar used to reinforce concrete construction in earthquake prone regions • A572 and A514 vanadium steel structures used in columns in airports and large unsupported spans in sports stadiums • Vanadium steels used in frames and roofs of industrial buildings	• High speed tools and dies used to manufacture automobiles and other heavy machinery • Dies for hot forging, stamping, and pressing operations • Tools used for machining of steel at high speed, as in the production of automobile components	• Steel plate used in shipbuilding applications • Ti6Al4V alloys used in aircraft engine blades, discs, and casings • Ti6Al4V alloys used in airframe parts • Ultra-high strength vanadium steels (i.e. 300M) used in aircraft undercarriage components, including in the Boeing 777 • A715-75 steels used in trucks and other military vehicles	• API 5L Grade X70 and other vanadium-steels used in oil and gas transmission pipelines • Vanadium steels used in transmission towers • Vanadium steels used in steel plate on wind turbines • Storage of renewable energy in the vanadium redox flow battery using V205 • Vanadium steels used in large diameter gas pipelines, including the Alaskan oil pipeline and the Northern Borders pipeline	• High strength, low alloy vanadium steel used in high performance rails • High strength low, alloy vanadium weathering steel such as COR-TEN, used in bridges • Vanadium steels used in tunnels • High strength, low alloy vanadium steel used in train carriages

Sources: Critical infrastructure sectors defined by the U.S. Department of Homeland Security, Roskill, Vanadium Outlook to 2028 (17^{th} ed. 2019), and application information available from AMG Vanadium and Vanitec.org.

EXHIBIT 11

Assessment of Critical Minerals: Updated Application of Screening Methodology

A Report by the

Subcommittee on Critical and Strategic Mineral Supply Chains

Committee on Environment, Natural Resources, and Sustainability

National Science and Technology Council

February 2018

About the National Science and Technology Council

The National Science and Technology Council (NSTC) is the principal means by which the Executive Branch coordinates science and technology policy across the diverse entities that make up the Federal research and development enterprise. A primary objective of the NSTC is to ensure science and technology policy decisions and programs are consistent with the President's stated goals. The NSTC prepares research and development strategies that are coordinated across Federal agencies aimed at accomplishing multiple national goals. The work of the NSTC is organized under committees that oversee subcommittees and working groups focused on different aspects of science and technology. More information is available at http://www.whitehouse.gov/ostp/nstc.

About the Office of Science and Technology Policy

The Office of Science and Technology Policy (OSTP) was established by the National Science and Technology Policy, Organization, and Priorities Act of 1976 to provide the President and others within the Executive Office of the President with advice on the scientific, engineering, and technological aspects of the economy, national security, homeland security, health, foreign relations, the environment, and the technological recovery and use of resources, among other topics. OSTP leads interagency science and technology policy coordination efforts, assists the Office of Management and Budget with an annual review and analysis of Federal research and development in budgets, and serves as a source of scientific and technological analysis and judgment for the President with respect to major policies, plans, and programs of the Federal Government. More information is available at http://www.whitehouse.gov/ostp.

About the Subcommittee on Critical and Strategic Mineral Supply Chains

The purpose of the NSTC Committee on Environment, Natural Resources, and Sustainability (CENRS), Subcommittee on Critical and Strategic Mineral Supply Chains is to advise and assist the CENRS and the NSTC on policies, procedures, and plans relating to identification and forecasting of mineral criticality, and risk mitigation in the procurement and downstream processing of minerals identified as or forecasted to become critical. Maintaining access to and availability of essential resources also fall within the scope of the Subcommittee, both as raw commodities and as a part of downstream supply chains that may be sensitive to disruptions in global supply.

About this Document

This document provides an update to the 2016 report, *Assessment of Critical Minerals: Screening Methodology and Initial Application*, describing enhancements to the screening tool, the latest application of the screening tool using recent data published by the United States Geological Survey, and the next steps for the NSTC Subcommittee. This report also discusses the interagency collaborative efforts being used to respond to Executive Order 13817, *A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals*.

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List of Acronyms

CENRS	Committee on Environment, Natural Resources, and Sustainability
DHS	Department of Homeland Security
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DOJ	Department of Justice
DOL	Department of Labor
DOS	Department of State
DOT	Department of Transportation
EPA	Environmental Protection Agency
EU	European Union
GAO	Government Accountability Office
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
NSC	National Security Council
NSTC	National Science and Technology Council
OSTP	Office of Science and Technology Policy
USDA	United States Department of Agriculture
USGS	United States Geological Survey
USITC	United States International Trade Commission

Introduction

The modern global economy has increasingly come to depend on access to non-fuel mineral resources. Advanced technologies from satellites to cell phones require a variety of specific minerals with unique chemical and physical properties—minerals that were not widely used or considered essential to manufacturing just a few decades ago. To meet rapidly rising demand, production for most non-fuel mineral resources has significantly increased over the past few decades. However, production of many high-demand minerals is concentrated in just a few foreign countries,[1] creating increased risk of price spikes and supply disruptions. If mineral supplies from these countries were suddenly interrupted, the Nation's economy and national security could be threatened.

The risk of price spikes and supply disruptions occurring can change over time as a result of geopolitical shifts, rapid increases in demand, or a suite of other supply chain factors. Understanding a mineral's potential for such disruption and the impact should its supply be disrupted, its "criticality", enables the United States to establish proactive risk management strategies, including diversifying mineral supplies, developing substitutes for materials and technologies that use specific minerals, increasing recycling, and ensuring critical minerals are efficiently used. For the purposes of this discussion, a mineral is critical if the supply chain is vulnerable to disruption, and it serves an essential function in the manufacturing of a product, the absence of which would cause significant economic or security consequences.

In 2010, the U.S. National Science and Technology Council (NSTC) chartered the Subcommittee on Critical and Strategic Mineral Supply Chains (hereafter referred to as the Subcommittee) to facilitate a Federal interagency effort to identify and address current and emerging risks to critical and strategic mineral supply chains. In 2016, the Subcommittee published a report to Congress[2] describing a two-stage methodology for assessing critical minerals, as illustrated in Figure 1. The first stage (Stage I) is an early warning screening tool that identifies potentially critical minerals

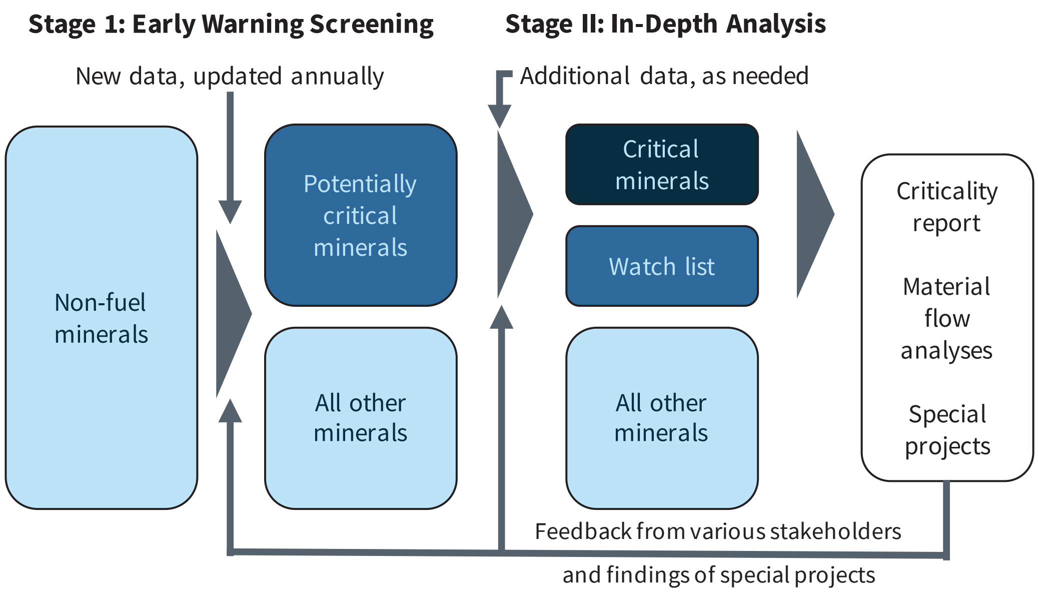

Figure 1. Overview of the interagency methodology for assessing critical minerals.

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[1] https://minerals.usgs.gov/minerals/pubs/mcs/

[2] https://www.whitehouse.gov/sites/whitehouse.gov/files/images/CSMSC%20Assessment%20of%20Critical%20Minerals%20Report%202016-03-16%20FINAL.pdf

using regularly-reported and publicly-available data. The screening tool was designed so that potential mineral criticality could be evaluated in a repeatable and transparent manner on an ongoing basis. The second stage (Stage II) of the methodology consists of in-depth supply chain analyses of selected minerals identified by the screening tool. This tool is updated annually by the U.S. Geological Survey (USGS) on behalf of the Subcommittee when the USGS releases a new year of mineral production and price data.

This report discusses the status of the interagency methodology for assessing critical minerals, including the updated application of the screening tool, data enhancements, in-depth supply chain analyses, ongoing productive collaborations, and next steps for the Subcommittee.

Supporting a Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals

On December 20, 2017, President Trump issued Executive Order 13817, *A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals*[3] that directs Federal agencies to develop a list of critical minerals, strategies to reduce reliance on critical minerals, and actions to support increased domestic supplies of critical minerals. The Executive Order establishes as Federal policy the need to identify new sources of critical minerals; increase activity at all levels of the supply chain, including exploration, mining, concentration, separation, alloying, recycling, and reprocessing critical minerals; ensure that our miners and producers have electronic access to the most advanced topographic, geologic, and geophysical data within U.S. territory; and streamline leasing and permitting processes to expedite exploration, production, processing, reprocessing, recycling, and domestic refining of critical minerals. The Subcommittee is assisting with the interagency coordination required to effectively respond to this Executive Order.

In response to the Executive Order, the Secretary of the Interior, in coordination with the Secretary of Defense and in consultation with the heads of other relevant executive departments and federal agencies, will publish a list of critical minerals in the Federal Registry in February 2018. The Subcommittee's early warning screening tool has been used as a starting point to develop this interagency critical minerals list. Additional input used for the development of this forthcoming list included information on U.S. mineral import reliance statistics, supply chain studies, and expert opinion from the Federal agencies representing the Subcommittee.

Updated Application of the Early Warning Screening Tool (Stage I)

The early warning screening tool assesses a mineral's potential criticality using three fundamental indicators: Supply Risk, Production Growth, and Market Dynamics. The indicators use data published annually by USGS, as well as other sources. The formulas for each indicator are discussed in the 2016 Subcommittee Report to Congress.[2]

In this update, the early warning screening tool has been applied to 77 mineral resources to generate a new list of potentially critical minerals by incorporating statistics available through USGS. The screening tool identified the following minerals in descending potential criticality: yttrium, the rare earth elements (lanthanum through lutetium on the Periodic Table), gallium, ferromolybdenum, mercury, tungsten, ruthenium, antimony, silicomanganese, graphite, germanium, ferronickel, monazite, strontium, iridium, tantalum, rhodium, bismuth (refinery),

[3] https://www.whitehouse.gov/presidential-actions/presidential-executive-order-federal-strategy-ensure-secure-reliable-supplies-critical-minerals/

niobium, and phosphate. Overall, potential criticality has decreased since the last report, but a number of minerals saw an increase in potential criticality. Minerals identified as potentially critical using the two most recent years of complete data from the USGS are shown in Figure 2. A hierarchical cluster analysis was utilized to help determine which subset of minerals should be identified as potentially critical. The results indicated a criticality potential cut-off value of 0.30.[4] The aim of this tool is to identify and assess emerging trends in mineral commodities and is not designed to produce a static list.

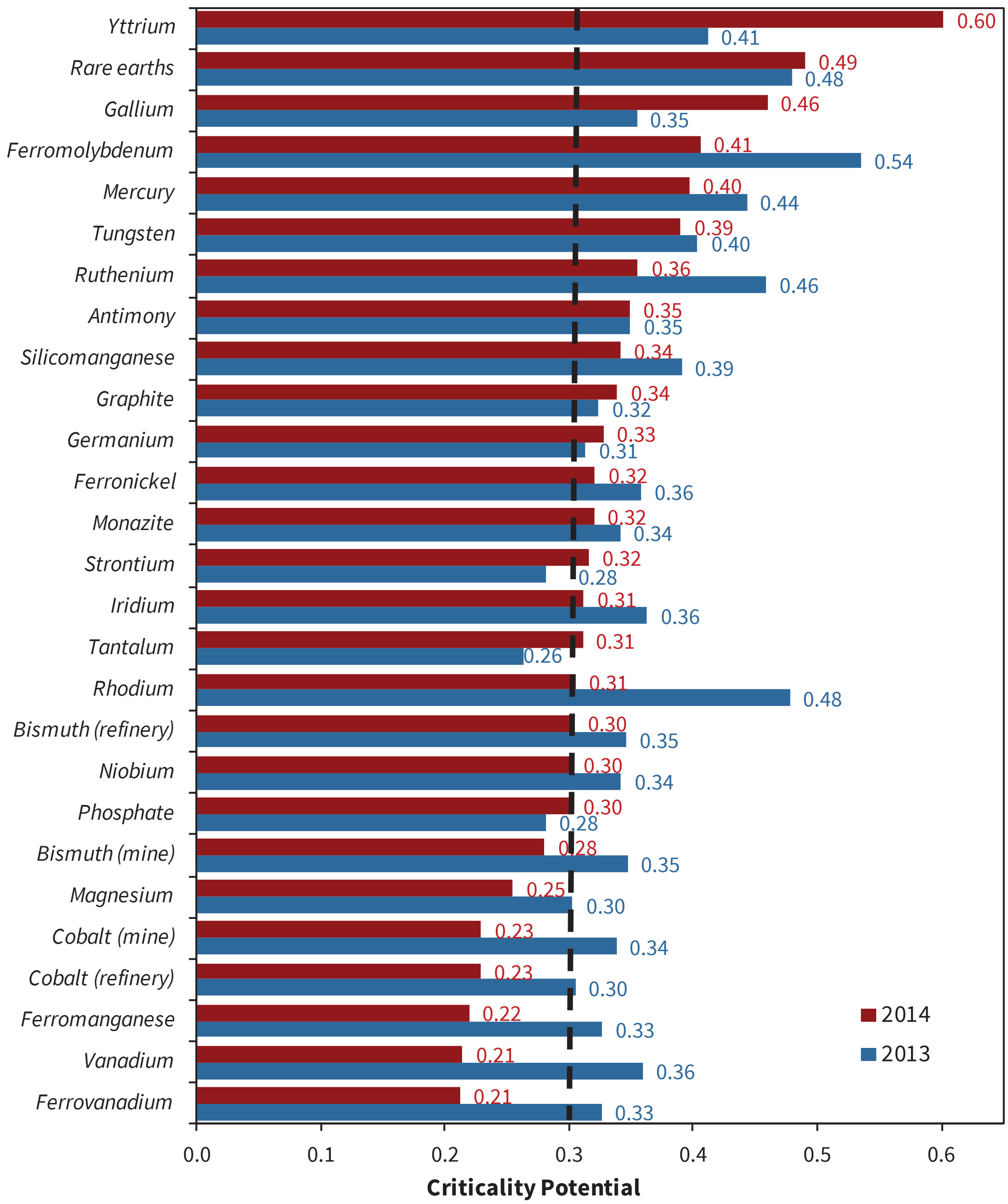


Figure 2. Results from the updated application of the early warning screening tool (Stage I). Only minerals with criticality potential values greater than 0.30 in either year are displayed.

[4] For more information on trends, in-depth analysis, and data enhancements for the screening tool, see https://pubs.er.usgs.gov/publication/70191019

Data Updates and Enhancements

In addition to identifying and stratifying minerals that are potentially critical, the interagency mineral criticality assessment effort also helps to address data needs. The initial application of the early warning screening tool helped identify areas ripe for data improvement in terms of consistency, granularity, and uniformity across data sets. In response, updates to historical information were made and incorporated into the updated application of the screening tool as used to produce the results in Figure 2. In a few cases, such as beryllium, prices were changed to reflect a consistent valuation of a mineral commodity throughout the time series. For instance, in the initial application of the screening tool, the time-series price data utilized differing forms of the same commodity that were not comparable in value. This affected the corresponding Market Dynamics indicator value, which is a component in the overall criticality potential of the mineral. The data were updated to reflect a uniform and more accurate measure of price across years. Another enhancement of price data was the differentiation of prices across multiple processing stages. For example, in the initial application of the screening tool, the same price was used for copper mining, smelting, and refining. This update employs separate prices for the three different forms. Similar efforts to include price data for the intermediate products of other applicable minerals were made.

In a few instances, production data were also modified to assure consistency and accuracy. For example, in the initial application of the screening tool, boron production was based on gross weight. In this updated application, the element content of boron production was utilized to more accurately reflect each country's production. For other minerals, production data were modified based on new, additional, or revised information.

The Subcommittee continues to enhance the performance of the early warning screening tool. By using historical events, such as the "Rare Earth Crisis" in 2010 when China temporarily restricted the export of rare earth elements, the Subcommittee is able to probe the ability of the tool to provide advanced warning of mineral criticality. Such retrospective analysis sheds light on and clarifies uncertainties that might be associated with the output from the tool. It also highlights opportunities to improve and refine the tool's indicators. In addition, to better understand what may be driving the results, the Subcommittee has been investigating the screening tool's sensitivity to variations in all three indicators: Supply Risk, Production Growth, and Market Dynamics.

In-Depth Supply Chain Analyses (Stage II) and Productive Interagency Collaboration

The second stage of the methodology involves detailed analysis of the underlying factors that result in the subset of minerals identified as potentially critical by Stage I of the screening tool. Several in-depth supply chain studies for a subset of minerals identified as potentially critical by the previous application of the screening tool have been recently completed or are ongoing, including studies for yttrium, the rare earth elements, germanium, bismuth, and cobalt.[5,6,7,8,9] Moving forward, the Subcommittee intends to expand its coverage of Stage II studies. The

[5] https://pubs.er.usgs.gov/publication/70176895 (titanium, zirconium, rare earths)
[6] https://www.osti.gov/biblio/1257654 (global markets)
[7] https://pubs.er.usgs.gov/publication/sir20165152 (major metals)
[8] https://minerals.usgs.gov/minerals/pubs/commodity/cobalt/cobalt-supply-security.pdf
[9] https://pubs.er.usgs.gov/publication/70178701 (tellurium, dysprosium, rare earths)

Subcommittee is developing a collaborative process by which appropriate Stage II studies can be prioritized and conducted by member agencies to further illuminate underlying market forces, trends, and risks for minerals identified as potentially critical by the early warning screening tool.

In addition to these in-depth supply chain analyses, numerous Subcommittee member agencies have incorporated the screening tool into their practices to further the objective of their individual missions. For example, the National Aeronautics and Space Administration (NASA) used the outcome of the first application of the screening tool to inform its programs' approaches to risk assessment and mitigation. The Department of Energy (DOE) is examining energy-relevant materials flagged by the screening tool in its upcoming update to the 2011 *Critical Materials Strategy*. The Department of Defense is also utilizing the screening tool to support various internal assessment efforts.

Stimulating Broader Collaboration

In September 2016, the U.S. Government Accountability Office (GAO) released a report[10] examining U.S. efforts to address critical mineral supply issues. In the report, GAO recommended that the Subcommittee strengthen the Federal approach to addressing critical material supply issues through enhanced interagency collaboration; to develop a strategy to address data limitations that are preventing additional materials from being included in the early warning screening tool; and to examine approaches used by other countries to see if there are any lessons learned that can be applied to the United States.

Since GAO issued their report, several agencies, including the Department of Homeland Security, NASA, the U.S. Forest Service, and the Environmental Protection Agency, have become more active in the Subcommittee. The Subcommittee has also helped facilitate the interagency collaboration necessary to effectively respond to Executive Order 13817.

The Subcommittee and its member agencies see the value in analyzing more minerals and non-minerals in the early warning screening tool to help inform policy decisions. In addition, extending coverage further down the supply chain would add significant value. Data for key mineral-derived materials such as specific forms or compounds that are common feedstocks for manufacturing components are often not available because there is no Government agency tasked with the collection of such information. Fulfilling this need will require additional dedicated personnel and financial resources for data collection, analysis, and distribution.

For the past seven years, Subcommittee member agencies have participated in an annual trilateral critical materials conference co-hosted by the United States, the European Union (EU), and Japan. Participation in this conference has enabled the United States to share methodological approaches for mineral criticality assessment, as well as research and development insights on reprocessing, recycling, and technological alternatives. Experts from USGS and DOE are also serving on advisory boards of EU-sponsored projects on mineral information, material flows, and materials criticality. The EU sponsored Mineral Intelligence Capabilities Assessment addresses mineral information and the MinFutures project addresses material flow methodologies. The Department of Defense also includes critical materials in a number of its collaborative efforts with partner countries.

[10] https://www.gao.gov/products/GAO-16-699

The Subcommittee intends to further facilitate coordination among agencies to identify, prioritize, and address data gaps; to share learning and insight from in-depth analyses; to prioritize supply chains for further analysis; and to continue to share lessons with international counterparts.

Future Work

The Subcommittee has already begun work on the next application of the early warning screening tool, drawing on recent data from the USGS Mineral Yearbook series. It is evaluating the utility of including additional indicators or making other enhancements to the tool. Decisions to make such changes to the early warning screening tool will be weighed against any impacts they have on the transparency and repeatability of the tool. Continuing to employ regularly-reported and publicly-available data in the screening tool is a high priority for the Subcommittee. Furthermore, member agencies are working with USGS to augment the early warning screening tool to address agency-specific needs. For example, the tool currently presents results from a non-country specific perspective; however, based on user feedback, a U.S.-centric version is under development. Both perspectives will be functional options for users. The Subcommittee intends to report on this work and provide an update on how the tool is being used across the various member agencies later this year.

The Subcommittee's member agencies plan to pursue in-depth supply chain analyses to better understand the risks and vulnerabilities associated with the subset of minerals identified as potentially critical by the early warning screening tool. Special attention will be paid to minerals that are newly identified as potentially critical by each year's updated application of the screening tool, and minerals whose potential criticality has increased significantly since the previous update.

To date, the Subcommittee's collaborative interagency efforts have yielded significant cross-organizational learning, which has led to both direct and indirect benefits, and have provided a richer understanding of mineral vulnerabilities and opportunities for policy interventions. In addition, the Subcommittee's efforts have introduced agencies to new perspectives and approaches, strengthening individual agency projects and laying the foundation for future collaborative efforts. Such benefits enhance the ability of member agencies to meet national needs. Understanding which minerals are vulnerable to emerging supply chain risks is important to ensuring that the United States has an adequate and affordable supply of critical minerals that are vital to our Nation's security and economy.

EXHIBIT 12

2018 U.S. Net Import Reliance

2018 U.S. NET IMPORT RELIANCE[1]

Commodity	Percent	Major import sources (2014–17)[2]
ARSENIC (trioxide)	100	Morocco, China, Belgium
ASBESTOS	100	Brazil, Russia
CESIUM	100	Canada
FLUORSPAR	100	Mexico, Vietnam, South Africa, China
GALLIUM	100	China, United Kingdom, Germany, Ukraine
GRAPHITE (natural)	100	China, Mexico, Canada, Brazil
INDIUM	100	China, Canada, Republic of Korea, Taiwan
MANGANESE	100	South Africa, Gabon, Australia, Georgia
MICA (sheet, natural)	100	China, Brazil, Belgium, Austria
NEPHELINE SYENITE	100	Canada
NIOBIUM (columbium)	100	Brazil, Canada, Russia, Germany
RARE EARTHS (compounds and metals)[3]	100	China, Estonia, France, Japan
RUBIDIUM	100	Canada
SCANDIUM	100	Europe, China, Japan, Russia
STRONTIUM	100	Mexico, Germany, China
TANTALUM	100	Brazil, Rwanda, Australia, Congo (Kinshasa)
THORIUM	100	India, United Kingdom
VANADIUM	100	Austria, Canada, Republic of Korea, Russia
GEMSTONES	99	India, Israel, Belgium, South Africa
BISMUTH	96	China, Belgium, Mexico, Republic of Korea
YTTRIUM	>95	China, Estonia, Japan, Republic of Korea
POTASH	92	Canada, Russia, Belarus, Israel
TITANIUM MINERAL CONCENTRATES	91	South Africa, Australia, Canada, Mozambique
DIAMOND (dust, grit, and powder)	89	China, Ireland, Republic of Korea, Romania
ANTIMONY (oxide)	85	China, Thailand, Belgium, Bolivia
ZINC	85	Canada, Mexico, Peru, Australia
BARITE	84	China, India, Mexico, Morocco
RHENIUM	84	Chile, Germany, Belgium, Poland
STONE (dimension)	82	Brazil, China, Italy, Turkey
TIN	78	Indonesia, Malaysia, Peru, Bolivia
ABRASIVES, fused Al oxide (crude)	>75	China, France, Hong Kong, Canada
ABRASIVES, silicon carbide (crude)	>75	China, Netherlands, South Africa, Romania
BAUXITE	>75	Jamaica, Brazil, Guinea, Guyana
TELLURIUM	>75	Canada, China, Germany
TITANIUM (sponge)	75	Japan, Kazakhstan, Ukraine, China
PLATINUM	73	South Africa, Germany, United Kingdom, Italy
CHROMIUM	71	South Africa, Kazakhstan, Russia
PEAT	70	Canada
GARNET (industrial)	68	Australia, India, South Africa, China
SILVER	65	Mexico, Canada, Peru, Republic of Korea
COBALT	61	Norway, China, Japan, Finland
NICKEL	52	Canada, Norway, Australia, Russia
GERMANIUM	>50	China, Belgium, Germany, Russia
IODINE	>50	Chile, Japan
IRON OXIDE PIGMENTS (natural)	>50	Cyprus, Spain, France, Austria
IRON OXIDE PIGMENTS (synthetic)	>50	China, Germany, Brazil, Canada
LITHIUM	>50	Argentina, Chile, China, Russia
TUNGSTEN	>50	China, Bolivia, Germany, Canada
ALUMINUM	50	Canada, Russia, United Arab Emirates, China
MAGNESIUM COMPOUNDS	48	China, Canada, Australia, Brazil
ALUMINA	45	Australia, Brazil, Suriname, Jamaica
SILICON	34	Russia, Brazil, Canada, China
PALLADIUM	33	South Africa, Russia, Italy, United Kingdom
COPPER	32	Chile, Canada, Mexico
VERMICULITE	30	South Africa, Brazil, China, Zimbabwe
LEAD	29	Canada, Mexico, Republic of Korea, India
PUMICE	29	Greece, Iceland, Mexico
SALT	28	Chile, Canada, Mexico, Egypt
MICA (scrap and flake, natural)	26	Canada, China, India, Japan
PERLITE	25	Greece, Mexico, Turkey
BROMINE	<25	Israel, Jordan, China
CADMIUM	<25	Canada, Australia, China, Belgium
MAGNESIUM METAL	<25	Israel, Canada, United Kingdom, Mexico
IRON and STEEL	24	Canada, Brazil, Republic of Korea

[1]Not all mineral commodities covered in this publication are listed here. Those not shown include mineral commodities for which the United States is a net exporter (abrasives, metallic; boron; clays; diatomite; gold; helium; iron and steel scrap; iron ore; kyanite; molybdenum concentrates; sand and gravel, industrial; selenium; soda ash; titanium dioxide pigment; wollastonite; zeolites; and zirconium) or less than 24% import reliant (beryllium; cement; diamond, industrial stones; feldspar; gypsum; iron and steel slag; lime; nitrogen (fixed)–ammonia; phosphate rock; sand and gravel, construction; stone, crushed; sulfur; and talc and pyrophyllite). For some mineral commodities (hafnium; mercury; quartz crystal, industrial; and thallium), not enough information is available to calculate the exact percentage of import reliance.

[2]In descending order of import share.

[3]Data include lanthanides.

Detailed Description

This chart shows several mineral commodities used by the United States, the percentage of each commodity that comes from foreign sources, and the major countries that supply that mineral to the United States.

Photographe

U.S. Geological Survey

Details

Image Dimensions: 1477 x 1973

Date Taken: THURSDAY, FEBRUARY 28, 2019

Location Taken: US

EXHIBIT 13

≡ DEFENSE LOGISTICS AGENCY (HTTPS://WWW.DLA.MIL/)

(https://www.dla.mil/)

Strategic Materials

Materials

- Strategic Materials Home (/HQ/Acquisition/StrategicMaterials)
- About Strategic Materials (https://www.dla.mil/HQ/Acquisition/StrategicMaterials/About/)
- What Strategic Materials Offers (https://www.dla.mil/HQ/Acquisition/StrategicMaterials/Offers/)
- Doing Business with Strategic Materials (https://www.dla.mil/HQ/Acquisition/StrategicMaterials/Business/)
- Sales (https://www.dla.mil/HQ/Acquisition/StrategicMaterials/Sales/)
- Reports (https://www.dla.mil/HQ/Acquisition/StrategicMaterials/Reports/)
- Materials (https://www.dla.mil/HQ/Acquisition/StrategicMaterials/Materials/)
- Resources (https://www.dla.mil/HQ/Acquisition/StrategicMaterials/Resource/)
- Announcements (https://www.dla.mil/HQ/Acquisition/StrategicMaterials/Announcements/)
- Event Calendar (https://www.dla.mil/HQ/Acquisition/StrategicMaterials/Events/)
- I Am the Key (https://www.dla.mil/HQ/Acquisition/StrategicMaterials/iamthekey/)
- Contact Strategic Materials (https://www.dla.mil/HQ/Acquisition/StrategicMaterials/Contact/)

Skip to main content (Press Enter).

Metals

Collapse All Expand All

- ⊞ Aluminum
- ⊞ Antimony
- ⊞ Beryllium
- ⊞ Bismuth
- ⊞ Cadmium
- ⊞ Chromium
- ⊞ Cobalt
- ⊞ Copper
- ⊞ Gallium
- ⊞ Hafnium
- ⊞ Indium
- ⊞ Lead
- ⊞ Lithium
- ⊞ Magnesium
- ⊞ Manganese
- ⊞ Mercury
- ⊞ Molybdenum
- ⊞ Nickel
- ⊞ Niobium
- ⊞ Rhenium
- ⊞ Strontium
- ⊞ Tantalum
- ⊞ Tin
- ⊞ Titanium
- ⊞ Tungsten
- ⊟ Vanadium

Material Description

Vanadium is a soft, silver-gray metallic element. There is no single mineral ore from which vanadium is recovered. However, it is found as a trace element in a several types of rock and is a by-product of other mining operations. Vanadinite (lead chlorovanadate) is mineral that contains vanadium.

Uses of vanadium?

- Steel
- Titanium-aluminum-vanadium alloys in jet engines and high-speed aircraft
- Cladding titanium to steel
- Energy storage

- ⊞ Zinc
- ⊞ Zirconium

Skip to main content (Press Enter).

Misc Non-Metals

Collapse All Expand All

- Arsenic
- Boron
- Carbon Fibers
- Energetic Materials
- Germanium
- Graphite
- Quartz
- Rubber (natural)
- Selenium
- Silicon Carbide
- Tellurium

Alloys

Collapse All Expand All

- Aluminum-Lithium Alloy
- Beryllium Copper Master Alloy
- Cadmium Zinc Telluride

Ores and Compounds

Collapse All Expand All

- Aluminum Oxide Fused Crude
- Beryl Ore
- Ferrochromium
- Ferromanganese
- Fluorspar

Rare Earths

Collapse All Expand All

- Cerium
- Dysprosium
- Erbium
- Europium
- Gadolinium
- Holmium
- Lanthanum
- Lutetium
- Neodymium
- Praseodymium
- Samarium
- Scandium
- Terbium
- Thulium
- Ytterbium
- Yttrium

Precious Metals

Collapse All Expand All

- Iridium
- Palladium
- Platinum

Skip to main content (Press Enter).

EXHIBIT 14

Official website of the Department of Homeland Security

U.S. Department of Homeland Security

CISA CYBER+INFRASTRUCTURE

Menu

CISA

Critical Infrastructure Sectors

There are 16 critical infrastructure sectors whose assets, systems, and networks, whether physical or virtual, are considered so vital to the United States that their incapacitation or destruction would have a debilitating effect on security, national economic security, national public health or safety, or any combination thereof. Presidential Policy Directive 21 (PPD-21): Critical Infrastructure Security and Resilience advances a national policy to strengthen and maintain secure, functioning, and resilient critical infrastructure. This directive supersedes Homeland Security Presidential Directive 7 (/homeland-security-presidential-directive-7) .

PPD-21 identifies 16 critical infrastructure sectors:

 (/cisa/chemical-sector)

Chemical Sector (/cisa/chemical-sector)

The Department of Homeland Security is designated as the Sector-Specific Agency for the Chemical Sector.

 (/cisa/commercial-facilities-sector)

Commercial Facilities Sector (/cisa/commercial-facilities-sector)

The Department of Homeland Security is designated as the Sector-Specific Agency for the Commercial Facilities Sector, which includes a diverse range of sites that draw large crowds of people for shopping, business, entertainment, or lodging.

 (/cisa/communications-sector)

 (/cisa/critical-manufacturing-sector)

Communications Sector

Communications Sector

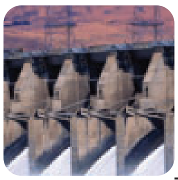
(/cisa/communications-sector)

The Communications Sector is an integral component of the U.S. economy, underlying the operations of all businesses, public safety organizations, and government. The Department of Homeland Security is the Sector-Specific Agency for the Communications Sector.

Critical Manufacturing Sector

(/cisa/critical-manufacturing-sector)

The Department of Homeland Security is designated as the Sector-Specific Agency for the Critical Manufacturing Sector.

 (/cisa/dams-sector)

Dams Sector

(/cisa/dams-sector)

The Department of Homeland Security is designated as the Sector-Specific Agency for the Dams Sector. The Dams Sector comprises dam projects, navigation locks, levees, hurricane barriers, mine tailings impoundments, and other similar water retention and/or control facilities.

 (/cisa/defense-industrial-base-sector)

Defense Industrial Base Sector

(/cisa/defense-industrial-base-sector)

The U.S. Department of Defense is the Sector-Specific Agency for the Defense Industrial Base Sector. The Defense Industrial Base Sector enables research, development, design, production, delivery, and maintenance of military weapons systems, subsystems, and components or parts to meet U.S. military requirements.

 (/cisa/emergency-services-sector)

Emergency Services Sector

(/cisa/emergency-services-sector)

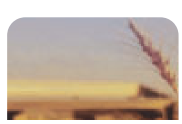
The Department of Homeland Security is designated as the Sector-Specific Agency for the Emergency Services Sector. The sector provides a wide range of prevention, preparedness, response, and recovery services during both day-to-day operations and incident response.

 (/cisa/energy-sector)

Energy Sector

(/cisa/energy-sector)

The U.S. energy infrastructure fuels the economy of the 21st century. The Department of Energy is the Sector-Specific Agency for the Energy Sector.



 (/cisa/financial-services-sector)

Financial Services Sector (/cisa/financial-services-sector)

The Department of the Treasury is designated as the Sector-Specific Agency for the Financial Services Sector.

 (/cisa/food-and-agriculture-sector)

Food and Agriculture Sector (/cisa/food-and-agriculture-sector)

The Department of Agriculture and the Department of Health and Human Services are designated as the co-Sector-Specific Agencies for the Food and Agriculture Sector.

 (/cisa/government-facilities-sector)

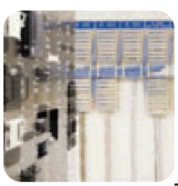
Government Facilities Sector (/cisa/government-facilities-sector)

The Department of Homeland Security and the General Services Administration are designated as the Co-Sector-Specific Agencies for the Government Facilities Sector.

 (/cisa/healthcare-and-public-health-sector)

Healthcare and Public Health Sector (/cisa/healthcare-and-public-health-sector)

The Department of Health and Human Services is designated as the Sector-Specific Agency for the Healthcare and Public Health Sector.

 (/cisa/information-technology-sector)

Information Technology Sector (/cisa/information-technology-sector)

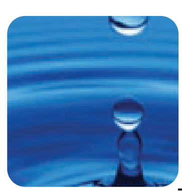
The Department of Homeland Security is designated as the Sector-Specific Agency for the Information Technology Sector.

 (/cisa/nuclear-reactors-materials-and-waste-sector)

Nuclear Reactors, Materials, and Waste Sector (/cisa/nuclear-reactors-materials-and-waste-sector)

The Department of Homeland Security is designated as the Sector-Specific Agency for the Nuclear Reactors, Materials, and Waste Sector.

 (/cisa/transportation-systems-sector)

 (/cisa/water-and-wastewater-systems-sector)

Transportation Systems Sector (/cisa/transportation-systems-sector)

The Department of Homeland Security and the Department of Transportation are designated as the Co-Sector-Specific Agencies for the Transportation Systems Sector.

sector).

Water and Wastewater Systems Sector (/cisa/water-and-wastewater-systems-sector)

The Environmental Protection Agency is designated as the Sector-Specific Agency for the Water and Wastewater Systems Sector.

EXHIBIT 15

missions, while using cutting-edge technology to reduce costs and lower wait times. To achieve this goal SCRA will be relying on industry and government partners in numerous states, resulting in employment sustained and created via manufacturing and research requirements. Matching funds are not applicable. I certify that neither I nor my spouse has any financial interest in this project.

Requesting Member: Congressman JOE WILSON

Bill Number: H.R. 3326—Department of Defense Appropriations Act, 2010

Account: Research, Development, Test, and Evaluation, Army

Legal Name of Requesting Entity: Lifeblood Medical

Address of Requesting Entity: 10120 Two Notch Road, Suite 2, Columbia, South Carolina 29223

Description of Request: I have secured $2,000,000 for the Lifeblood Medical's Human Organ and Tissue Preservation Technology (HOTPT). Funding will be used to continue and advance studies for Oxygen Therapeutics and Extending Room Temperature Organ Preservation so that the technology can be brought to FDA for approval. The use of funds is justified due to the potential of finding the first approved oxygen therapeutics which will solve the world issue of a lack of donated blood for trauma, military and casualty use. The use of funds is justified so that the supply of organs for transplantation can adequately meet the demand through extending the preservation time at room temperature. Large animal studies have proven successful in both oxygen therapeutics and organ preservation. Prior DoD funds have also proven that the Lifeblood technology can reverse cell damage and render organs that are labeled untransplantable into an acceptable organ for donation and transplantation. Matching funds will be provided by cash on hand, licensing fee revenues, and product sales. I certify that neither I nor my spouse has any financial interest in this project.

Requesting Member: Congressman JOE WILSON

Bill Number: H.R. 3326—Department of Defense Appropriations Act, 2010

Account: Procurement, Defense Wide

Legal Name of Requesting Entity: FN Manufacturing, LLC

Address of Requesting Entity: 797 Old Clemson Road, Columbia, SC 29229–4203

Description of Request: I have secured $2,500,000 for FN Manufacturing to continue production of the Special Operations Combat Assault Rifle (SCAR). The SCAR was selected after a full and open competition. It meets validated US SOCOM requirements for a 21st Century modular battle rifle available in 5.56 mm and 7.62 mm, and with Close Quarter Battle, Long-Range, and Sniper variants. Federal/taxpayer funding of the SCAR program will provide US Special Operations Forces with a far more effective and reliable combat rifle than the current M–4/M–16 family of rifles. In its various modular configurations, the SCAR will replace five different rifles now in use, greatly reducing the need for maintenance and logistics support and associated costs. Matching funds are not applicable. I certify that neither I nor my spouse has any financial interest in this project.

Requesting Member: Congressman JOE WILSON

Bill Number: H.R. 3326—Department of Defense Appropriations Act, 2010

Account: Research, Development, Test, and Evaluation, Army

Legal Name of Requesting Entity: Advanced Technology Institute

Address of Requesting Entity: 5300 International Blvd., North Charleston, SC 29418

Description of Request: I have secured $3,000,000 for Advanced Technology Institute to continue the Vanadium Technology Program. The Vanadium Technology Program funds the research, development and prototype-testing necessary to implement vanadium alloyed steel into warfighter protection and mobility. This funding builds on successes accomplished previously which include: reductions in weight, fabrication cost, and welding costs of 21%, 10%, and 53% respectively, leading to a smaller, higher-performing vanadium steel trailer design for the Army/Marine Joint Light Tactical Vehicle System; a longer span temporary bridge, designed by the Army Corps of Engineers and the University of South Carolina, to bridge road gaps in combat regions like Iraq; and, a new class of lighter, longer span trusses and joists, based on vanadium hot rolled steel angle shapes, have been developed and laboratory tested. Matching funds are not applicable. I certify that neither I nor my spouse has any financial interest in this project.

Requesting Member: Congressman JOE WILSON

Bill Number: H.R. 3326—Department of Defense Appropriations Act, 2010

Account: Aircraft Procurement, Army

Legal Name of Requesting Entity: South Carolina Army National Guard

Address of Requesting Entity: 1 National Guard Rd, Columbia, SC 29201

Description of Request: I have secured $3,000,000 for the South Carolina Army National Guard Vibration Management Enhancement Program (VMEP). This funding will continue fielding this proven capability on the Army National Guard's AH–64, CH–47, and UH–60 helicopter fleets. VMEP collects and utilizes information derived from onboard sensors to indicate the state and health of the helicopter drive system and rotational components. VMEP enabled the SCARNG to realize a total savings in parts costs over a 12-month period of $1.4 million, as well as an increase in mission capable rates. These funds would ensure that the South Carolina Army National Guard aviation program stays in the forefront of embedded technology doctrine. Matching funds are not applicable. I certify that neither I nor my spouse has any financial interest in this project.

Requesting Member: Congressman JOE WILSON

Bill Number: H.R. 3326—Department of Defense Appropriations Act, 2010

Account: Research, Development, Test, and Evaluation, Defense Wide

Legal Name of Requesting Entity: Two Stroke International

Address of Requesting Entity: 8 Schein Loop, Beaufort, SC 29906

Description of Request: I have secured $1,900,000 for the Non-Gasoline Burning Outboard Engine. The Navy SEAL's currently use a 30 hp and 55 hp engine on their Combat Rubber Raiding Crafts. This effort is focused on the 30 hp engine. The program name for this outboard motor project is ''Phoenix.'' The team broke down the existing motor to multiple elements; ignition system; carburetion; exhaust and intake silencing, lower unit, control apparatus, and enclosure cover. The goal of this effort is to provide the SEAL's with an advanced outboard reconnaissance engine that would burn multiple fuels (JP grades, gas, diesel, alcohol). It will be quiet for stealthy operations, have an extended fuel range using a microwave ignition system currently in development, and a lower unit that allows it to go through mud and kelp without harming the engine. Additionally the engine will take advantage of the newest technology to be resistant to salt water that make the engines last longer, decrease weight and increase range. I certify that neither I nor my spouse has any financial interest in this project.

EARMARK DECLARATION

HON. KEN CALVERT

OF CALIFORNIA

IN THE HOUSE OF REPRESENTATIVES

Wednesday, July 29, 2009

Mr. CALVERT. Madam Speaker, pursuant to the Republican Leadership standards on earmarks, I am submitting the following information regarding an earmark I received as part of the House-passed version of H.R. 3326—Department of Defense Appropriations Act for Fiscal Year 2010.

Requesting Member: Congressman KEN CALVERT

Bill Number: H.R. 3326

Account: Navy Research and Development—0604215N

Legal Name of Requesting Entity: U.S. Navy; Naval Surface Warfare Center, Corona Division

Address of Requesting Entity: Naval Surface Warfare Center, Corona Division, Corona, CA 92878–5000

Description of Request: I have secured $5,800,000 for the Measurement Standards Research and Development Program. The program includes testing for electro-optic and night vision systems; chem/bio and radiation detection systems; advanced sensor technologies; nano-technology. It also provides for improved and state of the art measurement calibration systems that ensure an accurate traceability of measurement from the weapon system parameter to National Standards maintained at NIST. Without adequate measurement capability, verification of performance for weapon and detection system readiness is not possible. This project results in the development of the measurement standards and calibration systems necessary to provide traceable measurements. These state-of-the-art measurement standards often reside at NIST and thus provide benefit to other federal agencies and industry as well. This project allows the Navy to make correct test decisions that ensure mission success and safety while reducing the cost of unnecessary rework. Substantial cost savings have resulted from past R&D project funding through this program.

Requesting Member: Congressman KEN CALVERT

Bill Number: H.R 3326

Account: Microelectonic Technology Development and Support—0603720S

Legal Name of Requesting Entity: Center for Nanoscale Science and Engineering, University of Riverside, California

Address of Requesting Entity: 900 University Avenue, Riverside, California 92521

Description of Request: I have secured $6,000,000 for the Center for Nanoscale Science and Engineering. The funds will be used for the 3–D Electronics program which aims to take advantage of recent advances in nanomaterials and nanodevices to begin to address the issue necessary to take the electronics industry beyond the two-dimensional silicon based devices and wiring and to develop high density, 3D-electronics technology together with associated packaging, heat dissipation solutions and the investigation of alternative electronic materials. Conventional electronics is based on 2D planar processes, but this is becoming prohibitively expensive as well as a barrier to performance. By stacking devices and interconnecting them in a 3D arrangement, a huge leap in functionality density is possible. 3D integration is a cornerstone of the coming revolution in electronics.

Requesting Member: Congressman KEN CALVERT

Bill Number: H.R 3326

Account: Navy Research and Development—0603739N

Legal Name of Requesting Entity: U.S. Navy; Naval Surface Warfare Center, Corona Division

Address of Requesting Entity: Naval Surface Warfare Center, Corona Division, Corona, CA 92878–5000

Description of Request: I have secured $1,800,000 for the NSWC Corona IUID Center which provides technical support, implementation assistance, training, and lessons learned for IUID, a DoD mandate, to various DoD programs and offices. The IUID Center leverages complementary efforts and catalogs, distributes lessons learned, and helps streamline implementation efforts, reducing IUID implementation cost. IUID itself will enable lifecycle traceability and improve data integrity, leading to more informed decisions and improved asset management. Substantial cost savings result from IUID implementation in DoD programs as well as major gains in asset management and tracking of critical DoD material.

Requesting Member: Congressman KEN CALVERT

Bill Number: H.R 3326

Account: Operation & Maintenance; 1C8C Depot Operations Support

Legal Name of Requesting Entity: U.S. Navy; Naval Surface Warfare Center, Corona Division

Address of Requesting Entity: Naval Surface Warfare Center, Corona Division, Corona, CA 92878–5000

Description of Request: I have secured $2,400,000 for the NSWC, Corona Fleet Readiness Data Assessment project which will update/replace existing tools to enable the accurate, efficient collection and transmission of data to quickly perform detailed readiness analyses. It will take advantage of the improved automation and data collection capability provided by the METBENCH calibration system. The analyses resulting from this project will quickly put accurate readiness information into the hands of Navy decision-makers and accelerate the savings resulting from METBENCH implementation in the Navy.

Requesting Member: Congressman KEN CALVERT

Bill Number: H.R 3326

Account: Operation and Maintenance, Navy—03 Training and Recruiting 3A2J

Legal Name of Requesting Entity: U.S. Naval Sea Cadet Corps

Address of Requesting Entity: U.S. Naval Sea Cadet Corps; 2300 Wilson Blvd, North, Arlington, VA 22201–3308

Description of Request: I have secured $651,000 for the U.S. Naval Sea Cadet Program. The Sea Cadet Program is focused upon development of youth ages 11–17, serving almost 9,000 Sea Cadets and adult volunteers in 387 units country-wide. It promotes interest and skill in seamanship and aviation and instills qualities that mold strong moral character in an anti-drug and anti-gang environment. Summer training onboard Navy and Coast Guard ships and shore stations is a challenging training ground for developing self-confidence and self-discipline, promotion of high standards of conduct and performance and a sense of teamwork. Funds will be utilized to ‘‘buy down’’ the out-of-pocket expenses for training to $120/week. NSCC instills in every Cadet a sense of patriotism, courage and the foundation of personal honor. A significant percent of Cadets join the Armed Services often receiving accelerated advancement, or obtain commissions. The program has significance in assisting to promote the Navy and Coast Guard, particularly in those areas of the U.S where these Services have little presence.

CITY OF BRANDON, MISSISSIPPI NAMED AS ONE OF THE BEST PLACES TO LIVE IN 2009

HON. GREGG HARPER

OF MISSISSIPPI

IN THE HOUSE OF REPRESENTATIVES

Wednesday, July 29, 2009

Mr. HARPER. Madam Speaker, the City of Brandon, Mississippi was recently named as one of America's top small towns in which to live, according to Money magazine. The CNN magazine named this Rankin County city number 54 in its annual list of 100 Best Places to Live. As a city in the Third Congressional District, which I am proud to represent, Brandon is the only Mississippi municipality to make the 2009 list.

The list of 100 American municipalities compares communities with populations of less than 50,000 and takes into account an area's school system, crime rate, median income and racial makeup.

Brandon's job growth was 30.4 percent from 2000–2008 versus about 19.6 percent nationally and the city posts a median income of $77,679. The city's population is currently 20,600, up from 16,436 in 2000 according to the latest census figures.

A low crime rate was also a key point for Brandon making the study. This is why many of the city's residents consider locking their doors as optional.

Brandon Mayor Tim Coulter said, ‘‘I think people are finding out what we've known for years, that Brandon is a great place to live.’’

Rankin County Chamber of Commerce director Gale Martin attributes this honor to Brandon's quality of life. He said, ‘‘You've got a small-town atmosphere with the big-city amenities,’’ said Martin. Martin credits quality schools, closeness to cities like Jackson, Meridian and Vicksburg and its short distance from Jackson-Evers International Airport to spurring Brandon's tremendous growth.

The residents of Brandon should also share the honor of this national recognition. Since 1829, residents, first responders, school teachers, pastors and local elected officials have worked tirelessly to ensure that Brandon maintains its standing as the ‘‘City of Red Hills with Golden Opportunities.’’ I salute Brandon, Mississippi and the State of Mississippi, both great places to live in America.

EARMARK DECLARATION

HON. ELTON GALLEGLY

OF CALIFORNIA

IN THE HOUSE OF REPRESENTATIVES

Wednesday, July 29, 2009

Mr. GALLEGLY. Madam Speaker, pursuant to the Republican Leadership standards on earmarks, I am submitting the following information regarding earmarks I received as part of H.R. 3326, the Department of Defense Appropriations Act, 2010:

Requesting Member: Rep. ELTON GALLEGLY

Bill: H.R. 3326, the Department of Defense Appropriations Act, 2010

Account: Research, Development, Test and Evaluation, Navy; Electronic Warfare Development

Legal Name of Requesting Entity: Regional Defense Partnership—21st Century

Address of Requesting Entity: 311 Main Road, Building 1, Point Mugu, CA 93042

Description of Request: Naval Air Warfare Center Weapons Division (NAWCWD) Point Mugu is an Electronic Warfare Center of Excellence for the development and maintenance of airborne electronic attack, tactical, and assault system platform electronic warfare (EW) systems. This request for $4,500,000 is for a laboratory upgrade at Point Mugu that would directly support EA–18G, EA–6B, MH–60, and E–2C platform development. Additionally, this enhanced capability would provide risk reduction to current acquisition programs such as the P–8A multi mission aircraft.

In order to be effective in modern battle scenarios containing multiple threats, the EW weapon system requires the exact location and type of all the threats in a 360 degree, or four quadrant, field of view. The current lab equipment is limited to simulating a 180 degree, or 2 quadrant, field of view of the battle space. The EW Center of Excellence at NAWCWD Point Mugu utilizes laboratory test equipment to simulate this complex electronic battle space. Testing that cannot be performed in the laboratory must be done using flight test hours on an open air EW range. This not only costs more, it is also very difficult to obtain test repeatability and exposes the system under test to electronic eavesdropping. No open air range can duplicate the dense electromagnetic environment of large numbers of threat and friendly emitters encountered in a modern battle scenario. This can only be replicated through laboratory simulation.

Funding is requested to upgrade the EW laboratory facility at NAWCWD Point Mugu to a four quadrant simulation capability and acquire the AMES III High Speed Calibrator and the Airborne Interceptor Simulator for real world threat simulations. The bill provides $4,000,000 in funding for this project request.

EXHIBIT 16

Press Release 1 Pryor

Senator Mark Pryor Press Releases December 22 2005 Press Release AR Lawmakers Secure Millions for Guard and Local Industries Bill Expected to be Sent to President by Week s End WASHINGTON D C U S Senators Mark Pryor and Blanche Lincoln along with Representatives Marion Berry D 1st Vic Snyder D 2nd John Boozman R 3rd and Mike Ross D 4th today announced final passage of the Fiscal Year 2006 Department of Defense DOD Appropriations Bill The bill includes significant funding for Arkansas military instillations research institutions and defense contractors Delegation members said that the 453 5 billion defense appropriations bill includes funding for military personnel operations and maintenance and equipment procurement In addition 50 billion is allotted to finance the wars in Iraq and Afghanistan for the first part of fiscal 2006 Arkansas is home to vital military installations as well as a growing cutting edge research and development industry that will bring our nation s defense capabilities to new levels Pryor said The projects in this bill reflect a year of hard work to secure funding that supports our national defense our troops in the field and Arkansas defense industry Our communities and industries in Arkansas have long played an important role in building a strong national defense Lincoln said In today s war on terror our military must have every resource they need to provide for our country s long term stability I am extremely proud of our state s significant contribution to America s national security Thanks to a united effort by Arkansas congressional delegation we were able to secure millions of dollars to support the state s growing defense industry said Berry These funds will not only improve existing military installations but advance cutting edge research that will strengthen military effectiveness and keep our troops safe as they fight overseas These projects being done right here in Arkansas demonstrate the changing nature of warfare said Snyder We must keep our edge technologically not just in education medicine or business but also in war fighting I have spent the past few days in Iraq visiting Arkansas soldiers on the front lines Boozman said They deserve the best equipment money can buy and the funds in this bill will help them get it It will also fund projects aimed at using new technologies to protect our troops I am proud that many of those advancements are being made right here at home in Arkansas The funds secured in this Defense Spending Bill will positively impact military installations and military contractors to who provide jobs and economic opportunities to Arkansas s working families Ross said During a time of war these funds are critical to homeland security and to ensuring our troops have the necessary tools to do their job safely and effectively The following Arkansas projects were included in the FY 2006 Department of Defense Appropriations Bill Russellville AR Mobile Medical Shelter 4 1 million was secured for the design and manufacturing of a new generation of mobile medical shelters Modern and sterile shelters are critical resources to medics treating military wounded on the battlefield In a partnership agreement with the City of Russellville the European Aeronautic Defense and Space EADS North America will develop two prototypes for a U S Army competition If the Army selects the EADS prototype and buys the mobile units final assembly testing and maintenance of the mobile medical shelter will take place in Russellville AR Pine Bluff AR Pine Bluff Arsenal Data Equipment Pine Bluff 7 million was secured to modernize and expand the automatic data collection capabilities at the Pine Bluff Arsenal as well as arsenals in Red River TX Anniston AL and Rock Island IL This technology will increase Army productivity and enable the real time tracking of manufacturing and distrbution of supplies including chemical and biological protection equipment Army Artillery 2 million was secured to provide the military with illumination and smoke producing artillery to support the war in Iraq Of this amount 1 million will be used to procure M485 illumination rounds and 1 million will be used for M110 smoke producing projectiles at the arsenal Jonesboro AR Standoff Sensor for Radionuclide Identification Arkansas State University 4 million was secured to invest in smart technologies called Standoff Sensor for Radionuclide Identification to detect nuclear chemical and biological weapons ASU The University of Hawaii and Florida A will continue collaborative work to expedite results on promising sensor research for the early detection of chemical and biological threats most likely to be used by terrorists Standoff Hazardous Agent Detection and Evaluation System SHADES Arkansas State University 2 million was secured to assist ASU in conjunction with industry to further sampling and analysis technologies to detect ultra low concentrations of weapons of mass destruction These technologies will include Solid Phase Micro Extraction SPME samplers and unique Gas Chromatography GC and Laser Spectroscopy LS techniques Wolverine Mountain Climbing Boots Jonesboro 1 million was secured to establish a U S production base for high performance boots for use by all special operations warfighters from all services Finding an adequate supply for high performance boots in the U S will solve the problem of outmoded and inadequate boots which has forced some unit leaders to purchase foreign off the shelf items for their personnel while others have relied on personal gear purchased at their own expense Fayetteville AR The Center for Ferroelectric Electronic Photonic Nanodevices University of Arkansas 2 million was secured to continue the Center s development of new revolutionary nano materials and breakthroughs in miniaturized electronic and photonic devices This work supports Army information and communication supremacy goals through ferroelectric and electronic photonic nanodevices Nanotechnology is a newly emerging field of science where scientists and engineers are beginning to manipulate matter at the molecular and atomic level in order to develop materials and systems with revolutionary properties The Logistics Institute University of Arkansas 1 million was secured to provide responsive cost effective methodologies to ensure readiness and sustainability for military operations TLI will aid in the development and analysis of concepts and technologies in support of Sense and Respond Logistics S to achieve the Air Force s goals in deploying current and future weapons systems Three Dimensional Packaging University of Arkansas 2 million was secured for the Three Dimensional packaging program a consortium research effort between the University of Arkansas the International Technology Center North Carolina State University and the University of Florida This is a third year program working on 3 D microcircuit packages to help the military lower the size and weight and improve thermal and electrical performance of radio communications equipment Space Photonics Intelligent Free Space Optical Satellite 3 million was secured for product development and space qualification of the critical elements of the Free Space Communications Node including high speed multi channel fiber optic transceivers high speed multi channel free space laser communications transceivers and intelligent and adaptive space communications networks This work supports the Air Force goal to improve the performance reliability and security of its space communications capability Space Photonics in Fayetteville is a growing business supporting high tech jobs in the Northwest region of Arkansas Farmington AR ZEUS Light Strike Vehicle Hybrid Electric Pilot 1 million was secured for the development of a multi purpose internally transportable off road vehicle Cal Zark is a company in Farmington that is working on the pilot project Rogers AR Machinery Control Surveillance System 3 5 million was secured for Visions Technology of Rogers to procure a machinery control surveillance system to monitor mission critical spaces aboard gas turbine ships The Naval Systems Command NAVSEA has identified the work of Visions Technology as important to the Navy s mission which demonstrates Visions rising stock as a provider of quality defense services Arkansas National Guard Meteorological Measuring Set 4 8 million will be divided among several states to support the procurement of a next generation artillery meteorological system M 22 Automatic Chemical Agent Alarm 11 2 million will be divided among several states to equip their guard units with chemical agent detection alarms The Army Guard has a requirement for over 19 000 such alarms and has only 231 Highland Park Camden AR Standard Missile Modifications 3 75 million was secured to modernize the rocket motors on about half of the missiles that would otherwise expire by 2010 due to age As part of its ongoing Standard Missile Service Life Extension Program SLEP the Navy qualified a rocket motor regrain process that re uses the major subcomponents thereby providing a new rocket motor at approximately 50 of the cost and in half the time required for a motor Standard Missile Improvements 1 3 million was secured to obtain new technologies to improve mature production weapons systems This additional funding will continue the Navy s FY05 effort to evaluate IM technology for inclusion on the Standard Missile in order to provide sailors with the safest weapon systems possible Hydra 70 70 mm 2 75 inch Rockets 156 8 million was protected for the Hydra 70 rocket system used by Army Navy Marine Corps and Special Operations helicopters and Navy Marine and Air Force jet aircraft The system is an effective area suppression weapon which has seen use most recently in Afghanistan and Iraq The Hydra 70 family of rockets includes seven different tactical warheads that provide combat overmatch and ensure a near term 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Press Release 2 Lincoln

AR Lawmakers Secure Millions for Guard and Local Industries Both AR Lawmakers Secure Millions for Guard and Local Industries FOR IMMEDIATE RELEASE December 22 2005Contact Katie Laning 202 224 4843 WASHINGTON D C U S Senators Blanche Lincoln and Mark Pryor along with Representatives Marion Berry D 1st Vic Snyder D 2nd John Boozman R 3rd and Mike Ross D 4th today announced final passage of the Fiscal Year 2006 Department of Defense DOD Appropriations Bill The bill includes significant funding for Arkansas military instillations research institutions and defense contractors Delegation members said that the 453 5 billion defense appropriations bill includes funding for military personnel operations and maintenance and equipment procurement In addition 50 billion is allotted to finance the wars in Iraq and Afghanistan for the first part of fiscal 2006 Our communities and industries in Arkansas have long played an important role in building a strong national defense Lincoln said In today s war on terror our military must have every resource they need to provide for our country s long term stability I am extremely proud of our state s significant contribution to

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EXHIBIT 17

107TH CONGRESS
1st Session

HOUSE OF REPRESENTATIVES

REPORT
107–298

DEPARTMENT OF DEFENSE APPROPRIATIONS BILL, 2002 AND SUPPLEMENTAL APPROPRIATIONS, 2002

R E P O R T

OF THE

COMMITTEE ON APPROPRIATIONS

[TO ACCOMPANY H.R. 3338]

together with

ADDITIONAL VIEWS

NOVEMBER 19, 2001.—Committed to the Committee of the Whole House on the State of the Union and ordered to be printed

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DIVISION A—DEPARTMENT OF DEFENSE APPROPRIATIONS BILL, 2002

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TITLE II. OPERATION AND MAINTENANCE—Continued

DIVISION B—FISCAL YEAR 2002 SUPPLEMENTAL APPROPRIATIONS

Navy and the Air Force to work together and by June 1, 2002, submit to the Committee a joint requirement and a development and procurement strategy to meet the requirement.

RESEARCH, DEVELOPMENT, TEST AND EVALUATION, ARMY

Fiscal year 2001 appropriation	$6,342,552,000
Fiscal year 2002 budget request	6,693,920,000
Committee recommendation	7,115,438,000
Change from budget request	421,518,000

This appropriation finances the research, development, test and evaluation activities of the Department of the Army.

Committee Recommendations

EXPLANATION OF PROJECT LEVEL CHANGES

[In thousands of dollars]

	Budget request	Committee recommended	Change from request
DEFENSE RESEARCH SCIENCES	138,281	146,150	+7,869
Advanced Target Recognition using Nanotechnologies			2,000
PASIS: Perpetually Assailable and Secure Information Systems, Research, Training and Education			7,500
Scientific Problems with Military Applications			−1,631
UNIVERSITY AND INDUSTRY RESEARCH CENTERS	69,147	77,347	+8,200
Center for Optics Manufacturing-Advanced Optics Program			3,000
Global Information Portal			1,200
Thermal Fluid Design Tool			2,000
Virtual Parts Engineering Research Center (Note: only for expansion of Design Immersion System Environment)			2,000
SENSORS AND ELECTRONIC SURVIVABILITY	25,797	28,797	+3,000
Passive Millimeter Wave Camera (Note: only for the purpose of providing additional flight worthy PMMW imagers to conduct flight tests in adverse weather, nap-of-the-earth navigation scenarios, including flight demonstrations of covert personnel location under the DoD's Personnel Recovery/Extraction Aided by Smart Sensor (PRESS) ACTD program)			3,000
AVIATION TECHNOLOGY	49,265	40,029	−9,236
National Rotocraft Tech Center			−9,236
MISSILE TECHNOLOGY	40,112	57,612	+17,500
Acceleration of Development and Testing for tactical missile components			3,500
MEMS/GPS/IMU Integration (Note: only to accelerate and focus efforts to significantly lower the cost and improve the performance of guidance sets for precision/guided munitions. Activities should focus on accelerated development of high-g one-degree per hour IMU's, and hardware/software development of "ultra-deep GPS/INS coupling" to improve anti-jam performance at low cost.)			10,000
Loitering Attack Munition for Aviation (LAM–A)			4,000
ADVANCED WEAPONS TECHNOLOGY	19,043	27,982	+8,939
Cooperative Micro-Satellite Experiment (CMSE)			8,000
Microelectro Mechanical Systems			9,500
Miniature Detection Devices and Analysis Methods			1,850
Rapid Target Acquisition & Tracking System (RTATS)			2,000
Reduce programmed growth			−12,411
MODELING AND SIMULATION TECHNOLOGY	20,579	28,579	+8,000
On-Line Contract Document Management			1,000
Modeling, Simulation and Training Infrastructure & Community Development			7,000
COMBAT VEHICLE AND AUTOMOTIVE TECHNOLOGY	82,441	86,441	+4,000
Combat Vehicle Transportation Technologies Program: Calstart/WestStart Electric Hybrid Technology			2,000

[In thousands of dollars]

	Budget request	Committee recommended	Change from request
Integration of Army Voice Interactive Device with an onboard central processing unit (Note: only to continue integration of AVID into the Smart Truck's voice activated central processing computer.)			2,000
CHEMICAL, SMOKE AND EQUIPMENT DEFEATING TECHNOLOGY	3,561	11,561	+8,000
Thermobaric Warhead Development			2,000
U.S. Army Center of Excellence in Biotechnology			6,000
WEAPONS AND MUNITIONS TECHNOLOGY	35,549	65,549	+30,000
Cooperative Energetics Initiative			2,000
Corrosion Measurement and Control			5,000
Future Combat System Propellant and Survivability			4,000
Green Armaments Technology (GAT)			7,500
Liquidmetal Alloy-Tungsten (LA–T) Armor Piercing Ammunition			4,000
Multiple Explosively-Formed Penetrators			2,000
Single Crystal Tungsten Alloy Penetrator			4,000
Smart Coatings			1,500
ELECTRONICS AND ELECTRONIC DEVICES	27,819	47,319	+19,500
Cylindrical Zinc Air Battery for Land Warrior System			1,500
Electronic Display Research			5,000
Fuel Cell Power Systems			5,000
Improved High Rate Alkaline Cell			1,000
Logistics Fuel Reformer			2,500
Low Cost Reusable Alkaline Manganese-Zinc			500
Polymer Extrusion/Multilaminate (Battery research)			3,000
Rechargeable Cylindrical Cell System			1,000
NIGHT VISION TECHNOLOGY	20,598	23,598	+3,000
Dual band detector imaging technology			3,000
COUNTERMINE SYSTEMS	16,689	22,689	+6,000
Acoustic Mine Detection			4,000
Integrated Countermine Testbed and Training Project			2,000
HUMAN FACTORS ENGINEERING TECHNOLOGY	16,466	21,966	+5,500
MedTeams (Medical Error Reduction Research)			3,500
Soldier Centered Design Tools for the Army			2,000
ENVIRONMENTAL QUALITY TECHNOLOGY	16,150	21,150	+5,000
Transportable Detonation Chamber Validation			5,000
Rangesafe Demonstration Program			5,000
Duplicative Technology Research			−5,000
MILITARY ENGINEERING TECHNOLOGY	42,850	60,850	+18,000
Climate Change Fuel Cell Program (Buydown)			7,000
DoD Fuel Cell Test and Evaluation Center			6,000
Ft. George G. Meade Fuel Cell Demonstration			5,000
WARFIGHTER TECHNOLOGY	27,061	34,561	+7,500
Airbeam Manufacturing Process (lightweight transportable military shelter technology)			1,000
Center for Reliable Wireless Communications Technology for Digital Battlefield (NDU)			1,000
Combat Feeding (Note: Only to continue research on food and fielding technologies to improve food quality to the warfighter.)			2,500
Standoff Precision Aerial Delivery System (S/PADS)			3,000
MEDICAL TECHNOLOGY	82,494	104,994	+22,500
Diabetes Project (Pittsburgh)			6,000
Emergency Hypothermia for Advanced Combat Casualty and delayed resuscitation			3,000
Medical Area Network for Virtual Technologies			8,000
Osteoporosis Research			4,000
Speech Capable Personal Digital Assistant			1,500
DUAL USE SCIENCE AND TECHNOLOGY	10,045	15,045	+5,000
Manufacturing RDE Center for Nanotechnologies			5,000
WARFIGHTER ADVANCED TECHNOLOGY	60,332	58,017	−2,315
Advanced Personal Navigation Technology MEMS INS/GPS precision location information			4,000
Metrology			1,500
Pneumatic Muscle Soft Landing Technology			1,000
Force Projection Logistics			−2,500

[In thousands of dollars]

	Budget request	Committee recommended	Change from request
Portable Cooling System Development (Note: only for heat actuated cooling for FCS apparel)	....	....	1,000
Warfighter Advanced Technology	....	....	−7,315
MEDICAL ADVANCED TECHNOLOGY	17,541	212,541	+195,000
Advanced Diagnostics and Therapeutic Digital Technologies	....	....	+2,500
Artificial Hip (Volumetrically Controlled Manufacturing)	....	....	5,000
Biology, Education, Screening, Chemoprevention and Treatment (BESCT) Lung Cancer Research Program	....	....	6,000
Biosensor Research	....	....	3,500
Blood Safety (Note: only for the continuation of the current program to provide improved blood products and safety systems compatible with military field use.)	....	....	8,000
Brain Biology and Machine	....	....	4,000
Cancer Center of Excellence (Notre Dame)	....	....	3,000
Center for Integration of Medicine and Innovative Technology—Computer-assisted minimally invasive surgery	....	....	10,000
Center for Untethered Healthcare at Worcester Polytechnic Institute	....	....	2,000
Comprehensive Neuroscience Center (Note: only for a public/private comprehensive program in neurosciences for DoD medical beneficiaries in the areas of brain injury, headache, seizures/epilepsy, and other degenerative disorders. It shall be a coordinated effort among Walter Reed Army Medical Center, the Uniformed Services University of the Health Sciences, an appropriate non-profit medical Foundation, and a primary health care center, with funding management accomplished by the Uniformed Services University of the Health Sciences.)	....	....	8,000
Continous Expert Care Network Telemedicine Program	....	....	3,000
Controlling Mosquito and Tick Transmitted Disease	....	....	3,500
Disaster Relief and Emergency Medical Services (DREAMS)	....	....	8,000
Fragile X (Note: only to support an intervention study aimed at finding effective methods of treatment—both pharmacological and nonpharmacological—for the symptoms and behavioral problems associated with Fragile X Syndrome.)	....	....	1,000
Hemoglobin Based Oxygen Carrier	....	....	2,000
Hepatitis C	....	....	4,000
Joint U.S.-Norwegian Telemedicine	....	....	2,000
Joslin Diabetes Research—eye care	....	....	6,000
Life Support for Trauma and Transport (LSTAT)	....	....	3,500
Secure Telemedicine Technology Program (Note: only for C Suite of secure, Scalable, customizable and internet-based telemedicine solutions able to be used with a variety of operating platforms)	....	....	4,000
Memorial Hermann Telemedicine Network	....	....	1,000
Molecular Genetics and Musculoskeletal Research Program (Note: only to continue the current Army program.)	....	....	9,000
Monoclonal Antibodies, Massachusetts Biological Lab	....	....	2,000
Emergency Telemedicine Response and Advanced Technology Program	....	....	3,000
National Medical Testbed (Note: the Committee provides $4,000,000 only for for on-going programs, and $5,000,000 only for recipient Emergency/Trauma Care advanced technology programs	....	....	9,000
Neurofibromatosis Research Program (NF)	....	....	25,000
Neurology Gallo Center-alcoholism research	....	....	8,000
Neurotoxin Exposure Treatment Research Program (NETRP) Parkinsons & neurological disorders	....	....	20,000
Polynitroxylated Hemoglobin	....	....	1,000
Retinal Scanning Display Technology	....	....	3,000
Saccadic Fatigue Measurement	....	....	1,000
SEAtreat cervical cancer visualization and treatment	....	....	3,500
Smart Aortic Arch Catheter	....	....	1,000
Synchrotron Based Scanning Research (Note: only to continue the current Army Synchrotron-based scanning program, to begin protocol testing for delivery to patients and to expand this service into the arena of proton telemedicine.)	....	....	10,000

[In thousands of dollars]

	Budget request	Committee recommended	Change from request
U.S. Army Center of Excellence in Biotechnology			7,500
Veterans Collaborative Care Model Program			2,000
AVIATION ADVANCED TECHNOLOGY	44,843	36,545	−8,298
Aviation Advanced Technology (Note: only for Airborne Manned/Unmanned System Technology (AMUST) Wideband RF Network)			3,000
Aviation Advanced Technology (Note: only for design, development, test and demonstration of a turbo shaft engine for use in UAVs)			5,000
Aviation Advanced Technology-Reduce programmed growth			−16,298
WEAPONS AND MUNITIONS ADVANCED TECHNOLOGY	29,684	39,684	+10,000
Low Cost Course Correction Technology			5,000
SMAW–D Shoulder-Launched Multipurpose Assault Weapon & Munitions Engineering Development			5,000
COMBAT VEHICLE AND AUTOMOTIVE ADVANCED TECHNOLOGY	193,858	222,358	+28,500
Aluminum Reinforced Metal Matrix Composites for Track Shoes			5,000
Combat Vehicle Research-Weight Reduction			7,000
Electrochromatic Glass for Combat Vehicles (Note: only to the National Automotive Center for research and development of inorganic electrochromatic materials and processing for combat vehicle smart, switchable windows.)			2,000
Fuel Catalyst Research Evaluation			500
Mobile Parts Hospital			7,000
Movement Tracking System (MTS) for Family of Heavy Tactical Vehicles			2,000
NAC Standardized Exchange of Product Data (N–STEP) Combat Vehicle Automotive Advanced Technology			5,000
COMMAND, CONTROL, COMMUNICATIONS ADVANCED TECHNOLOGY	31,865	35,865	+4,000
Battlefield Ordnance Awareness			4,000
EW TECHNOLOGY	13,868	24,368	+10,500
Multi-functional Intelligence and Remote Sensor System			5,500
Shortstop (SEPS)			5,000
MISSILE AND ROCKET ADVANCED TECHNOLOGY	59,518	77,018	+17,500
Missile Recycling Program (Note: Only to transition the AMCOM-developed Missile Recycling Capabilities (MRC) technologies to the Anniston Munitions Center to establish an organic MRC.)			5,000
Standoff NATO International Precision Enhanced Rocket (SNIPER) Laser Guidance for 2.75 in. Rocket			3,000
Volumetrically Controlled Manufacturing (VCM) Composites Technology			3,500
Wide Bandwith Technology			6,000
LINE-OF-SIGHT TECHNOLOGY DEMONSTRATION	57,384	70,456	+13,072
Transfer from Missile Procurement, Army			13,072
NIGHT VISION ADVANCED TECHNOLOGY	37,081	56,581	+19,500
BUSTER Backpack UAV (Note: only for continued development of the backpack unmanned autonomous sensor for surveillance and target acquisition to enhance reconnaissance (BUSTER) UAV)			7,000
Helmut Mounted Infa-Red Sensor System			2,500
Night Vision Advanced Technology-Digital Fusion			7,000
Soldier Vision 2000 (through wall surveillance radar)			3,000
ENVIRONMENTAL QUALITY TECHNOLOGY DEMONSTRATIONS	4,826	9,826	+5,000
Proton Exchange Membrane (PEM) fuel cell demonstration (Note: only for the demonstration of domestically produced PEM fuel cells on military facilities)			5,000
ARMY MISSILE DEFENSE SYSTEMS INTEGRATION (DEM/VAL)	19,491	37,491	+18,000
Advanced Warfare Environment (AWarE) (Note: only for acquisition of commercial technology solutions for the Advanced Warfare Environment (AWarE) Deployed Access to imagery archives)			1,000
Micropower Devices for Missile Defense Applications			1,000
Reduce programmed growth			-1,000
Super Cluster Distributed Memory Technology			4,000
THEL			10,000
Thermionic Technology			3,000
TANK AND MEDIUM CALIBER AMMUNITION	32,986	51,000	+18,014

[In thousands of dollars]

	Budget request	Committee recommended	Change from request
Conventional tank ammunition			-2,986
Global Positioning System Interference Suppression (GPS ISU)			1,000
TERM TM3			5,000
XM 1007 Tank Extended Range Munition (TERM)			15,000
SOLDIER SUPPORT AND SURVIVABILITY	17,482	14,000	-3,482
Reduce programmed growth			-3,482
NIGHT VISION SYSTEMS ADVANCED DEVELOPMENT	12,756	10,000	-2,756
Reduce programmed growth			−2,756
ENVIRONMENTAL QUALITY TECHNOLOGY DEM/VAL	7,536	37,036	+29,500
Plasma Energy Pyrolysis (Note: only for the installation and demonstration of an on-site operational Plasma Energy Pyrolysis System at Anniston Army Depot at Anniston, Alabama, for the demonstrated destruction of toxic and hazardous waste streams generated on-site.)			6,000
Commercializing Dual Use Technologies			8,000
Environmental Cleanup Demonstration (Note: only to demonstrate and validate new environmental cleanup technology at Porta Bella)			5,000
Fort Ord Cleanup Demonstration Project			4,000
Technology Development for unexploded ordnance in support of military readiness (Note: only for the National Center for Environmental Excellence to demonstrate and validate technology to efficiently identify, characterize, and neutralize unexploded ordnance to support military readiness, promote humanitarian assistance activities, and advance peacekeeping combat missions.)			4,000
Vanadium Technology Program			2,500
AVIATION—ADV DEV	9,105	13,105	+4,000
Virtual Cockpit Optimization			4,000
WEAPONS AND MUNITIONS—ADV DEV	31,670	35,670	+4,000
Precision Guided Mortor Munition			4,000
LOGISTICS AND ENGINEER EQUIPMENT-ADV DEV	7,456	8,456	+1,000
Man Tech-Cylindrical Zinc Batteries for Land Warrior System			1,000
MEDICAL SYSTEMS—ADV DEV	15,506	16,506	+1,000
IMED Tools Rural Mobile Communications Platform			1,000
MEADS CONCEPTS–DEM/VAL	73,645	0	−73,645
Transfer to Title IX—RDTE, BMDO			−73,645
AIRCRAFT AVIONICS	57,474	58,974	+1,500
Airborne Separation Video System (ASVS)			1,500
COMANCHE	787,866	816,366	+28,500
Transfer from Missile Procurement, Army			28,500
EW DEVELOPMENT	57,010	61,010	+4,000
ATIRCM/CMWS-Installed Systems Test Facility at CECOM			4,000
ALL SOURCE ANALYSIS SYSTEM	42,166	45,666	+3,500
All Source Analysis System (Note: only for the development of the Intelligence Analysis Advanced Tool Sets (IAATS) Communications Control Sets for ASAS)			2,000
ASAS Light			1,500
COMMON MISSILE	16,731	10,927	−5,804
Reduce programmed growth			−5,804
JAVELIN	492	5,492	+5,000
Javelin Pre-Planned Product Improvements			5,000
TACTICAL UNMANNED GROUND VEHICLE (TUGV)	0	3,000	+3,000
Viking Mine Clearing System			3,000
NIGHT VISION SYSTEMS–ENG DEV	24,201	28,201	+4,000
Avenger Upgrade of First Generation FLIR (Only for the Navy Center of Excellence in ElectroOptics Manufacturing to finalize technology transfer and fabricate a pilot quantity to validate manufacturing technology.)			4,000
AIR DEFENSE COMMAND, CONTROL AND INTELLIGENCE–ENG DEV	18,233	21,233	+3,000
Air Defense Alerting Device (ADAD) for Avenger			3,000
AUTOMATIC TEST EQUIPMENT DEVELOPMENT	11,582	13,582	+2,000
Integrated Family of Test Equipment			2,000
AVIATION—ENG DEV	2,263	4,763	+2,500

[In thousands of dollars]

	Budget request	Committee recommended	Change from request
CH–47 Cockpit Airbag System			2,500
WEAPONS AND MUNITIONS—ENG DEV	7,046	21,046	+14,000
Common Remotely Operated Weapon Station (CROWS)			4,000
M795E1 155mm Extended Range, High Explosive Base Burner Projectile			3,000
Shoulder-Launched Multipurpose Assault Weapon-Disposable Confined Space			5,000
Small Arms Fire Control System II (MK–19 Grenade Launcher, M–2, .50 Cal., .50 Cal. Sniper Rifle)			2,000
LOGISTICS AND ENGINEER EQUIPMENT—ENG DEV	30,673	35,973	+5,300
Intelligent Power Management for Shelters and Vehicles			5,300
COMMAND, CONTROL, COMMUNICATIONS SYSTEMS—ENG DEV	122,644	132,644	+10,000
Applied Communications and Information Networking (Note: The Committee commends CECOM for their aggressive implementation of ACIN and recommends the Army work with the ASD(C31) to ensure the applicability of the ACIN to the overall DoD communications architecture.)			10,000
MEDICAL MATERIEL/MEDICAL BIOLOGICAL DEFENSE EQUIPMENT	8,228	10,228	+2,000
Cartledge Infuser			2,000
LANDMINE WARFARE/BARRIER—ENG DEV	89,153	69,153	−20,000
Reduce programmed growth			−20,000
ARTILLERY MUNITIONS—EMD	67,258	63,322	−3,936
Trajectory Correctable Munitions (TCM) Sense and Destroy Armament Missile Engineering Development			5,000
Reduce programmed growth			−8,936
ARMY TACTICAL COMMAND & CONTROL HARDWARE & SOFTWARE	50,887	58,887	+8,000
Next Generation Command and Control System (Note: only for Advanced Warfare Environment 3-dimension display technology to support Army's C2 modernization.)			8,000
PATRIOT PAC–3 THEATER MISSILE DEFENSE ACQUISITION	107,100	0	−107,100
Transfer to Title IX—RDTE, BMDO			−107,100
THREAT SIMULATOR DEVELOPMENT	16,011	18,011	+2,000
Threat Simulator Development-Anti Tank Guided Missile Program			2,000
RAND ARROYO CENTER	19,972	17,972	−2,000
Reduce FFRDC/CAAS			−2,000
CONCEPTS EXPERIMENTATION PROGRAM	33,067	35,067	+2,000
Battlelab Cooperative and Collaborative Research			4,000
Concepts Experimentation Program (Note: only for acquisition of commercial licenses and integration support for commercial geo-spatial distributed data visualization and management network at Ft. Huachuca Army Battle Lab.)			6,000
MANPRINT Analysis			2,000
Reduce programmed growth			−10,000
ARMY TECHNICAL TEST INSTRUMENTATION AND TARGETS	34,259	35,009	+750
ACES			750
SURVIVABILITY/LETHALITY ANALYSIS	27,794	37,794	+10,000
Information Operations/Vulnerability and Survivability Analysis (IOVSA)			10,000
DOD HIGH ENERGY LASER TEST FACILITY	14,570	19,570	+5,000
Manufacturing of solid state laser diode arrays for the Solid State Heat Capacity Laser			5,000
SUPPORT OF OPERATIONAL TESTING	89,047	94,047	+5,000
MATTRACKS			5,000
PROGRAMWIDE ACTIVITIES	69,096	60,096	−9,000
Reduce programmed growth			−9,000
TECHNICAL INFORMATION ACTIVITIES	33,749	43,749	+10,000
Army High Performance Computing Research Center			15,000
Reduce programmed growth			−5,000
MUNITIONS STANDARDIZATION, EFFECTIVENESS AND SAFETY	16,072	34,072	+18,000
Public Private Partnering Initiative			15,000
Cryofracture Anti-personnel Mine Disposal System (Note: only to continue current anti-personnel mine disposal program.)			3,000
DOMESTIC PREPAREDNESS AGAINST WEAPONS OF MASS DESTRUCT	0	3,000	+3,000

[In thousands of dollars]

	Budget request	Committee recommended	Change from request
WMD First Responder Training at the National Terrorism Preparedness Institute			3,000
COMBAT VEHICLE IMPROVEMENT PROGRAMS	195,602	168,141	−27,461
Combat Vehicle Improvement Programs			5,000
Reduce programmed growth			−32,461
AIRCRAFT MODIFICATIONS/PRODUCT IMPROVEMENT PROGRAMS	143,631	132,431	−11,200
Guardrail/Aerial Common Sensor termination of JSAF/LBSS			−11,200
AIRCRAFT ENGINE COMPONENT IMPROVEMENT PROGRAM	13,017	17,017	+4,000
Universal Full Authority Digital Engine Control (FADEC)			2,000
VDVP and LOLA Equipped Fuel Delivery Unit			2,000
DIGITIZATION	29,302	36,302	+7,000
Digitization (Note: only to conduct battalion level testing of the digital intelligence situation mapboard.)			2,000
University XXI Effort—Digitization at Ft. Hood			5,000
RAPID ACQ PROGRAM FOR TRANSFORMATION	23,593	0	−23,593
Reduction			−23,593
OTHER MISSILE PRODUCT IMPROVEMENT PROGRAMS	84,935	78,935	−6,000
Reduce programmed growth			−6,000
TRACTOR CARD	6,551	11,551	+5,000
Transfer from Missile Procurement, Army (IBCT Studies)			5,000
SECURITY AND INTELLIGENCE ACTIVITIES	452	2,452	+2,000
Security & Intelligence Activities (Note: only for continued development of information technology support at INSOCM's Information Dominance Center.)			2,000
SATCOM GROUND ENVIRONMENT (SPACE)	47,647	39,347	−8,300
STAR-T termination			−8,300
AIRBORNE RECONNAISSANCE SYSTEMS	6,862	12,862	−6,000
Hyperspectral long-wave imager			6,000
DISTRIBUTED COMMON GROUND SYSTEMS (JMIP)	85,242	72,742	−12,500
Transfer to Tactical Surveillance System and Guardrail Modifications			−12,500
END ITEM INDUSTRIAL PREPAREDNESS ACTIVITIES	45,697	66,697	+21,000
MANTECH for Munitions			16,000
Totally Integrated Munitions Enterprise (TIME)			6,000
Laser Peening Technology for Aircraft and Ground Equipment			2,000
Rechargeable Bipolar Wafer Cell NiMH Battery for SINCGARS			1,000
Femtosecond Laser			6,000
Reduced program growth			−10,000

ARMY VENTURE CAPITAL SCIENCE AND TECHNOLOGY DEMONSTRATION

The Committee believes the Army must do much more to improve its ability to exploit advanced technology in a timely and efficient manner if it is to meet the ambitious timelines it has established for transformation. The Army's transformation plan is dependent on significant technological advances in weapons, armor, communications and propulsion systems, many of which will originate in the commercial technology development sector. Private companies have outspent the federal government in applied research for several years now and are spending a large and growing share of the country's basic research dollars. Unfortunately, while the Army leadership has recognized the growing need to tap the commercial technology sector, the Army R&D community appears to be experiencing continuing difficulty in developing better collaborative ties with the young, small, growth-oriented companies that take risks and push innovation. This appears to be due in part to the rigidity of traditional contracting mechanisms as well as an acquisition culture that has little concern for the business needs and methods of the commercial world. The Committee sees little hope

EXHIBIT 18

111TH CONGRESS
1st Session

HOUSE OF REPRESENTATIVES

REPORT
111–230

DEPARTMENT OF DEFENSE APPROPRIATIONS BILL, 2010

R E P O R T

OF THE

COMMITTEE ON APPROPRIATIONS

[TO ACCOMPANY H.R. 3326]

JULY 24, 2009.—Committed to the Committee of the Whole House on the State of the Union and ordered to be printed

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[In millions of dollars]

	Budget authority	Outlays
Financial assistance to State and local governments for 2010	2	[1] 2

[1] Excludes outlays from prior year budget authority.

DISCLOSURE OF EARMARKS AND CONGRESSIONALLY DIRECTED SPENDING ITEMS

The Committee has taken unprecedented action to increase transparency and reduce funding for earmarks. In fiscal year 2009, this bill reduced earmarks by 42 percent from the fiscal year 2006 level. The bill continues to reduce earmarks in fiscal year 2010. For fiscal year 2010, earmarks are expected to be 50 percent below the fiscal year 2006 level. It should also be noted that under the policies adopted by the Committee, member earmarks will no longer be provided to for-profit entities as a functional equivalent of no-bid contracts. In cases where the Committee is funding an earmark designated by a member for a for-profit entity, the Committee includes legislative language requiring the Executive Branch to nonetheless issue a request for proposal that gives other entities an opportunity to apply and requires the agency to evaluate all bids received and make a decision based on merit. This gives the original designee an opportunity to be brought to the attention of the Department, but with the possibility that an alternative entity may be selected.

2006 Enacted	2008 Enacted		2009 Enacted		2010 Committee	
$ in millions	#	$ in millions	#	$ in millions	#	$ in millions
$8,400	2,048	$4,982	2,025	$4,866	1,102	$2,709

The following table is submitted in compliance with clause 9 of rule XXI, and lists the congressional earmarks (as defined in paragraph (e) of clause 9) contained in the bill or in this report. Neither the bill nor the report contain any limited tax benefits of limited tariff benefits as defined in paragraphs (f) or (g) of clause 9 of rule XXI.

DEFENSE
[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
AP,A	Army CH-47 Helicopter Forward and Aft Hook Project	$3,000,000	Baird
AP,A	Army National Guard UH-60 Rewiring Program	$10,000,000	Granger
AP,A	Civil Support Communications Systems for KY-ARNG UH-60 Aircraft	$2,000,000	Rogers (KY)
AP,A	Forward Looking Infrared sensors for UH-60 Medevac Helicopters for the Minnesota National Guard	$1,000,000	Oberstar
AP,A	Internal Auxiliary Fuel Tank System	$3,000,000	Franks (AZ); Bishop (UT); Pastor (AZ)
AP,A	Vibration Management Enhancement Program	$3,000,000	Clyburn; Wilson (SC)
AP,AF	C-130 Active Noise Cancellation System	$3,000,000	Tiahrt
AP,AF	Civil Air Patrol	$5,000,000	Tiahrt
AP,AF	Large Aircraft Podded Infrared Countermeasures Systems for Air Force Reserve KC-135	$1,500,000	Bean
AP,N	Advanced Skills Management Command Portal	$2,000,000	Dicks
AP,N	AN/AAR-47D(V)X Missile Warning System	$5,000,000	Young (FL)
AP,N	Crane Integrated Defensive Electronic Countermeasures Depot Capability	$2,000,000	Ellsworth
AP,N	Multi-Mission Helicopter Avionics System Test Bed	$1,500,000	Hoyer
AP,N	Universal Avionics Recorder Wireless Flight Download Data	$1,000,000	Harman
DHP	Composite Operational Health and Occupational Risk Tracking System	$3,000,000	Tiahrt
DHP	Fort Drum Regional Health Planning Organization	$430,000	McHugh
DHP	Madigan Army Medical Center Trauma Assistance	$2,500,000	Dicks; Smith (WA)

DEFENSE—Continued
[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
DHP	Military Physician Combat Medical Training Naval Hospital Jacksonville	$1,000,000	Brown, Corrine (FL)
DHP	Shock Trauma Center Operating Suites	$3,000,000	Ruppersberger; Cummings
DHP	Web-Based Teaching Programs for Military Social Work	$4,000,000	Roybal-Allard
DHP	Wide Area Virtual Environment Simulation for Medical Readiness Training	$3,000,000	Van Hollen
DPA	Aluminum Oxy-Nitride and Spinel Optical Ceramics	$3,000,000	Bono Mack; Higgins; Tierney
DPA	Armor and Structures Transformation Initiative-Steel to Titanium	$8,100,000	Murtha
DPA	Flexible Aerogel Materials Supplier Initiative	$2,000,000	Kennedy
DPA	High Performance Thermal Battery Infrastructure Project	$3,000,000	Young (FL)
DPA	Inventory for Defense Applications	$10,000,000	Murtha
DPA	Low Cost Military Global Positioning System (GPS) Receiver	$4,000,000	Loebsack; Latham
DPA	Metal Injection Molding Technological Improvements	$1,000,000	Pascrell
DPA	Military Lens System Fabrication and Assembly	$4,000,000	Murtha
DPA	Navy Production Capacity Improvement Project	$1,000,000	Dent
DPA	Production of Miniature Compressors for Electronics and Personal Cooling	$4,500,000	Rogers (KY)
DPA	Radiation Hardened Cryogenic Read Out Integrated Circuits	$2,000,000	Simpson
DRUGS	Delaware National Guard Counter-Drug Task Force	$300,000	Castle
DRUGS	Florida Counter-Drug Program	$2,900,000	Putnam; Brown, Corrine (FL); Young (FL)

DRUGS	Indiana National Guard Counter-Drug Program	$3,000,000	Visclosky
DRUGS	Kentucky National Guard Counter-Drug Program	$3,500,000	Rogers (KY)
DRUGS	Nevada National Guard Counter-Drug Program	$4,000,000	Titus; Berkley
DRUGS	North Carolina Counter-Drug Task Force	$1,000,000	Jones (NC); Butterfield; Shuler
DRUGS	Regional Counter-Drug Training Academy	$1,500,000	Harper
DRUGS	Tennessee National Guard Appalachia High Intensity Drug Trafficking Area	$4,000,000	Tanner; Davis (TN)
DRUGS	Western Region Counter-Drug Training Center	$2,500,000	Dicks; Baird; Larsen (WA); McDermott; Smith (WA)
GP	Arrest Deterioration of Ford Island Aviation Control Tower, Pearl Harbor, HI	$4,800,000	Abercrombie
GP	Center for Military Recruitment, Assessment and Employment	$3,000,000	Roskam
GP	Edward M. Kennedy Institute for the Senate	$7,400,000	Markey (MA)
GP	Marshall Legacy Institute	$500,000	Murtha
GP	New Jersey Technology Center	$3,000,000	Holt; Pallone
GP	Our Military Kids	$1,000,000	Connolly; Kennedy; Kilroy; Moran (VA); Ortiz
GP	Paralympics Military Program	$5,000,000	Kennedy, Langevin
GP	Riverside General Hospital, Houston, TX (Technical Correction)		Jackson-Lee (TX)
GP	SOAR Virtual School District	$6,000,000	Braley
GP	The Presidio Heritage Center	$5,000,000	Pelosi
GP	Vietnam Veterans Memorial Fund for De-Mining Activities	$1,000,000	Murtha
GP	Women In Military Service for America Memorial	$2,000,000	Richardson; Bordallo; Granger; Schakowsky

DEFENSE—Continued
[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
ICMA	Counter- Threat Finance—Global	$2,000,000	Ryan (OH)
ICMA	Language Mentorship Program incorporating an electronic portfolio	$1,000,000	Boswell
MILPERS, ARNG	WMD Civil Support Team for Florida	$1,200,000	Young (FL)
MILPERS, ARNG	WMD Civil Support Team for New York	$250,000	McMahon; Hall (NY); Hinchey
OM,A	Air-Supported Temper Tent	$3,000,000	Rogers (KY)
OM,A	Americans with Disabilities Act Compliance for the Historical Fort Hamilton Community Club	$1,800,000	McMahon
OM,A	Anti-Corrosion Nanotechnology Solutions for Logistics	$1,000,000	Rahall
OM,A	Army Command and General Staff College Leadership Training Program	$2,000,000	Jenkins
OM,A	Army Force Generation Synchronization Tool	$1,000,000	Dent; Bishop (UT); Dingell
OM,A	Common Logistics Operating System	$2,000,000	Bishop (GA)
OM,A	Critical Language Instruction for Military Personnel, Education, Training and Distance Learning	$3,000,000	Putnam
OM,A	Defense- Fire Alarm / Detection System Installation for the Historical Fort Hamilton Community Club	$500,000	McMahon
OM,A	Defense Job Creation and Supply Chain Initiative	$3,000,000	Posey; Brown, Corrine (FL)
OM,A	Defense- Sprinkler System Installation for the Historical Fort Hamilton Community Club	$1,200,000	McMahon
OM,A	Diversity Recruitment for West Point Military Academy	$1,000,000	Hall (NY)
OM,A	Fort Benning National Incident Management System Compliant Installation Operations Center	$5,000,000	Bishop (GA); Rogers (AL)
OM,A	Fort Bliss Data Center	$1,700,000	Reyes

OM,A	Fort Hood Training Lands Restoration and Maintenance	$2,500,000	Carter; Edwards (TX)
OM,A	Genocide Prevention Course through Combined Arms Center	$1,600,000	Israel
OM,A	Ground Combat System Knowledge Center and Technical Inspection Data Capture	$1,000,000	Moran (VA)
OM,A	Initiative to Increase Minority Participation In Defense	$8,000,000	Fattah
OM,A	Lighweight Tactical Utility Vehicles	$4,500,000	Petri, Kissell
OM,A	Logistics Interoperability	$1,500,000	Rahall
OM,A	M24 Sniper Weapons System Upgrade	$3,000,000	Arcuri
OM,A	Modular Command Post Tent	$6,000,000	Rogers (KY)
OM,A	Net-Centric Decision Support Environment Sense and Respond Logistics	$2,500,000	Bishop (GA)
OM,A	Online Technology Training Program at Joint Base Lewis-McChord	$2,000,000	Dicks
OM,A	Operational/Technical Training Validation for Joint Maneuver Forces at Fort Bliss	$1,000,000	Reyes
OM,A	Repair Heating, Ventilation, Air Conditioning System at Ft. Leavenworth	$2,796,000	Jenkins
OM,A	Repair Heating, Ventilation, Air Conditioning System in National Simulations Center	$1,785,000	Jenkins
OM,A	ROTC and Reserve Component Strategic Language Hub Pilot	$1,500,000	Deal, Marshall
OM,A	TRANSIM Driver Training	$3,500,000	Kingston; Bishop (UT); Matheson
OM,A	UH-60 Leak Proof Drip Pans	$2,500,000	Rogers (KY)
OM,A	US Army ROTC Emergency Facility Renovation	$935,000	Posey
OM,AF	Advanced Autonomous Robotic Inspections for Aging Aircraft	$1,000,000	Cole; Fallin
OM,AF	Air Education and Training Command Range Improvements at the Barry M.Goldwater Range	$1,500,000	Giffords; Franks (AZ); Grijalva; Pastor (AZ)
OM,AF	Defense Critical Languages and Cultures Initiative	$2,000,000	Conaway; Rehberg

DEFENSE—Continued
[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
OM,AF	Demonstration Project for Contractors Employing Persons with Disabilities	$4,000,000	Tiahrt
OM,AF	Diversity Recruitment for Air Force Academy	$550,000	Becerra
OM,AF	Engine Health Management Plus Data Repository Center	$3,000,000	Murtha
OM,AF	Expert Knowledge Transformation Project	$2,000,000	Gonzalez
OM,AF	HQ-USNORTHCOM—National Center for Integrated Civilian-Military Domestic Disaster Medical Response	$2,000,000	DeLauro
OM,AF	Joint Aircrew Combined System Tester (JCAST)	$2,000,000	Biggert
OM,AF	MacDill Air Force Base Online Technology Program	$1,000,000	Castor (FL)
OM,AF	Military Medical Training and Disaster Response Program	$2,000,000	Mitchell
OM,AF	Minority Aviation Training Program	$1,250,000	Meek (FL)
OM,AF	Research Cybersecurity of Critical Control Networks	$1,700,000	Terry
OM,AF	Wage Issue Modification for USFORAZORES Portuguese National Employees	$240,000	Frank (MA)
OM,AF	Warner Robins Air Logistics Center Strategic Airlift Aircraft Availability Improvement	$4,000,000	Kingston; Marshall
OM,ANG	190th Air Refueling Wing Squadron Operations Facility	$1,000,000	Jenkins
OM,ANG	Force Protection and Training Equipment	$465,000	Graves
OM,ANG	Joint Interoperability Coordinated Operations and Training Exercise	$515,000	Kingston
OM,ANG	Smoky Hill Range Access Road Improvements	$1,000,000	Moran (KS)
OM,AR	Nevada National Guard Joint Operations Center	$1,000,000	Heller

OM,ARNG	Advanced Law Enforcement Rapid Response Training	$1,000,000	Doggett
OM,ARNG	Advanced Trauma Training Course for the Illinois National Guard	$2,500,000	Davis (IL); Jackson (IL)
OM,ARNG	Army National Guard M939A2 Repower Program	$5,000,000	Carter
OM,ARNG	Camp Ethan Allen Training Site Road Equipment	$300,000	Welch
OM,ARNG	CID Equipment	$449,000	Cuellar
OM,ARNG	Florida Army National Guard Future Soldier Trainer	$3,000,000	Meek (FL)
OM,ARNG	Full Cycle Deployment Support Pilot Program	$3,000,000	Hodes; Shea-Porter
OM,ARNG	Joint Command Vehicle and Supporting C3 System	$2,250,000	Shea-Porter; Hodes
OM,ARNG	MN Guard Beyond the Yellow Ribbon Reintegration Program	$2,000,000	Walz; Ellison; Oberstar; Paulsen; Peterson
OM,ARNG	Multi-Jurisdictional Counter-Drug Task Force Training	$3,500,000	Young (FL)
OM,ARNG	National Guard Civil Support Team/CBRNE Enhanced Response Force Package	$1,500,000	Dicks; Hastings (WA)
OM,ARNG	Regional Geospatial Service Centers	$2,156,000	Gohmert
OM,ARNG	Training Aid Suite for Vermont NG Training Sites	$1,308,000	Welch
OM,ARNG	Trauma Response Simulation Training	$1,500,000	Boswell
OM,ARNG	UH-60 Leak Proof Drip Pans	$2,500,000	Rogers (KY)
OM,ARNG	Vermont Army National Guard Security Upgrades	$930,000	Welch
OM,ARNG	WMD Civil Support Team for Florida	$2,000,000	Young (FL)
OM,ARNG	WMD Civil Support Team for New York	$500,000	McMahon; Hinchey
OM,ARNG	WMD Multi-Sensor Response and Infrastructure Project System	$2,000,000	Fallin
OM,ARNG	Yellow Ribbon Project—Oregon National Guard Reintegration Program	$1,200,000	Schrader

DEFENSE—Continued
[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
OM,DW	Almaden AFS Environmental Assessment and Remediation	$4,000,000	Honda; Lofgren
OM,DW	Castner Range Conservation Conveyance Study	$300,000	Reyes
OM,DW	Centerville Naval Housing Transfer	$6,000,000	Thompson (CA)
OM,DW	Critical Language Training	$2,000,000	Davis (CA)
OM,DW	Drydock #1 Remediation and Disposal	$3,000,000	Pelosi
OM,DW	Eliminate Public Safety Hazards	$1,340,000	Slaughter
OM,DW	George AFB (New and existing infrastructure improvements)	$1,000,000	McKeon
OM,DW	Hunters Point Naval Shipyard Remediation	$9,000,000	Pelosi
OM,DW	McClellan AFB Infrastructure Improvements	$1,000,000	Matsui
OM,DW	Middle East Regional Security Program	$3,000,000	Berman
OM,DW	Military Intelligence Service Historic Learning Center	$1,000,000	Pelosi
OM,DW	Naval Station Ingleside Redevelopment	$1,000,000	Ortiz
OM,DW	Norton AFB (New and Existing Infrastructure Improvements)	$6,000,000	Lewis (CA)
OM,DW	Phase I of Berth N-2 Reconstruction of MOTBY Ship Repair Facility	$4,500,000	Sires
OM,DW	Remediation of Jet Fuel Contamination at Floyd Bennett Field	$3,000,000	Weiner
OM,DW	Soldier Center at Patriot Park, Ft. Benning	$5,000,000	Bishop (GA)
OM,DW	Special Operations Forces Modular Glove System	$1,500,000	Kratovil; Baird; Castle; McDermott

OM,DW	Strategic Language Initiative	$3,600,000	Richardson; Royce; Watson
OM,DW	Thorium/Magnesium Excavation—Blue Island	$2,000,000	Jackson (IL)
OM,DW	Translation and Interpretation Skills for DoD	$2,000,000	Farr
OM,MC	Flame Resistant High Performance Apparel	$1,500,000	Kissell
OM,MC	MGPTS Type III or Rapid Deployable Shelter	$3,000,000	Hinchey
OM,MC	Ultra Lightweight Camouflage Net System (ULCANS)	$3,500,000	Etheridge; Coble
OM,N	ATIS Maintenance and Enhancement Program	$1,000,000	Rahall
OM,N	Brown Tree Snake Program	$500,000	Bordallo
OM,N	Center for Defense Technology and Education for the Military Services (CDTEMS)	$7,000,000	Farr
OM,N	Continuing Education—Distance Learning at Military Installations	$2,000,000	Brown-Waite, Ginny (FL)
OM,N	Diversity Recruitment for Naval Academy	$1,000,000	Becerra
OM,N	Enhanced Navy Shore Readiness Integration	$5,000,000	Dicks
OM,N	Fleet Readiness Data Assessment	$2,400,000	Calvert
OM,N	Institute for Threat Reduction and Response- Simulated and Virtual Training Environments	$1,200,000	Brown, Corrine (FL)
OM,N	Navy Ship Disposal—Carrier Demonstration Project	$3,000,000	Ortiz
OM,N	Puget Sound Naval Maintenance and Repair Process Improvements	$2,100,000	Dicks
OM,N	Puget Sound Navy Museum	$600,000	Dicks
OM,NR	Developing and Testing Environmentally Safe Decontaminating Agents for Bio-defense, Biomedical, and Environmental Use	$1,500,000	Diaz-Balart, Mario (FL)
OP,A	Combat Skills Marksmanship Trainer	$4,000,000	Kingston; Gingrey (GA)
OP,A	Combined Arms Virtual Trainers	$500,000	Luján

DEFENSE—Continued
[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
OP,A	Combined Arms Virtual Trainers for the Tennessee National Guard	$5,000,000	Davis (TN); Wamp; Duncan
OP,A	Communications Aerial Platforms for Increased Situational Awareness for the Minnesota National Guard	$2,360,000	Paulsen; Oberstar; Walz
OP,A	Fifth-Wheel Towing Devices for the Puerto Rico Army National Guard	$700,000	Pierluisi
OP,A	Ft. Bragg Range 74 Combined Arms Collective Training Facility	$1,000,000	Kissell
OP,A	Individual Gunnery; Tank Gunnery; and Tabletop Full-Fidelity Trainers	$2,000,000	Luján
OP,A	Kentucky National Guard Emergency Response Generator Stockpile	$6,000,000	Rogers (KY)
OP,A	Laser Marksmanship Training System	$2,000,000	Kennedy
OP,A	Life Support for Trauma and Transport	$1,000,000	Sanchez, Loretta (CA); Reyes
OP,A	Machine Gun Training System for the Pennsylvania National Guard	$3,000,000	Holden
OP,A	Mobile Defensive Fighting Position	$2,000,000	Maffei
OP,A	Mobile Firing Range for Texas National Guard	$1,500,000	Conaway; Granger
OP,A	Multi-Temperature Refrigerated Container System	$3,500,000	Davis (KY)
OP,A	Radio Personality Modules for SINCGARS Test Sets	$3,000,000	Tiahrt
OP,A	Regional Emergency Response Network Emergency Cell Phone Capability	$5,000,000	Hastings (FL); Stearns; Brown, Corrine (FL); Young (FL)
OP,A	Tactical Operations Center for the Washington National Guard	$2,300,000	Reichert, Baird, McDermott
OP,A	Ultralight Utility Vehicles for the National Guard	$2,000,000	Obey
OP,A	Virtual Convoy Operations Trainer	$1,500,000	Luján

OP,A	Virtual Interactive Combat Environment Training System for the Virginia National Guard	$2,000,000	Connolly; Moran (VA)
OP,AF	Air National Guard Joint Threat Emitter—Savannah Combat Readiness Training Centers	$1,000,000	Lee (NY)
OP,AF	Aircrew Body Armor and Load Carriage Vest System	$3,000,000	Akin
OP,AF	Eagle Vision III	$6,000,000	Bilbray; Davis (CA)
OP,AF	Eagle Vision Program	$1,500,000	Clyburn; Wilson (SC)
OP,AF	Nevada Air National Guard Scathe View	$1,000,000	Titus; Berkley; Heller
OP,AF	One AF/One Network Infrastructure	$2,000,000	Olson; Rothman
OP,AF	One AF/One Network Infrastructure for the Pennsylvania National Guard	$2,000,000	Schwartz
OP,N	Adaptive Diagnostic Electronic Portable Testset	$1,000,000	Young (FL)
OP,N	AN/USQ-167 COMSEC Upgrade	$1,000,000	Filner
OP,N	Deployable Joint Command and Control Shelter Upgrade Program	$3,000,000	Salazar
OP,N	Enhanced Detection Adjunct Processor	$4,000,000	Kaptur
OP,N	Force Protection Boats (Small)	$2,000,000	Melancon
OP,N	Hydroacoustic Low Frequency Source Generation Systems	$2,000,000	Massa; Lee (NY)
OP,N	LSD-41/49 Diesel Engine Low Load Upgrade Kit	$2,000,000	Baldwin
OP,N	Multi-Climate Protection System	$2,500,000	Rogers (MI); Hodes, Shea-Porter; Tsongas
OP,N	Secure Remote Monitoring Systems	$2,000,000	Moran (VA)
OP,N	SPAWAR Systems Center (SSC/ITC) New Orleans	$7,500,000	Cao; Scalise
P,DW	Expansion of the Forensic Intelligence Technologies and Training Support Center of Excellence	$2,000,000	Young (FL)
P,DW	Intelligence Broadcast Receiver for AFSOC MC-130	$1,000,000	Miller (FL)

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[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
P,DW	Light Mobility Vehicle—Internally Transportable Vehicle	$2,000,000	Waters
P,DW	NSW Protective Combat Uniform	$2,500,000	Granger
P,DW	SOPMOD II (M4 Carbine Rail System)	$2,500,000	Kingston
P,DW	Special Operations Forces Combat Assault Rifle	$2,500,000	Wilson (SC)
P,MC	Marine Corps MK 1077 Flatracks	$3,000,000	Aderholt
P,MC	Microclimate Cooling Unit for M1 Abrams Tank	$1,000,000	Lee (NY); Higgins
P,MC	Portable Armored Wall System	$1,000,000	Adler; Bishop (UT)
P,MC	Portable Military Radio Communications Test Set	$1,500,000	Tiahrt
PA,A	Ammunition Production Base Support (Scranton AAP)	$3,500,000	Kanjorski; Carney
PA,A	Blue Grass Army Depot Equipment	$3,000,000	Chandler
PA,A	Bombline Modernization	$2,000,000	Boren
PA,A	M721 60mm Illuminating Mortar	$2,000,000	Ross
PA,A	M722 60mm White Phosphorus Smoke Mortar	$2,000,000	Ross
PA,A	Magneto Inductive Remote Activation Munitions System (MI-RAMS) M156/M39 Kits and M40 Receivers	$9,000,000	Lewis (CA)
PA,A	Small Caliber Ammunition Production Modernization	$5,000,000	Graves; Cleaver
PANMC	Enhanced Laser Guided Training Round	$4,500,000	Carney
RDTE,A	Achieving Lightweight Casting Solutions	$2,000,000	Schock

RDTE,A	Acid Alkaline Direct Methanol Fuel Cell	$2,000,000	McIntyre
RDTE,A	Advanced Affordable Turbine Engine Program	$4,000,000	Larson (CT); Courtney; DeLauro; Pastor (AZ)
RDTE,A	Advanced Battery Materials and Manufacturing	$5,000,000	Halvorson, Biggert
RDTE,A	Advanced Bio-Engineering for Enhancement of Soldier Survivability	$3,000,000	Johnson (GA); Bishop (GA); Gingrey (GA); Kingston; Lewis (GA); Scott (GA)
RDTE,A	Advanced Bonded Diamond for Optical Applications	$2,500,000	Kingston
RDTE,A	Advanced Cancer Genome Institute	$2,500,000	Higgins; Lee (NY); Slaughter
RDTE,A	Advanced Carbon Hybrid Battery for Hybrid Electic Vehicles	$1,000,000	Bishop (GA)
RDTE,A	Advanced Communications for Mobile Networks	$4,000,000	Mollohan
RDTE,A	Advanced Composite Ammunition Magazine/Mount System	$2,000,000	Obey
RDTE,A	Advanced Composite Armor for Force Protection	$2,000,000	Coble
RDTE,A	Advanced Composite Materials Research for Land, Marine, and Air Vehicles	$3,500,000	Rogers (MI)
RDTE,A	Advanced Composite Nickel-Manganese-Cobalt Lithium Ion Battery	$3,000,000	Hinchey
RDTE,A	Advanced Composite Research for Vehicles	$5,000,000	Kilpatrick
RDTE,A	Advanced Composites for Light Weight, Low Cost Transportation Systems using a 3+ Ring Extruder	$3,000,000	Stupak
RDTE,A	Advanced Conductivity Program	$1,000,000	Young (FL)
RDTE,A	Advanced Detection of Explosives	$2,000,000	Young (FL)
RDTE,A	Advanced Diagnostic and Therapeutic Digital Technologies	$2,000,000	Capuano; Cummings; Watson
RDTE,A	Advanced Digital Hydraulic Drive System	$2,500,000	Upton
RDTE,A	Advanced Field Artillery Tactical Data System	$4,500,000	Souder

DEFENSE—Continued
[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
RDTE,A	Advanced Flexible Solar Photovoltaic Technologies	$3,000,000	Obey
RDTE,A	Advanced Fuel Cell Research Program	$4,000,000	Poe
RDTE,A	Advanced Functional Nanomaterials for Biological Processes	$2,500,000	Snyder
RDTE,A	Advanced Ground EW and Signals Intelligence System	$2,500,000	Larsen (WA); Smith (WA)
RDTE,A	Advanced Lightweight Gunner Protection Kit for Lightweight MRAP Vehicle	$1,000,000	Altmire
RDTE,A	Advanced Lightweight Multifunctional Multi-Threat Composite Armor Material Technology	$3,000,000	Rangel
RDTE,A	Advanced Lithium Ion Phosphate Battery System for Army Combat Hybrid HMMWV and Other Army Vehicle Platforms	$2,000,000	Dingell
RDTE,A	Advanced Live, Virtual, and Constructive Training Systems	$3,500,000	Latham
RDTE,A	Advanced Military Wound Healing Research and Treatment	$1,000,000	Lee (NY)
RDTE,A	Advanced Nanocomposite Materials for Lightweight Integrated Armor Systems	$2,000,000	Ryan (OH)
RDTE,A	Advanced Packaging Materials for Combat Rations	$1,000,000	Gingrey (GA)
RDTE,A	Advanced Polymer Systems for Defense Application—Power Generation, Protection and Sensing	$3,000,000	Emerson
RDTE,A	Advanced Power Generation Unit for Military Applications	$650,000	Roskam
RDTE,A	Advanced Power Source for Future Soldiers	$1,500,000	Carson
RDTE,A	Advanced Power Technologies for Nano-Satellites	$2,000,000	Rogers (KY)
RDTE,A	Advanced Radar Transceiver IC Development	$1,000,000	Harman
RDTE,A	Advanced Rarefaction Weapon Engineered System	$4,000,000	Kaptur

RDTE,A	Advanced Reactive Armor Systems	$2,000,000	Hinchey
RDTE,A	Advanced Tactical Laser Flashlight	$1,000,000	Kilpatrick
RDTE,A	Advanced Technology for Energy Storage	$2,000,000	Visclosky
RDTE,A	Advanced Technology, Energy Manufacturing Sciences	$7,000,000	Frelinghuysen
RDTE,A	Advanced Thermal Management System	$3,000,000	Stupak
RDTE,A	Advancement of Bloodless Medicine	$1,866,000	Rothman
RDTE,A	Air Drop Mortar Guided Munition for the Tactical UAV	$3,000,000	Hastings (WA)
RDTE,A	Alginate Oligomers to Treat Infectious Microbial Biofilms	$2,000,000	Kilroy
RDTE,A	All Composite Bus Program	$2,500,000	Kennedy
RDTE,A	Alliance for Nanohealth	$5,000,000	Culberson
RDTE,A	ALS Therapy Development Institute—Gulf War Illness Research Project	$2,000,000	Capuano; Brown (SC)
RDTE,A	Alternative Power Technology for Missile Defense	$1,000,000	Herseth Sandlin
RDTE,A	Aluminum Armor Project	$1,050,000	Capito
RDTE,A	AN/ALQ 211 Networked EW Controller	$1,000,000	Pascrell
RDTE,A	Antennas for Unmanned Aerial Vehicles	$1,000,000	Bonner
RDTE,A	Anti-Microbial Bone Graft Product	$2,000,000	Crenshaw; Stearns
RDTE,A	Antioxidant Micronutrient Therapeutic Countermeasures	$1,000,000	McCarthy (NY)
RDTE,A	Anti-Tamper Research and Development	$3,800,000	Alexander
RDTE,A	Applied Communication and Information Networking	$3,800,000	Andrews; LoBiondo
RDTE,A	ARL 3D Model-Based Inspection and Scanning	$3,000,000	Ryan (OH)

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[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
RDTE,A	Armament System Engineering and Integration Initiative	$2,000,000	Frelinghuysen; Sires
RDTE,A	Armaments Academy	$3,000,000	Frelinghuysen
RDTE,A	Army Center of Excellence in Acoustics, National Center for Physical Acoustics	$4,000,000	Childers
RDTE,A	Army/Joint STARS Surveillance and Control Data Link Technology Refresh	$1,000,000	Davis (CA)
RDTE,A	Army Portable Oxygen Concentration System	$1,500,000	Moran (VA)
RDTE,A	Army Vehicle Condition Based Maintenance	$5,000,000	Murtha
RDTE,A	Asymmetric Threat Response and Analysis Project	$2,500,000	Giffords
RDTE,A	Atomized Magnesium Domestic Production Design and Development	$2,000,000	Kaptur
RDTE,A	Automated Portable Field System for Rapid Detection and Diagnosis of Endemic Diseases and Other Pathogens	$2,000,000	Massa
RDTE,A	Automotive Technology Tactical Metal Fabrication System	$2,500,000	Clyburn; Brown (SC)
RDTE,A	Automotive Tribology Center	$2,000,000	Peters
RDTE,A	Autonomous Sustainment Cargo Container	$1,500,000	Bartlett
RDTE,A	Ballistic Armor Research	$1,000,000	Dent
RDTE,A	Battlefield Exercise and Combat Related Spinal Cord Injury Research	$3,000,000	Brown-Waite, Ginny (FL)
RDTE,A	Battlefield Nursing	$2,000,000	Cohen
RDTE,A	Battlefield Related Injury Translational Research Strategies	$2,250,000	Castor (FL)
RDTE,A	Battlefield Research Accelerating Virtual Environments for Military Individual Neuro Disorders (BRAVEMIND)	$1,000,000	Harman

RDTE,A	Beneficial Infrastructure for Rotorcraft Risk Reducation	$1,000,000	Sestak
RDTE,A	Bio Battery	$1,000,000	Griffith
RDTE,A	Biological Air Filtering System Technology	$3,000,000	Berry
RDTE,A	Bio-Printing of Skin for Battlefield Burn Repairs	$1,000,000	Johnson, Sam (TX)
RDTE,A	Biowaste-to-Bioenergy Center	$2,500,000	Murphy (NY); Tonko
RDTE,A	Blood and Bone Marrow Collection Fellowship	$2,500,000	Bishop (GA)
RDTE,A	Blood Safety and Decontamination Technology	$3,000,000	Gerlach; DeLauro; Fattah; Markey (MA); McDermott; Tonko
RDTE,A	Brain Interventional Surgical Hybrid Initiative	$3,000,000	Wasserman Schultz
RDTE,A	Brain Safety Net	$3,000,000	Walden; Blumenauer; DeFazio; Wu
RDTE,A	Breast Cancer Medical Information Network Decision Support	$1,000,000	Berman
RDTE,A	Brownout Situational Awareness Sensor	$3,000,000	Hunter; Olver
RDTE,A	Buster/Blacklight UAV Development	$1,000,000	Gonzalez; Ortiz; Rodriguez
RDTE,A	Cadmium Emissions Reduction—Letterkenny Army Depot	$1,000,000	Shuster
RDTE,A	Cancer Prevention through Remote Biological Sensing	$2,000,000	Bishop (NY)
RDTE,A	Capabilities Expansion of Spinel Transparent Armor Manufacturing	$2,000,000	Perlmutter
RDTE,A	Captive Carry Sensor Test-Bed	$3,000,000	Davis (AL); Bachus
RDTE,A	Carbide Derived Carbon for Treatment of Combat Related Sepsis	$1,000,000	Sestak
RDTE,A	Cellular Therapy for Battlefield Wounds	$3,500,000	Fudge
RDTE,A	Cellulose Nanocomposites Panels for Ballistic Protection	$2,000,000	Michaud; Pingree (ME)
RDTE,A	Center for Bone Repair and Military Readiness	$1,500,000	Cleaver

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[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
RDTE,A	Center for Cancer Immunology Research	$2,000,000	Culberson
RDTE,A	Center for Defense Systems Research	$1,000,000	Reyes
RDTE,A	Center for Genetic Origins of Cancer	$2,500,000	Dingell; Upton
RDTE,A	Center for Hetero-Functional Materials	$1,000,000	Doggett; Conaway; Rodriguez
RDTE,A	Center for Injury Biomechanics	$4,000,000	Boucher
RDTE,A	Center for Integration of Medicine and Innovative Technology	$9,000,000	Capuano; Lynch
RDTE,A	Center for Nanoscale Bio-Sensors as a Defense against Biological Threats	$3,000,000	Boozman
RDTE,A	Center for Ophthalmic Innovation	$3,000,000	Diaz-Balart, Mario (FL); Ros-Lehtinen
RDTE,A	Center for Virtual Reality Medical Simulation Training	$1,500,000	Bachus; Davis (AL)
RDTE,A	Center of Excellence in Infectious Diseases and Human Microbiome	$3,000,000	Maloney; King (NY)
RDTE,A	Ceramic and MMC Armor Development using Ring Extruder Technology	$1,000,000	Stupak
RDTE,A	CERDEC Integrated Tool Control System	$2,000,000	Pallone
RDTE,A	Chronic Tinnitus Treatment Program	$1,000,000	Dent
RDTE,A	Clinical Technology Integration for Military Health	$2,000,000	Markey (MA)
RDTE,A	Clinical Trial to Investigate Efficacy of Human Skin Substitute	$1,000,000	Baldwin
RDTE,A	Cognitive Based Modeling and Simulation for Tactical Decision Support	$2,000,000	Bishop (GA)
RDTE,A	Collaboration Skills Training for Time-Critical Teams, Squads and Workgroups	$2,000,000	Davis (IL)

RDTE,A	Collagen-Based Wound Dressing	$1,000,000	Altmire
RDTE,A	Combat Medic Trainer	$2,000,000	Schwartz; Hunter
RDTE,A	Combat Mental Health Initiative	$2,000,000	Kaptur
RDTE,A	Combat Wound Initiative	$3,000,000	Kennedy
RDTE,A	Command, Control, Communications Technology	$2,000,000	Pascrell
RDTE,A	Compact Biothreat Rapid Analysis Concept	$3,000,000	Capuano
RDTE,A	Compact Pulsed Power Initiative	$4,000,000	Conaway
RDTE,A	Composite Applied Research and Technology for FCS and Tactical Vehicle Survivability	$1,500,000	Castle
RDTE,A	Composite Small Main Rotor Blades	$3,000,000	Tiahrt
RDTE,A	Compostable and Recyclable Fiberboard Material for Secondary Packaging	$2,500,000	Obey
RDTE,A	Construct Training Program	$1,500,000	Gutierrez; Jackson (IL)
RDTE,A	Control of Vector-Borne Diseases	$3,000,000	Visclosky
RDTE,A	Conversion of Municipal Solid Waste to Renewable Diesel Fuel	$3,150,000	Rothman; Lance; Sires
RDTE,A	Cooperative Developmental Energy Program	$2,000,000	Bishop (GA)
RDTE,A	Crewmember Alert Display Development Program	$2,000,000	Kingston
RDTE,A	Current Force Common Active Protection System Radar	$2,000,000	Johnson, Sam (TX); Hall (TX); Johnson, Eddie Bernice (TX)
RDTE,A	Customized Nursing Programs for Fort Benning	$2,000,000	Bishop (GA)
RDTE,A	Cyber Threat Analytics	$3,000,000	Lewis (CA)
RDTE,A	Defense Metals Technology Center	$2,500,000	Boccieri; Ryan (OH)
RDTE,A	Defense Support for Civil Authorities for Key Resource Protection	$1,000,000	Shuster

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[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
RDTE,A	Defense Support to Civil Authorities Automated Support System	$2,000,000	Moran (VA)
RDTE,A	Define Renewable Energy Sources for Base Energy Independence	$1,000,000	Teague
RDTE,A	Demonstration of Thin Film Solar Modules as a Renewable Energy Source	$1,000,000	Reyes
RDTE,A	Dermal Matrix Research	$2,000,000	Lance
RDTE,A	Development of Enabling Chemical Technologies for Power from Green Sources	$1,500,000	Olver
RDTE,A	Development of Improved Lighter-Weight IED/EFP Armor Solutions	$2,000,000	Tiahrt
RDTE,A	Developmental Mission Integration	$7,000,000	Frelinghuysen
RDTE,A	De-Weighting Military Vehicles through Advanced Composites Manufacturing Technology	$2,000,000	Davis (KY)
RDTE,A	Diabetes Care in the Military	$2,000,000	Kilpatrick
RDTE,A	Direct Carbon Fuel Cell	$3,500,000	Capito
RDTE,A	Distributed Power from Wastewater	$2,500,000	Wilson (OH); Space
RDTE,A	Distributed, Networked, Unmanned Ground Systems	$2,000,000	Matheson
RDTE,A	DoD Diabetes Research and Development Initiative (DRDI)	$3,200,000	Dicks
RDTE,A	Domestic Production of Nanodiamond for Military Applications	$2,000,000	Thompson (PA)
RDTE,A	Drive System Composite Structural Component Risk Reduction Program	$3,000,000	Brady (PA)
RDTE,A	Dual Stage Variable Energy Absorber	$3,000,000	Murphy, Patrick (PA)
RDTE,A	Effects Based Operations Decision Support Services	$2,000,000	Moran (VA)

RDTE,A	Electric All Terrain Ultra Light Vehicle for the Minnesota National Guard	$2,000,000	Oberstar
RDTE,A	Electrically Charged Mesh Defense Net Troop Protection System	$7,500,000	Aderholt
RDTE,A	Electronic Combat and Counter Terrorism Threat Developments to Support Joint Forces	$3,000,000	Kingston
RDTE,A	Enabling Optimization of Reactive Armor	$3,000,000	Whitfield; Rogers (KY)
RDTE,A	Enhanced Driver Situational Awareness	$1,000,000	Kennedy
RDTE,A	Enhancing Military Ophthalmic Education and Overcoming Urban Healthcare Disparities with Telemedicine	$3,000,000	Brady (PA)
RDTE,A	Enhancing the Commercial Joint Mapping Toolkit to Support Tactical Military Operations	$4,000,000	Lewis (CA)
RDTE,A	Enhancing Wound Healing, Tissue Regeneration, and Biomarker Discovery	$2,500,000	Berkley; Titus
RDTE,A	Environmentally Intelligent Moisture and Corrosion Control for Concrete	$2,100,000	Rothman
RDTE,A	Epigenetic Disease Research	$2,000,000	McMorris Rodgers
RDTE,A	Evaluation of Integrative Approaches to Resilience	$2,000,000	Moran (VA)
RDTE,A	Exceptional Family Transitional Training Program for US Military Soldiers, Sailors, Marines and Airmen	$800,000	Murtha
RDTE,A	Execution of a Quality Systems Program for FDA Regulation Activities	$1,500,000	Bishop (GA)
RDTE,A	Extended Duration Silver Wound Dressing—Phase II	$1,000,000	Shuler
RDTE,A	Eye Trauma and Visual Restoration	$1,000,000	Schiff
RDTE,A	Eye-Safe Standoff Fusion Detection of CBE Threats	$2,500,000	Doyle
RDTE,A	Field Deployable Hologram Production System	$4,800,000	Granger; Conaway
RDTE,A	Fighting Combat-related Fatigue Syndrome	$1,000,000	Kosmas; Brown, Corrine (FL)
RDTE,A	Fire Shield	$4,000,000	Dreier
RDTE,A	Fire Suppression System	$1,425,000	Sullivan

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[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
RDTE,A	Flexible Solar Cell for Man-portable Power Generator	$1,000,000	Jackson (IL); Rush
RDTE,A	Florida Trauma Rehabilitation Institute for Returning Military Personnel	$3,000,000	Bilirakis
RDTE,A	Flu Vaccine Technology Program	$1,500,000	Rahall
RDTE,A	Foil Bearing Supported UAV Engine	$1,000,000	Larson (CT)
RDTE,A	Foliage Penetrating, Reconnaissance, Surveillance, Tracking, and Engagement Radar (FORESTER) Phase II	$2,000,000	Maffei; McHugh
RDTE,A	Framework for Electronic Health Record-Linked Predictive Models	$3,000,000	Murtha
RDTE,A	Friction Stir Welding Program	$3,000,000	Jordan; Kaptur
RDTE,A	Fuel System Component Technology Research	$2,000,000	Manzullo
RDTE,A	Fully Burdened Cost of Fuel and Alternative Energy Methodology and Conceptual Model	$3,500,000	Kaptur
RDTE,A	Fused Silica for Large-Format Transparent Armor	$4,000,000	Space
RDTE,A	Gas Engine Driven Air Conditioning	$3,000,000	Pastor (AZ); Berkley; Franks (AZ)
RDTE,A	Geosciences/Atmospheric Research	$3,000,000	Markey (CO); Salazar
RDTE,A	Geospatial Airship Research Platform	$4,000,000	Kaptur
RDTE,A	Green Armament and RangeSafe Technology Initiatives	$2,000,000	Frelinghuysen; Sires
RDTE,A	Hadron Particle Therapy	$2,000,000	Foster
RDTE,A	Headborne Energy Analysis and Diagnostic System	$2,000,000	Carney
RDTE,A	Health Disparities in Troop Readiness	$8,000,000	Clyburn

RDTE,A	Heavy Fuel Engine Family for Unmanned Systems	$4,000,000	Hoekstra
RDTE,A	High Performance Alloy Materials and Advanced Manufacturing of Steel Castings for New Light Weight and Robotic Weapon Systems	$3,000,000	Emerson
RDTE,A	High Performance Computing in Biomedical Engineering and Health Sciences	$1,500,000	Watt
RDTE,A	High Strength Glass Production and Qualification for Armor Applications	$2,000,000	Tonko
RDTE,A	Highlander Electro-Optical Sensors	$2,000,000	Moran (VA)
RDTE,A	Highly Integrated Lethality Systems Development	$4,000,000	Frelinghuysen
RDTE,A	Highly Integrated Production for Expediting Reset	$2,500,000	Brown (SC); Altmire; Rogers (AL); Wilson (SC)
RDTE,A	High-Volume Manufacturing Development for Thin-film Lithium Stack Battery Technologies	$1,000,000	Honda; Carter
RDTE,A	HIV Prevention and Reducing Risk to US Military Personnel	$3,000,000	Pelosi
RDTE,A	Hostile Fire Indicator for Aircraft	$2,000,000	Holt; Hodes
RDTE,A	Human Genomics, Molecular Epidemiology, and Clinical Diagnostics for Infectious Diseases	$1,500,000	Pastor (AZ)
RDTE,A	Human Organ and Tissue Preservation Technology	$2,000,000	Wilson (SC)
RDTE,A	Hybrid Electric Drive All Terrain Vehicle	$2,000,000	Peters
RDTE,A	Hybrid Electric Heavy Truck Vehicle	$2,000,000	Bartlett
RDTE,A	Hybrid Energy Systems Design and Testing	$2,000,000	Simpson
RDTE,A	Hyper Spectral Sensor for Improved Force Protection	$2,000,000	Akin
RDTE,A	Imaging and Cognitive Evaluation of Soldiers	$800,000	Kilpatrick
RDTE,A	Improved HELLHOUND 40mm Low Velocity High Explosive Ammunition	$750,000	Boyd
RDTE,A	Improved Thermal Batteries for Guided Munitions	$3,000,000	Schwartz

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Account	Project	Amount	Requester(s)
RDTE,A	Improved Thermal Resistant Nylon for Enhanced Durability and Thermal Protection in Combat Uniforms	$1,500,000	Castle; Barrett
RDTE,A	Improving Soldier Recovery from Catastrophic Bone Injuries	$4,000,000	Murphy (CT)
RDTE,A	Infection Prevention Program for Battlefield Wounds	$2,000,000	McGovern
RDTE,A	Infectious and Airborne Pathogen Reduction	$2,800,000	Whitfield; Arcuri; Childers; Higgins
RDTE,A	Injection Molded Ceramic Body Armor	$1,000,000	Olver
RDTE,A	Ink-based Desktop Electronic Material Technology	$2,000,000	Frelinghuysen
RDTE,A	Institute for Simulation and Interprofessional Studies	$5,800,000	Dicks; McDermott; McMorris Rodgers; Smith (WA)
RDTE,A	Integrated Defense Technical Information	$2,000,000	Rogers (KY)
RDTE,A	Integrated Family of Test Equipment V6 Product Improvement Program	$3,000,000	Kingston
RDTE,A	Integrated Information Technology Policy Analysis Research and Technology Commercialization and Management Network	$4,000,000	Lewis (CA)
RDTE,A	Integrated Lightweight Tracker System	$2,000,000	Obey
RDTE,A	Integrated Patient Electronic Record System	$2,000,000	Lee (CA)
RDTE,A	Intelligence, Surveillance and Reconnaissance (ISR) Simulation Integration Laboratory	$2,000,000	Smith (NJ)
RDTE,A	Intelligent Energy Control Systems	$3,000,000	Granger
RDTE,A	Intelligent Network-Centric Sensor Development Program	$1,500,000	Cohen
RDTE,A	Intelligent Orthopedic Fracture Implant Program	$1,000,000	Kildee
RDTE,A	Intensive Quenching for Advanced Weapon Systems	$1,500,000	Sutton; Ryan (OH); Tonko

RDTE,A	Inter Turbine Burner for Turbo Shaft Engines	$3,000,000	Lewis (CA)
RDTE,A	Internal Base Facility Energy Independence	$3,200,000	Kaptur
RDTE,A	In-Theater Evaluation of Ballistic Protection	$1,000,000	Michaud; Pingree (ME)
RDTE,A	IR-Vascular Facial Fingerprinting	$3,000,000	Moran (VA)
RDTE,A	IUID Data Platform	$2,500,000	Kennedy
RDTE,A	Jackson Health System Military Trauma Training Enhancement Initiative	$2,500,000	Meek (FL); Wasserman Schultz
RDTE,A	Javelin Warhead Improvement Program	$5,000,000	Bright; Brown, Corrine (FL)
RDTE,A	Joint Fires and Effects Trainer System Enhancements	$2,500,000	Cole; Fallin
RDTE,A	Joint Medical Simulation Technology Center	$1,600,000	Kosmas
RDTE,A	Joint Munitions and Lethality Mission Integration	$2,000,000	Frelinghuysen
RDTE,A	Joint Precision AirDrop Systems-Wind Profiling Portable Radar	$2,300,000	Murtha
RDTE,A	Joint Threat Emitters	$5,000,000	Kingston
RDTE,A	Laboratory for Engineered Human Protection	$2,000,000	Fattah
RDTE,A	Large Format Li-Ion Battery	$600,000	Moore (WI)
RDTE,A	Large-Scale Manufacturing of Revolutionary Nanostructured Materials	$1,500,000	Moore (WI)
RDTE,A	Lens-Less Dual-Mode Micro Seeker for Medium-Caliber Guided Projectiles	$2,500,000	Dreier
RDTE,A	Leonard Wood Institute	$15,000,000	Skelton
RDTE,A	Lifestyle Modifications to Reduce Chronic Disease in Military Personnel	$1,500,000	Pelosi
RDTE,A	Lightweight 10-meter Antenna Mast	$2,500,000	Obey
RDTE,A	Lightweight Magnesium Parts for Military Applications	$2,000,000	Holden

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[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
RDTE,A	Lightweight Metal Alloy Foam for Armor	$4,000,000	Kaptur
RDTE,A	Lightweight Munitions and Surveillance System for Unmanned Air and Ground Vehicles	$4,800,000	Garrett
RDTE,A	Lightweight Packaging System for Enhancing Combat Munitions Logistics	$2,000,000	Frelinghuysen; Rothman
RDTE,A	Lightweight Polymer Designs for Soldier Combat Optics	$1,000,000	Olver
RDTE,A	Lightweight Protective Roofing	$1,500,000	Moran (VA)
RDTE,A	Lightweight, Battery Driven, and Battlefield Deployment Ready NG Feeding Tube Cleaner	$500,000	Thompson (PA)
RDTE,A	Linear Accelerator Cancer Research Project	$1,000,000	Rangel; Lowey; Maloney
RDTE,A	Locating and Tracking Explosive Threats with Wireless Sensors and Networks	$6,000,000	Emerson
RDTE,A	Logistical Fuel Processors Development	$1,500,000	Bachus; Rogers (AL)
RDTE,A	LW25 Gun System and Demonstration	$3,000,000	Kingston
RDTE,A	M109A6 Paladin	$2,000,000	Rogers (AL)
RDTE,A	Maine Center for Toxicology and Environmental Health, Toxic Particles Research and Equipment	$2,000,000	Pingree (ME)
RDTE,A	Maine Institute for Human Genetics and Health	$2,000,000	Michaud
RDTE,A	Malaria Vaccine Development	$2,000,000	McDermott; Smith (WA)
RDTE,A	Manufacturing and Industrial Technology Center	$500,000	Boyd
RDTE,A	Manufacturing Lab for Next Generation Engineers	$2,000,000	Schock
RDTE,A	Mariah Hypersonic Wind Tunnel Development Program	$4,000,000	Rehberg

RDTE,A	Market Viable, Dual-Use, Advanced Energy Storage Solutions Development	$5,000,000	Hinchey
RDTE,A	Marty Driesler Lung Cancer Project	$2,000,000	Rogers (KY)
RDTE,A	Mass Casualty First Responders Disaster Surge Technology Program	$3,000,000	Pallone; Rothman
RDTE,A	Materials Processing and Applications Development Center of Excellence for Industry	$1,500,000	Bachus
RDTE,A	Medical Biosurveillance and Efficiency Program	$2,000,000	Altmire
RDTE,A	Medical Errors Reduction Initiative	$2,500,000	Rothman
RDTE,A	Medium Caliber Metal Parts Upgrade	$3,100,000	Kanjorski
RDTE,A	Micro Inertial Navigation Unit Technology	$1,500,000	Doyle
RDTE,A	Microencapsulation and Vaccine Delivery Research	$1,000,000	Edwards (TX)
RDTE,A	Micromachined Switches in Support of Transformational Communications Architecture	$3,000,000	Miller, George (CA)
RDTE,A	Mid-Infrared Super Continuum Laser	$1,000,000	Kilpatrick
RDTE,A	Midwest Traumatic Injury Rehabilitation Center	$1,460,000	Ehlers
RDTE,A	Military Burn Trauma Research Program	$2,000,000	Matsui; Lungren
RDTE,A	Military Drug Management System	$3,000,000	Mollohan
RDTE,A	Military Family Coping Patterns	$500,000	Edwards (TX)
RDTE,A	Military Fuel Cell Genset Technology Demonstration	$2,500,000	Boccieri
RDTE,A	Military Low Vision Research	$3,000,000	Lynch; Capuano
RDTE,A	Military Mental Health Initiative	$750,000	Kilpatrick; Dingell
RDTE,A	Military Pediatric Training and Support	$5,000,000	Norton
RDTE,A	Mission Hospital Computerized Physician Order Entry	$1,000,000	Shuler

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[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
RDTE,A	Mobile Integrated Diagnostic and Data Analysis	$2,000,000	Adler
RDTE,A	Mobile Mesh Network Node	$2,200,000	Obey
RDTE,A	Mobile Power 30 kW System Power Control Unit Development Project	$1,000,000	Harman
RDTE,A	Model for Green Laboratories and Clean Rooms	$1,500,000	Bishop (GA)
RDTE,A	Modeling and Testing of Next Generation Body Armor	$1,500,000	Rush
RDTE,A	Molecular Electronics for Flash Memory Production	$2,000,000	Lipinski
RDTE,A	Montefiore Critical Looking Glass	$1,500,000	Engel
RDTE,A	Mortar Anti-Personnel/Anti-MaterielTechnology	$4,000,000	Rothman
RDTE,A	MOTS All Sky Imager	$1,200,000	Reyes; Rodriguez
RDTE,A	Multi-Campus Base Facility Energy Independence	$4,000,000	Kaptur
RDTE,A	Multi-layer Co-extrusion for High Performance Packaging	$2,000,000	Obey
RDTE,A	Multiplexed Human Fungal Infection Diagnostic	$2,000,000	Frank (MA)
RDTE,A	Multi-Utility Materials for Future Combat Systems	$1,000,000	Herseth Sandlin; Brown, Corrine (FL); Latham; Meek
RDTE,A	Musculoskeletal Interdisciplinary Research Initiative	$2,000,000	Bilirakis
RDTE,A	Myositis Association—exposure to environmental toxins	$1,250,000	Israel
RDTE,A	Nano Advanced Cluster Energetics	$2,000,000	Frelinghuysen
RDTE,A	Nanocrystal Source Display	$950,000	Markey (MA)

RDTE,A	Nanofiber Based Synthetic Bone Repair Device for Limb Salvage	$1,000,000	Wamp
RDTE,A	Nanofluid Coolants	$500,000	Davis (KY)
RDTE,A	Nano-imaging Agents for Early Disease Detection	$1,000,000	Green, Al (TX); Culberson
RDTE,A	Nanomanufacturing of Multifunctional Sensors	$2,000,000	Tsongas
RDTE,A	Nanophotonic Biosensor Detection of Bioagents and Pathogens	$1,900,000	Kingston; Bishop (GA)
RDTE,A	Nanotechnology for Potable Water and Waste Treatment	$2,000,000	Sutton; Murphy, Tim (PA)
RDTE,A	Nanotechnology Fuze	$2,000,000	Obey
RDTE,A	Nanotechnology-Enabled Self-Healing Anti-Corrosion Coating Products	$2,000,000	Holt
RDTE,A	National Biodefense Training Center	$5,000,000	Olson
RDTE,A	National Center for Defense Manufacturing and Machining	$2,000,000	Murphy, Tim (PA)
RDTE,A	National Eye Evaluation and Research Network	$3,000,000	Lewis (CA); Sarbanes
RDTE,A	National Functional Genomics Center	$6,000,000	Bilirakis; Castor (FL); Young (FL)
RDTE,A	National Oncogenomics and Molecular Imaging Center	$5,950,000	Kilpatrick
RDTE,A	NAU-TGen North Dangerous Pathogens DNA Forensics Center Upgrades	$2,000,000	Kirkpatrick
RDTE,A	Near Infrared Spectroscopy Military Personnel Assessment	$1,000,000	Castor (FL)
RDTE,A	Networked Reliability and Safety Early Evaluation System	$2,000,000	Dent
RDTE,A	Neural Control of External Devices	$1,000,000	Kennedy
RDTE,A	Neuroimaging and Neuropsychiatric Trauma in US Warfighters	$6,250,000	Pelosi
RDTE,A	Neuro-Performance Research	$2,000,000	Moran (VA)
RDTE,A	Neuroscience Research Consortium to Study Spinal Cord Injury	$1,500,000	Diaz-Balart, Lincoln (FL); Ros-Lehtinen; Wasserman Schultz

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Account	Project	Amount	Requester(s)
RDTE,A	New York Medical College Bioterrorism Research	$165,000	Lowey
RDTE,A	Next Generation Communications System	$1,000,000	Altmire
RDTE,A	Next Generation Green, Economical and Automated Production of Composite Structures for Aerospace	$1,000,000	Grijalva
RDTE,A	Next Generation Machining Technology and Equipment	$2,000,000	Murphy (NY)
RDTE,A	Next Generation Precision Airdrop System	$2,500,000	Larson (CT)
RDTE,A	Next Generation Wearable Video Capture System	$1,000,000	Stupak
RDTE,A	Nicholson Center for Surgical Advancement Medical Robotics and Simulation	$5,250,000	Grayson
RDTE,A	Night Vision and Electronic Sensors Directorate	$2,500,000	Olver
RDTE,A	Non-Leaching Antimicrobial Surface for Orthopedic Devices	$1,500,000	Capuano
RDTE,A	Northern Illinois Proton Treatment and Research Center	$3,500,000	Foster
RDTE,A	Novel Zinc Air Power Sources for Military Applications	$2,500,000	Rogers (AL)
RDTE,A	Nurse Education Center of Excellence for Remote and Medically Underserved Populations	$2,000,000	Shuster
RDTE,A	Nursing Teaching and Leadership Program	$1,000,000	McDermott
RDTE,A	OMNI Active Vibration Control System	$3,000,000	Dahlkemper
RDTE,A	ONAMI Miniaturized Tactical Energy Systems Development	$2,500,000	Schrader; Blumenauer; DeFazio; Walden; Wu
RDTE,A	One-Step JP-8 Bio-Diesel Fuel	$2,000,000	Obey
RDTE,A	Operating Room of the Future	$2,500,000	Berman

RDTE,A	Operation Re-Entry NC	$3,000,000	Butterfield
RDTE,A	Optimization of the US Army Topographic Data Management Enterprise	$2,600,000	Murtha; Moran (VA)
RDTE,A	Optimizing Natural Language Processing of Open Source Intelligence	$1,500,000	Bishop (UT)
RDTE,A	Organic Semiconductor Modeling and Simulation	$1,100,000	Gohmert
RDTE,A	Pacific Command Renewable Energy Security Systems	$3,000,000	Abercrombie
RDTE,A	Parsons Institute for Information Mapping	$1,500,000	Nadler
RDTE,A	Pediatric Cancer Research and Clinical Trials	$2,000,000	Ryan (OH); Culberson; Rothman; Van Hollen
RDTE,A	Perpetually Available and Secure Information Systems	$4,000,000	Doyle
RDTE,A	Personal Miniature Thermal Viewer	$1,000,000	Michaud
RDTE,A	Personal Status Monitor	$1,000,000	Maffei; McHugh
RDTE,A	Plant-Based Vaccine Research	$2,500,000	Guthrie
RDTE,A	Plasma Sterilizer	$3,000,000	Ellison; McCollum
RDTE,A	Plug-in Architecture for DOD Medical Imaging	$1,500,000	Moran (VA)
RDTE,A	Polymeric Web Run-Flat Tire Inserts for Convoy Protection	$3,500,000	Obey
RDTE,A	Portable Fuel Cell Power Source	$3,000,000	Price (NC)
RDTE,A	Portable Low-Volume Therapy for Severe Blood Loss	$2,000,000	Oberstar
RDTE,A	Portable Mobile Emergency Broadband Systems	$3,000,000	Gerlach; Sestak
RDTE,A	Portable Sensor for Toxic Gas Detection	$2,600,000	Granger
RDTE,A	Positron Capture and Storage	$1,500,000	McMorris Rodgers
RDTE,A	Power Efficient Microdisplay Development for US Army Night Vision	$3,000,000	Hall (NY)

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[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
RDTE,A	Prader Willi Syndrome Research	$2,000,000	Royce
RDTE,A	Precision Guidance Kit Technology Development	$7,500,000	Mollohan; Bartlett
RDTE,A	Precision Guided Airdropped Equipment	$1,500,000	Velázquez; Towns
RDTE,A	Predictive Casting Process Modeling for Rapid Production of Critical Defense Components	$2,000,000	Hall (TX)
RDTE,A	PrideCenter for America's Wounded Veterans	$2,000,000	Berry
RDTE,A	Printed and Conformal Electronics for Military Applications	$2,000,000	Mitchell; Lance; Lofgren; Ryan (OH); Schakowsky; Tonko
RDTE,A	Project National Shield Integration Center	$1,500,000	Capito
RDTE,A	Protective 3-D Armor Structure to Safeguard Military Vehicles and Troops	$2,000,000	Levin
RDTE,A	Protective Gear Development through Man-In-Stimulant-Test Chamber	$1,000,000	Etheridge; Miller (NC)
RDTE,A	Protein Hydrogel for Surgical Repair of Battlefield Injuries	$1,000,000	Gingrey (GA)
RDTE,A	Qualification and Insertion of New High Temperature Domestic Sourced PES for Military Aircraft	$3,000,000	Johnson, Eddie Bernice (TX)
RDTE,A	Rapid Insertion of Developmental Technologies into Fielded Systems	$2,000,000	Frelinghuysen; Sires
RDTE,A	Rapid Response Force Projection Systems	$2,000,000	Rothman
RDTE,A	Rapid Wound Healing Cell Technology	$2,500,000	Doyle
RDTE,A	Rare Earth Mining Separation and Metal Production	$3,000,000	Lewis (CA)
RDTE,A	RDT&E for the Family of Heavy Tactical Vehicles (FHTV)	$2,000,000	Kagen
RDTE,A	Reactive Materials	$1,500,000	Barton

RDTE,A	Recovery, Recycle, and Reuse of DOE Metals for DoD Applications	$2,400,000	Granger
RDTE,A	Reduced Manning Situational Awareness	$5,000,000	Young (FL)
RDTE,A	Reducing First Responder Casualties with Physiological Monitoring	$1,500,000	Hodes
RDTE,A	Regenerative Medicine Research	$2,000,000	Michaud
RDTE,A	Reliability and Affordability Enhancement for Precision Guided Munition Systems	$6,000,000	Frelinghuysen
RDTE,A	Remote Bio-Medical Detector	$3,500,000	Murtha
RDTE,A	Remote Environmental Monitoring and Diagnostics in the Perishables Supply Chain	$2,750,000	Stearns
RDTE,A	Remote Explosive Analysis and Detection System	$1,000,000	Griffith
RDTE,A	Renewable Energy Testing Center	$1,000,000	Matsui; Lungren
RDTE,A	Research to Develop Strategies to Improve Prognosis of Soldiers Suffering Abdominal Trauma	$2,000,000	Yarmuth
RDTE,A	Research to Treat Cancerous Brain Tumors using Neural Stem Cells	$2,000,000	Lewis (CA)
RDTE,A	Rocket Motor Contained System	$1,000,000	Heller
RDTE,A	Ruggedized Military Laptop Fuel Cell Power Supply- Project Phase 3	$4,000,000	Brown, Corrine (FL); Crenshaw
RDTE,A	Rural Health Center of Excellence for Remote and Medically Underserved Populations	$2,000,000	Shuster
RDTE,A	Scaleable Efficient Power for Armament Systems and Vehicles Dual Use	$5,000,000	Rothman
RDTE,A	School of Nursing Advancement	$2,000,000	Pelosi
RDTE,A	Science, Technology, Engineering, Mathematics (STEM) at Coppin University	$1,000,000	Cummings
RDTE,A	Secure Open Source Initiative	$3,000,000	Price (NC); Miller (NC)
RDTE,A	Self Powered Prosthetic Limb Technology	$2,000,000	Thompson (PA)
RDTE,A	Self-Powered Sensor System for Munition Guidance and Health Monitoring	$2,000,000	Holt

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Account	Project	Amount	Requester(s)
RDTE,A	Sensor Tape Physiological Monitoring	$2,500,000	Bishop (GA)
RDTE,A	Shared Vision	$3,000,000	Latham
RDTE,A	SHARK Precision Guided Artillery Round—105mm	$5,000,000	Young (FL)
RDTE,A	Silent Watch, IB NPS 1160 Lithium-Ion Advanced Battery	$1,000,000	Dent
RDTE,A	Silver Fox and Manta Unmanned Aerial Systems	$2,000,000	Franks (AZ)
RDTE,A	Smart Machine Platform Initiative	$3,000,000	Driehaus; Tonko
RDTE,A	Smart Oil Sensor	$3,000,000	Thompson (PA)
RDTE,A	Smart Plug-In Hybrid Vehicle Program	$4,100,000	Kilpatrick; Conyers; Dingell; Rogers (MI)
RDTE,A	Smart Wound Dressing for MRSA Infected Battlefield Wounds	$1,000,000	Driehaus; Cummings; Ruppersberger; Scott (VA)
RDTE,A	Soldier Personal Cooling System	$1,200,000	Kosmas
RDTE,A	Soldier Protection through Unmanned Ground Vehicles	$1,500,000	Nye
RDTE,A	Soldier Situational Awareness Wristband	$1,400,000	Capuano
RDTE,A	Solid Oxide Fuel Cell Powered Tactical Charger	$1,200,000	Maffei
RDTE,A	Solid State Processing of Titanium Alloys for Advanced Materiel Armaments	$1,500,000	Kaptur; LaTourette
RDTE,A	Specialized Compact Automated Mechanical Clearance Platform	$4,000,000	Murphy, Patrick (PA)
RDTE,A	Spectroscopic Materials Identification Center	$2,000,000	Berry
RDTE,A	Spinal Cord Restoration Therapies	$1,000,000	Hoyer; Cummings; Ruppersberger

RDTE,A	Spinal Muscular Atrophy Research Program	$3,000,000	Pelosi; Nadler; Rangel
RDTE,A	Standard Ground Station—Enhancement Program	$2,500,000	Lance; Rothman
RDTE,A	Standoff Improvised Explosive Detection Program	$6,000,000	Boyd; Berry; Brown, Corrine (FL); Hirono; Meek
RDTE,A	Stress Disorders Research Initiative at Fort Hood	$3,000,000	Edwards (TX)
RDTE,A	Superlattice Semiconductors for Mobile SS Lighting and Solar Power Applications	$3,500,000	Hinchey
RDTE,A	Surveillance Augmentation Vehicle	$1,500,000	Childers
RDTE,A	Sustainable Alternative Energy	$2,000,000	Obey
RDTE,A	Synchrotron-Based Scanning Research Neuroscience and Proton Institute	$6,000,000	Lewis (CA)
RDTE,A	Tactical Cogeneration System	$1,000,000	Hastings (WA)
RDTE,A	Tactical Metal Fabrication System (TacFab)	$1,000,000	Turner; Adler; Andrews; Cole; Lance; Markey (MA); Ryan (OH); Tsongas
RDTE,A	Tactical Overwatch High Altitude System	$1,000,000	Griffith
RDTE,A	Tamper Proof Organic Packaging as Applied to Remote Armament Systems	$6,000,000	Hinchey
RDTE,A	Techniques to Manage Noncompressible Hemorrhage Following Combat Injury	$2,500,000	Smith (TX); Carter; Gonzalez; Rodriguez
RDTE,A	Technologies for Military Equipment Replenishment	$2,000,000	Obey
RDTE,A	Technology Development at the Quad Cities Manufacturing Laboratory	$2,000,000	Hare
RDTE,A	Technology Solutions for Brain Cancer Detection and Treatment	$1,500,000	Cohen
RDTE,A	Telepharmacy Robotic Medicine Device Unit	$1,000,000	Brady (PA)
RDTE,A	Terahertz Sensing and Imaging Technology	$2,000,000	Boozman
RDTE,A	Testing of Microneedle Device for Multiple Applications	$1,200,000	Baldwin

DEFENSE—Continued
[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
RDTE,A	Threat Detection and Neutralization	$4,000,000	Mollohan
RDTE,A	Tire to Track Transformer System for Light Vehicles	$2,000,000	Peterson
RDTE,A	Titanium Powder Advanced Forged Parts Program	$3,800,000	Murtha
RDTE,A	Translational Research for Muscular Dystrophy	$2,000,000	Michaud; Pingree (ME)
RDTE,A	Transportable Renal Replacement Therapy for Battlefield Applications	$1,000,000	Altmire
RDTE,A	Treatment of Battlefield Spinal Cord and Burn Injuries	$450,000	Wu; Baird; Blumenauer; Schrader
RDTE,A	Tungsten Heavy Alloy Penetrator and Warhead Development	$1,500,000	Carney
RDTE,A	Turbo Fuel Cell Engine	$4,000,000	Murtha
RDTE,A	UH-60 Transmission/Gearbox Galvanic Corrosion Reduction	$1,500,000	Kissell
RDTE,A	Ultra Light Metallic Armor	$1,000,000	Costello
RDTE,A	Ultra Light Weight Transmissions	$2,000,000	Schauer
RDTE,A	Understanding Blast Induced Brain Injury	$3,000,000	Fortenberry
RDTE,A	Universal Control	$2,500,000	Larson (CT)
RDTE,A	University Center for Disaster Preparedness and Emergency Response	$1,500,000	Pallone; Holt
RDTE,A	University of Miami Ryder Trauma Center/William Lehman Injury Research Center	$4,000,000	Diaz-Balart, Lincoln (FL)
RDTE,A	Unmanned Hybrid Projectiles	$3,000,000	Larson (CT); Courtney
RDTE,A	Unmanned Robotic System Utilizing a Hydrocarbon Fueled Solid Oxide Fuel Cell System	$3,000,000	Dingell

RDTE,A	Unmanned System Algorithm Development	$4,000,000	Mollohan
RDTE,A	Vanadium Safety Readiness	$4,200,000	Dahlkemper; Paul; Space
RDTE,A	Vanadium Technology Program	$3,000,000	Wilson (SC)
RDTE,A	Video Compression Technology	$2,000,000	Holt
RDTE,A	Vision Integrating Strategies in Ophthalmology and Neurochemistry	$4,000,000	Granger
RDTE,A	Voice Recognition and Cross Platform Speech Interface System	$2,500,000	Shuster
RDTE,A	VTOL Man-Rated UAV and UGV for Medical Multi-Missions and CASEVAC	$1,000,000	Harman
RDTE,A	Waterside Wide Area Tactical Coverage and Homing	$4,000,000	Aderholt
RDTE,A	Westchester County Medical Center Health Imaging Upgrades	$1,500,000	Lowey
RDTE,A	Wireless HUMS for Condition Based Maintenance of Army Helicopters	$2,000,000	Rothman
RDTE,A	Wireless Medical Monitoring System	$3,000,000	Boswell; Latham; Miller, Gary (CA)
RDTE,A	Womens Cancer Genomics Center	$3,000,000	McCarthy (NY); Lowey
RDTE,A	Wounded Servicemember Bioelectrics Research	$1,500,000	Nye
RDTE,A	Zinc-Flow Electrical Energy Storage	$2,500,000	Johnson (IL)
RDTE,A	Zumwalt National Program for Countermeasures to Biological and Chemical Threats	$1,500,000	Neugebauer
RDTE,AF	3D Bias Woven Perform Development	$3,000,000	Schwartz; Gerlach; Sestak
RDTE,AF	Accelerated Insertion of Advanced Materials and Certification for Military Aircraft Structure Material Substitution and Repair	$2,500,000	Tiahrt
RDTE,AF	Accelerator-Driven Non-Destructive Testing	$2,000,000	Simpson
RDTE,AF	Advance Propulsion Non-Tactical Vehicle	$2,000,000	Massa
RDTE,AF	Advanced Aerospace Heat Exchangers	$750,000	Wilson (OH)

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[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
RDTE,AF	Advanced Deformable Mirrors for High Energy Laser Weapons	$2,000,000	Heinrich
RDTE,AF	Advanced Electromagnetic Location of IEDs Defeat System	$1,500,000	Kaptur
RDTE,AF	Advanced Electronic Components for Sensor Arrays	$3,000,000	Young (FL)
RDTE,AF	Advanced Lithium Battery Scale-up and Manufacturing	$2,000,000	Scott (GA); Bishop (GA); Johnson (GA)
RDTE,AF	Advanced Modular Avionics for Operationally Responsive Satellite Use	$3,100,000	Heinrich
RDTE,AF	Advanced Vehicle Propulsion Center	$3,000,000	McKeon
RDTE,AF	Aerospace Lab Equipment Upgrade	$1,500,000	Napolitano
RDTE,AF	Aerospace Laser Micro Engineering Station	$1,000,000	Wittman; Nye; Scott (VA)
RDTE,AF	AFRL Edwards Rocket Test Stand 2-A Technical Improvements	$1,500,000	McCarthy (CA)
RDTE,AF	ALC Logistics Integration Environment	$1,000,000	Shuster
RDTE,AF	Algal-Derived Jet Fuel for Air Force Applications	$3,000,000	LaTourette
RDTE,AF	AT-6B Demonstration for ANG	$7,000,000	Tiahrt
RDTE,AF	B-1 AESA Radar Operational Utility Evaluation	$1,000,000	Herseth Sandlin
RDTE,AF	B-2 Advanced Tactical Data Link	$6,000,000	McKeon
RDTE,AF	B-52 Tactical Data Link Capability	$6,000,000	Tiahrt
RDTE,AF	Ballistic Missile Technology	$2,000,000	Young (FL)
RDTE,AF	Base Facility Energy Independence, Stewart Air National Guard Base	$5,000,000	Hinchey

RDTE,AF	BATMAV Program Miniature Digital Data Link	$2,000,000	Young (FL)
RDTE,AF	Big Antennas Small Structures Efficient Tactical UAV	$2,000,000	Harman
RDTE,AF	Bio-JP8 Fuel Development	$5,000,000	Boyd
RDTE,AF	Body Armor Improved Ballistic Protection, Research and Development	$2,200,000	Murtha
RDTE,AF	Carbon Nano-Materials for Advanced Aerospace Applications	$1,000,000	Culberson
RDTE,AF	Carbon Nanotube Enhanced Power Sources for Space	$2,000,000	Markey (MA)
RDTE,AF	Center for Solar Electricity and Hydrogen	$5,000,000	Kaptur
RDTE,AF	Center for Space Entrepreneurship	$2,000,000	Polis
RDTE,AF	Center for UAS Research, Education and Training Infrastructure	$3,000,000	Pomeroy
RDTE,AF	Close Proximity Space Situational Awareness	$1,000,000	Edwards (TX)
RDTE,AF	Command and Control Service Level Management (C2SLM) Program	$4,000,000	Blunt
RDTE,AF	Corrosion Detection and Visualization Program	$1,000,000	Smith (WA)
RDTE,AF	COTS Technology for Space Command and Control	$2,000,000	Gerlach
RDTE,AF	Cyber Attack and Security Environment	$4,000,000	McHugh; Arcuri
RDTE,AF	Cyber Security Research Program	$1,500,000	Alexander
RDTE,AF	Demonstration and Validation of Renewable Energy Technology	$1,000,000	Bishop (GA)
RDTE,AF	Development and Testing of Advanced Hybrid Rockets for Space Applications	$3,500,000	Lofgren
RDTE,AF	Distributed Mission Interoperability Toolkit (DMIT)	$4,000,000	LoBiondo; Andrews; Sestak
RDTE,AF	Domestic Manufacturing of 45nm Electronics	$2,000,000	Simpson
RDTE,AF	Efficient Utilization of Transmission Hyperspace	$2,500,000	Arcuri

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[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
RDTE,AF	Eglin AFB Range Operations Control Center	$2,500,000	Miller (FL)
RDTE,AF	Electromagnetic Battlespace Management	$2,000,000	Edwards (TX)
RDTE,AF	EMI Grid Fabrication Technology	$3,000,000	Bono Mack
RDTE,AF	Energy and Sensor Informatics Research and Translation	$1,000,000	Lee (NY)
RDTE,AF	Fine Water Mist Fire Suppression Technology to Replace Halon	$2,500,000	Boyd
RDTE,AF	Florida National Guard Total Force Integration	$3,000,000	Young (FL)
RDTE,AF	Frank R. Seaver Science and Engineering Initiative	$2,200,000	Waters
RDTE,AF	Gallium Nitride (GaN) Microelectronics and Materials	$2,000,000	Coble
RDTE,AF	GAPS/AWS Horizontal Integration	$5,000,000	Murtha
RDTE,AF	Hawaii Microalgae Biofuel Project	$4,400,000	Hirono
RDTE,AF	High Bandwidth, High Energy Storage, Exawatt Laser Glass Development	$3,500,000	Kanjorski
RDTE,AF	High Energy Li-Ion Technology for Aviation Batteries	$1,500,000	Bishop (GA)
RDTE,AF	High Pressure Pure Air Generator System	$2,000,000	Frelinghuysen
RDTE,AF	Hybrid Bearings	$1,000,000	Shuler; Coble; Wilson (OH)
RDTE,AF	Hybrid Nanoparticle-based Coolant Technology Development and Manufacturing	$1,000,000	Dent
RDTE,AF	Institute for Science and Engineering Simulation	$4,500,000	Burgess
RDTE,AF	Integrated Engine Starter/Generator	$2,000,000	Turner

RDTE,AF	Integrated Passive Electronic Components	$1,700,000	Simpson
RDTE,AF	Integrated Propulsion Analysis and Spacecraft Engineering Tools (IPAT/ISET)	$6,000,000	Lewis (CA)
RDTE,AF	Inter-Base Facility Energy Independence	$3,000,000	Kaptur
RDTE,AF	Large Area, APVT Materials Development for High Power Devices	$2,000,000	Frelinghuysen
RDTE,AF	Laser Peening for Friction Stir Welded Aerospace Structures	$2,000,000	Tiahrt
RDTE,AF	Long-Loiter, Load Bearing Antenna Platform for Pervasive Airborne Intelligence	$5,000,000	Blunt
RDTE,AF	Low-Defect Density Gallium Nitride Materials for High-Performance Electronic Devices	$3,500,000	Price (NC)
RDTE,AF	Micromachined Switches for Next Generation Modular Satellites	$3,000,000	Miller, George (CA)
RDTE,AF	Micro-Satellite Serial Manufacturing to Include Academic Outreach Educational Program	$1,500,000	Harman
RDTE,AF	Minuteman III Advanced Third Stage Domestic Fiber Motor Case Development	$3,000,000	Lungren
RDTE,AF	Mission Design and Analysis Tool	$2,000,000	Kingston
RDTE,AF	Mitigating RoHS Lead-Free Issues in Aerospace Circuit Board Manufacturing	$1,000,000	Kaptur; Sutton
RDTE,AF	Multilingual Text Mining Platform for Intelligence Analysts	$1,000,000	Lee (NY)
RDTE,AF	Multi-Mode Propulsion Phase IIA: High Performance Green Propellant	$2,000,000	Kratovil
RDTE,AF	Multiple UAS Cooperative Concentrated Observation and Engagement Against a Common Ground Objective	$2,000,000	Bartlett
RDTE,AF	National Test Facility for Aerospace Fuels Propulsion	$1,640,000	Buyer
RDTE,AF	Net-Centric Sensor Grids	$3,000,000	Hill
RDTE,AF	Nuclear Enterprise Surety Tracking	$5,000,000	Fleming
RDTE,AF	ONAMI Safer Nanomaterials and Nanomanufacturing	$2,000,000	DeFazio; Blumenauer; Schrader; Walden; Wu
RDTE,AF	Open Source Research Centers	$1,000,000	Turner

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[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
RDTE,AF	Partnership for Energy and Automation Technologies	$2,000,000	Duncan
RDTE,AF	Pennsylvania NanoMaterials Commercialization Center	$1,000,000	Doyle
RDTE,AF	Planar Lightwave Circuit Development for High Power Military Laser Applications	$3,000,000	Lance; Rothman
RDTE,AF	Predator C	$1,500,000	Bilbray; Hunter; McKeon
RDTE,AF	Process Integrated Mechanism for Human-Computer Collaboration and Coordination	$1,000,000	Stearns
RDTE,AF	Production of Nanocomposites for Aerospace Applications	$2,000,000	Turner
RDTE,AF	Reconfigurable Secure Computing	$2,000,000	Moran (VA)
RDTE,AF	Reconstitution of B-52 Nuclear Capability Study	$3,000,000	Fleming
RDTE,AF	Remote Language-Independent Suspect Identification	$3,200,000	Alexander
RDTE,AF	Renewable Hydrocarbon Fuels for Military Applications	$2,500,000	Kucinich; Kaptur
RDTE,AF	Rivet Joint Services Oriented Architecture	$2,500,000	Hall (TX)
RDTE,AF	Safeguarding End-User Military Software	$1,500,000	Fortenberry
RDTE,AF	Senior Scout Communications Intelligence (COMINT) Capability Upgrade	$3,000,000	Andrews; LoBiondo
RDTE,AF	Small Responsive Spacecraft at Low-Cost	$3,000,000	Bishop (UT)
RDTE,AF	Small Turbofan Versatile Affordable Advanced Turbine Engine Program	$4,000,000	Pastor (AZ)
RDTE,AF	Synthetic Liquid Fuels	$3,000,000	Young (AK)
RDTE,AF	Technical Order Modernization Environment	$1,500,000	Kaptur

RDTE,AF	Texas Research Institute for Environmental Studies	$1,000,000	Rodriguez
RDTE,AF	Thermal and Energy Management for Aerospace	$4,000,000	Manzullo
RDTE,AF	Ultra-High Temperature Materials for Hypersonic Aerospace Vehicles	$3,000,000	Emerson
RDTE,AF	Unmanned Aerial Systems Mission Planning and Operation Center	$3,500,000	Moran (KS)
RDTE,AF	Unmanned Sense, Track, and Avoid Radar	$2,000,000	Lamborn
RDTE,AF	Watchkeeper	$2,000,000	Rehberg
RDTE,AF	Wavelength Agile Spectral Harmonic Oxygen Sensor and Cell-Level Battery Controller	$1,500,000	Dreier
RDTE,AF	Wire Integrity Technology	$2,000,000	Marshall; Bishop (GA)
RDTE,DW	3-D Electronics and Power	$6,000,000	Calvert
RDTE,DW	3-D Technology for Advanced Sensor Systems	$2,000,000	Simpson
RDTE,DW	Active Duty Training and Education Program	$2,000,000	Clyburn
RDTE,DW	Advanced Battery Technology	$2,000,000	Young (FL)
RDTE,DW	Advanced Decision Support System	$2,500,000	Rothman; Payne
RDTE,DW	Advanced Development of Antiviral Prophylactics and Therapeutics	$3,000,000	Pelosi
RDTE,DW	Advanced Development of Mobile Rapid Response Prototypes	$2,000,000	Rothman
RDTE,DW	Advanced Scientific Missile Intelligence Preparation of the Battlespace	$2,500,000	Griffith
RDTE,DW	Advanced Technologies Sensors and Payloads/Unattended SIGINT Node	$6,000,000	Lewis (CA)
RDTE,DW	Advanced, Long Endurance Unattended Ground Sensor Technologies	$2,000,000	Harper; Childers; Taylor
RDTE,DW	AELED IED/WMD Electronic Signature Detection	$6,000,000	Murtha
RDTE,DW	AESA Technology Insertion Program	$3,000,000	Ackerman; McCarthy (NY)

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[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
RDTE,DW	Affordable Miniature FOPEN Radar for Special Operations Craft—Riverine (SOC-R)	$3,500,000	Murtha
RDTE,DW	Affordable Robust Mid-Sized Unmanned Ground Vehicle	$2,000,000	Tsongas
RDTE,DW	Aging Systems Sustainment and Enabling Technologies	$3,000,000	Lucas
RDTE,DW	Alternative SOF Submersible Concept Design Study	$1,000,000	Scalise
RDTE,DW	American Museum of Natural History Infectious Disease Research	$1,500,000	Lowey; Nadler
RDTE,DW	Automated Sample Preparation for Biological Detection	$1,000,000	Slaughter; Bartlett
RDTE,DW	Autonomous Control and Video Sensing for Robots	$1,000,000	Lee (NY)
RDTE,DW	Autonomous Machine Vision for Mapping and Investigation of Remote Sites	$2,000,000	Davis (CA)
RDTE,DW	Battle-Proven Packbot	$1,500,000	Tierney
RDTE,DW	BioButanol Production Research	$2,000,000	Clyburn
RDTE,DW	Biological and Chemical Warfare Online Repository of Technical Holdings	$2,000,000	Hastings (WA)
RDTE,DW	Biometric Optical Surveillance System	$5,000,000	Guthrie
RDTE,DW	Botulinum Neurotoxin Research	$2,500,000	Baldwin
RDTE,DW	Botulinum Toxin Treatment Therapy	$1,000,000	Bishop (GA)
RDTE,DW	Broad Spectrum Therapeutic Countermeasure to OP Nerve Agents	$2,000,000	DeLauro
RDTE,DW	California Enhanced Defense Small Manufacturing Suppliers Program	$2,000,000	Roybal-Allard
RDTE,DW	Carbon Nanotube Thin Film Near Infrared Detector	$2,000,000	Lewis (CA)

RDTE,DW	CBRN Detection Unmanned Aircraft	$2,000,000	Young (FL)
RDTE,DW	Cellulosic—Derived Biofuels Research	$3,000,000	Chandler
RDTE,DW	Center for Nonproliferation Studies, Monterey Institute for International Affairs	$2,000,000	Berman
RDTE,DW	Center for Research on Minority Health Prostate Cancer Outreach Project	$1,000,000	Jackson-Lee (TX); Green, Al (TX)
RDTE,DW	Chemical and Biological Agent Fate Appropriate Response Operational Tool	$2,000,000	Kildee
RDTE,DW	Chemical and Biological Defense Program—Advanced Development	$2,000,000	Baldwin
RDTE,DW	Chemical and Biological Resistant Clothing	$2,000,000	Sestak; Gerlach
RDTE,DW	Chemical and Biological Threat Reduction Coating	$3,000,000	Barrett
RDTE,DW	Comprehensive and Integrated Procedures for Risk Assessment and Resource Allocation	$2,500,000	Brady (PA)
RDTE,DW	Comprehensive Maritime Domain Awareness	$4,000,000	Young (FL)
RDTE,DW	Copper-Base Casting Technology Applications	$2,000,000	Perlmutter
RDTE,DW	Corrosion Resistant Ultrahigh-Strength Steel for Landing Gear	$2,000,000	Schakowsky
RDTE,DW	Corrosion Training Simulation Program	$1,500,000	Oberstar
RDTE,DW	Countermeasures to Chemical and Biological Controls—Rapid Response	$3,500,000	Young (FL)
RDTE,DW	Countermeasures to Combat Protozoan Parasites (Toxoplasmosis and Malaria)	$2,000,000	Young (FL)
RDTE,DW	Counterproliferation Analysis and Planning System	$5,000,000	McNerney; Tauscher
RDTE,DW	Covert Waveform for Software Defined Radios	$1,000,000	Gingrey (GA)
RDTE,DW	Cybersecurity and Operational Identity Management	$2,000,000	Farr
RDTE,DW	Detection and Remediation of Bio/Chemical Weapons Program	$2,000,000	Clyburn
RDTE,DW	Distributed Network Switching and Security	$2,000,000	Sanchez, Loretta (CA)

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Account	Project	Amount	Requester(s)
RDTE,DW	DLA VetBiz Initiative for National Sustainment	$1,000,000	Sarbanes
RDTE,DW	End to End Semi Fab Alpha Tool	$2,000,000	Sanchez, Loretta (CA)
RDTE,DW	Enhancement of Geo-location Systems	$4,000,000	Posey
RDTE,DW	Environmentally Friendly Nanometal Electroplating Processes for Cadmium and Chromium Replacement	$3,000,000	Obey
RDTE,DW	Facility Security Using Tactical Surveys	$4,500,000	Lewis (CA)
RDTE,DW	Feature Size Yield Enhancement Advanced Reconfigurable Manufacturing for Semiconductors Foundry	$3,000,000	Lungren; Matsui
RDTE,DW	Field Experiment Program for Special Operations	$2,000,000	Farr
RDTE,DW	FirstLink Technology Transfer Program	$3,000,000	Murtha
RDTE,DW	Flashlight Soldier-to-Soldier Combat Identification System	$4,500,000	Granger; Rodriguez
RDTE,DW	GMTI Radar for Class II UAVs	$1,000,000	Moran (VA)
RDTE,DW	Gulf Range Mobile Instrumentation Capability	$3,000,000	Miller (FL)
RDTE,DW	Hand-Held Apparatus for Mobile Mapping and Expedited Reporting	$3,500,000	Murtha
RDTE,DW	Hand-held, Lethal Small Unmanned Aircraft System	$1,000,000	Dreier
RDTE,DW	Helicopter Cable Warning and Obstacle Avoidance	$1,500,000	Harman
RDTE,DW	Heterogeneous Gallium Nitride/Silicon Microcircuit Technology	$2,000,000	Lungren
RDTE,DW	High Accuracy Network Determination System—Intelligent Optical Networks	$2,000,000	Abercrombie
RDTE,DW	High Efficiency Solar Energy Generation and Storage	$1,000,000	Jackson-Lee (TX)

RDTE,DW	High Speed Optical Interconnects for Next Generation Supercomputing	$1,500,000	Dent
RDTE,DW	Hybrid Power Generating System	$2,000,000	Simpson
RDTE,DW	Hydrogen Fuel Cell Research	$4,000,000	Clyburn
RDTE,DW	HyperAcute Vaccine Development	$4,500,000	Latham
RDTE,DW	Improving Support to the Warfighter	$7,000,000	Lewis (CA)
RDTE,DW	Independent Advisory Group to Review Ballistic Missile Defense Training Needs	$500,000	Lamborn
RDTE,DW	Institute for Collaborative Sciences Research	$2,600,000	Diaz-Balart, Lincoln (FL); Meek; Wasserman Schultz
RDTE,DW	Integrated Analysis Environment	$2,000,000	Moran (VA)
RDTE,DW	Integrated Cryo-cooled High Power Density Systems	$4,000,000	Boyd
RDTE,DW	Integrated Rugged Checkpoint Container	$2,500,000	Taylor
RDTE,DW	Intelligence, Surveillance, and Reconnaissance Global Sensors Architecture (ISR-GSA)	$2,000,000	Young (FL)
RDTE,DW	Intelligent Remote Sensing for Urban Warfare Operations II	$1,500,000	Sestak
RDTE,DW	Joint Gulf Range Complex Test and Training	$3,000,000	Miller (FL)
RDTE,DW	Joint Robotics Training Program	$2,000,000	Clyburn
RDTE,DW	Joint Services Aircrew Mask Don/Doff Inflight Upgrade	$1,500,000	Castle
RDTE,DW	Laboratory for Advanced Photonic Composites Research	$1,600,000	Barrett
RDTE,DW	Laser Ablation Resonance Ionization Mass Spectrometer	$3,000,000	Polis
RDTE,DW	Lifetime Power for Wireless Control Sensors	$1,000,000	Altmire
RDTE,DW	Lithium-ion Battery Safety Detection and Control of Impending Failures	$1,500,000	Carson
RDTE,DW	Low Cost Stabilized Turret	$1,000,000	Crenshaw

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Account	Project	Amount	Requester(s)
RDTE,DW	Material, Design and Fabrication Solutions for Advanced SEAL Delivery System External Structural Components	$2,000,000	Simpson
RDTE,DW	MEMS Sensors for Real-Time Sensing of Weaponized Pathogens	$2,500,000	Biggert; Lipinski
RDTE,DW	Military/Law Enforcement Counterterrorism Test Bed	$3,000,000	Young (FL)
RDTE,DW	Miniature Day Night Sight for Crew Served Weapons	$1,500,000	Sestak
RDTE,DW	Miniature Divert and Altitude Controls System Thruster	$2,000,000	McKeon
RDTE,DW	Miniaturized Chemical Detector for Chemical Warfare Protection	$2,000,000	McGovern
RDTE,DW	Mismatch Repair Derived Antibody Medicines to Treat Staphylococcus-derived Bioweapons	$1,000,000	Sestak
RDTE,DW	Missile Activity and Characteristics—Releasable	$3,000,000	Perriello
RDTE,DW	Modeling and Simulation Standards Study	$800,000	Forbes
RDTE,DW	Moldable Fabric Armor	$2,800,000	Inglis
RDTE,DW	Morehouse College, John H. Hopps Defense Research Scholars Program	$3,000,000	Lewis (GA); Bishop (GA); Kingston; Scott (GA)
RDTE,DW	Mosaic Camera Technology Transition	$2,000,000	Doyle
RDTE,DW	MS GIS Educational and Research Program	$1,000,000	Lewis (CA)
RDTE,DW	Multi-target Shipping Container Interrogation System Mobile Continuous Air Monitor	$2,000,000	Brown, Corrine (FL)
RDTE,DW	National Center for Blast Mitigation	$1,500,000	Moran (VA)
RDTE,DW	National Radio Frequency Research, Development and Technology Transfer	$5,000,000	Buyer; Ellsworth
RDTE,DW	National Terrorism Preparedness Institute, Anti-Terrorism/Counter-Terrorism Technology Development and Training	$3,500,000	Young (FL)

RDTE,DW	New Drug Targets in Multi-Drug Resistant Bacteria	$2,000,000	Slaughter
RDTE,DW	Non-Gasoline Burning Outboard Engine	$1,900,000	Mollohan; Wilson (SC)
RDTE,DW	Northwest Manufacturing Initiative	$2,500,000	Blumenauer; DeFazio; Schrader; Walden; Wu
RDTE,DW	Optical Surveillance Equipment	$2,000,000	Duncan
RDTE,DW	Partnership for Defense Innovation Wi-Fi Laboratory Testing and Assessment Center	$1,500,000	Kissell; Etheridge; McIntyre
RDTE,DW	Personalized Medicine Initiative	$3,000,000	Edwards (MD)
RDTE,DW	Photovoltaic Ribbon Solar Cell Technology Project	$3,600,000	Hinchey
RDTE,DW	Portable Device for Latent Fingerprint Identification	$1,800,000	Smith (WA)
RDTE,DW	Portable Rapid Bacterial Warfare Detection Unit	$4,000,000	Latham; Boswell
RDTE,DW	Potent Human Monoclonal Antibodies Against BoNT A, B and E Suited for Mass Production and Treatment of Large Populations	$1,000,000	Gerlach
RDTE,DW	Progressive Research for Sustainable Manufacturing	$1,500,000	Rogers (KY)
RDTE,DW	Protective Self-Decontaminating Surfaces	$2,000,000	Grijalva; Aderholt
RDTE,DW	Radio Frequency Identification Technologies	$1,000,000	Yarmuth
RDTE,DW	Radio Inter-Operability System	$2,000,000	Moran (VA)
RDTE,DW	Reduced Cost Supply Readiness	$1,500,000	Lynch
RDTE,DW	Regenerative Filtration System for CBRN Defense	$3,000,000	LaTourette
RDTE,DW	Remote VBIED Detection and Defeat System	$1,500,000	Doyle
RDTE,DW	Rigid Aeroshell Variable Buoyancy Air Vehicle	$5,000,000	Sherman; Napolitano
RDTE,DW	Savannah CRTC Training Enabled Maneuver Instrumentation (STEM)	$4,500,000	Kingston

DEFENSE—Continued
[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
RDTE,DW	Science, Technology, Engineering and Mathematics (STEM) Initiative	$2,000,000	Green, Gene (TX); Green, Al (TX); Jackson-Lee (TX)
RDTE,DW	Sea Catcher UAS Launch and Recovery System	$2,000,000	Sarbanes
RDTE,DW	Secure, Miniaturized, Hybrid, Free Space, Optical Communications	$2,000,000	Rothman; Lance
RDTE,DW	Security for Critical Communication Networks	$7,000,000	Rothman; Sires
RDTE,DW	Self-decontaminating Polymer System for Chemical and Biological Warfare Agents	$3,500,000	Blunt
RDTE,DW	Semiconductor Photomask Technology Infrastructure Initiative	$2,000,000	Tauscher
RDTE,DW	Solid Oxide Fuel Technology	$1,000,000	Clyburn
RDTE,DW	Spintronics Memory Storage Technology	$3,500,000	Lewis (CA)
RDTE,DW	Superconducting Quantum Information Technology	$1,000,000	Moore (KS)
RDTE,DW	Synchrotron Beamline Experimental Station	$4,000,000	Clarke; Ackerman; Bishop (NY); McCarthy (NY); Tonko; Towns
RDTE,DW	Tactical, Cargo, and Rotary Wing Aircraft Decon	$2,000,000	LaTourette
RDTE,DW	Technology for Shallow Water Special Operation Forces Mobility	$3,600,000	Boyd
RDTE,DW	Thermal Pointer/Illuminator for Force Protection	$2,000,000	Reichert
RDTE,DW	Thurgood Marshall College Fund Defense Leadership and Technology Initiative	$1,500,000	Bishop (GA)
RDTE,DW	Tidewater Full Scale Exercise	$2,900,000	Forbes
RDTE,DW	Total Perimeter Surveillance	$2,000,000	Schauer

RDTE,DW	Transformer Technology for Combat Submersibles	$4,500,000	Ros-Lehtinen; Bishop (NY)
RDTE,DW	UAV Directed Energy Weapons Systems Payloads	$1,000,000	Tiahrt
RDTE,DW	UAV Systems and Operations Validation Program	$2,000,000	Teague
RDTE,DW	UAV/UAS Test Facility	$3,000,000	Cole
RDTE,DW	Ultra Low Profile EARS Gunshot Localization System	$1,500,000	Moran (VA)
RDTE,DW	Under-Vehicle Inspection System	$3,000,000	Young (AK); Bishop (UT)
RDTE,DW	Unified Management Infrastructure System	$1,000,000	Schakowsky
RDTE,DW	United States Special Operations Command—USSOCOM / STAR-TEC Partnership Program	$2,000,000	Young (FL)
RDTE,DW	United States Special Operations Command SOCRATES High Assurance Platform Program	$1,000,000	Young (FL)
RDTE,DW	University Multi-Spectral Laboratories	$2,500,000	Lucas
RDTE,DW	Wellhead Treatment of Perchlorate Contaminated Wells	$2,000,000	Baca
RDTE,DW	X-Band/W-Band Solid State Power Amplifier	$1,000,000	Young (FL)
RDTE,N	76mm Swarmbuster Capability	$2,000,000	Crenshaw
RDTE,N	AARGM Counter Air Defense Future Capabilities	$2,500,000	Mollohan
RDTE,N	Accelerating Fuel Cells Manufacturability	$2,000,000	Slaughter
RDTE,N	Advanced Battery System for Military Avionics Power Systems	$2,000,000	Sherman
RDTE,N	Advanced Capability Build 12 and 14	$2,000,000	Adler
RDTE,N	Advanced Composite Manufacturing for Composite High-Speed Boat Design	$2,000,000	Pingree (ME)
RDTE,N	Advanced Energetics Initiative	$4,000,000	Hoyer
RDTE,N	Advanced Fuel Filtration System	$1,500,000	Neal; Frelinghuysen

DEFENSE—Continued
[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
RDTE,N	Advanced Linear Accelerator Facility	$1,200,000	Hill
RDTE,N	Advanced Logistics Fuel Reformer for Fuel Cells (Phase II)	$3,000,000	DeLauro
RDTE,N	Advanced Manufacturing for Submarine Bow Domes and Rubber Boots	$2,000,000	Crenshaw
RDTE,N	Advanced Molecular Medicine Initiative	$1,000,000	Schiff; Dreier
RDTE,N	Advanced Simulation Tools for Composite Aircraft Structures	$2,000,000	Clay
RDTE,N	Aegis Research and Development	$5,000,000	Miller, Gary (CA)
RDTE,N	Agile Port and High Speed Ship Technology	$2,000,000	Sánchez, Linda (CA)
RDTE,N	Aging Military Aircraft Fleet Support	$2,000,000	Tiahrt
RDTE,N	Air Readiness/Effectiveness Measurement Program	$2,000,000	Moran (VA); Nye
RDTE,N	AN/SLQ—25D Integration	$8,000,000	Murtha
RDTE,N	Arc Fault Circuit Breaker with Arc Location	$1,000,000	Matheson
RDTE,N	Automated Fiber Optic Manufacturing Initiative for Navy Ships	$2,500,000	Nye; Tsongas
RDTE,N	Automated Missile Tracking	$1,000,000	Moran (VA)
RDTE,N	Autonomous Anti-Submarine Warfare Vertical Beam Array Sonar	$2,000,000	Miller (NC); Coble
RDTE,N	Autonomous Marine Sensors and Networks for Rapid Littoral Assessment	$3,000,000	Young (FL)
RDTE,N	Autonomous UUV Delivery and Communication System Integration	$4,500,000	Dicks
RDTE,N	Avionics Life Extension	$1,000,000	Edwards (TX)

RDTE,N	Bow Lifting Body Project	$4,000,000	Kagen; Stupak
RDTE,N	Center for Assured Critical Application and Infrastructure Security	$1,500,000	Johnson (IL)
RDTE,N	Center for Autonomous Solar Power—Supercapacitors for Integrated Power Storage	$5,000,000	Hinchey
RDTE,N	Center for Commercialization of Advanced Technology	$2,500,000	Lewis (CA); Davis (CA)
RDTE,N	Characterization and Exploitation of Magnetic and Electric Fields in the Coastal Ocean Environment	$2,500,000	Klein (FL); Wasserman Schultz; Wexler
RDTE,N	Cognitive Radio Institute	$1,000,000	Gordon
RDTE,N	Common Air Mine Countermeasures Tow Cable	$3,000,000	Boyd
RDTE,N	Common Command and Control System Module	$4,000,000	Langevin; Courtney; Kennedy
RDTE,N	Common Digital Sensor Architecture	$3,000,000	Obey
RDTE,N	Common Safety System Controller	$3,000,000	Pastor (AZ)
RDTE,N	Continuous Active Sonar for Torpedo DCL Systems	$4,500,000	Courtney
RDTE,N	Cooperative Engagement Capability	$5,000,000	Young (FL)
RDTE,N	Countermine LIDAR UAV-Based Systems	$2,000,000	Taylor
RDTE,N	Deployable Command and Control Vehicle	$3,800,000	Boyd
RDTE,N	Deployment Health and Chronic Disease Surveillance	$1,000,000	Moran (VA)
RDTE,N	Electronic Motion Actuation Systems	$1,000,000	Shuler; Bishop (UT)
RDTE,N	Energetic Nano-Materials Agent Defeat Initiative	$2,000,000	Rothman; Payne
RDTE,N	Energetics S&T Workforce Development	$3,500,000	Hoyer
RDTE,N	Environmentally Sealed, Ruggedized Avionics Displays	$4,000,000	Butterfield
RDTE,N	EP-3E Requirements Capability Migration Systems Integration Lab	$6,250,000	Edwards (TX)

DEFENSE—Continued
[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
RDTE,N	Floating Area Network Littoral Sensor Grid	$5,000,000	Dicks
RDTE,N	Flow Path Analysis Tool	$2,000,000	Lewis (CA); McCarthy (CA)
RDTE,N	Gallium Nitride (GaN) Power Technology	$2,000,000	Coble
RDTE,N	Hampton University Proton Cancer Treatment Initiative	$5,000,000	Scott (VA); Moran (VA)
RDTE,N	HBCU Applied Research Incubator	$1,000,000	Kilpatrick; Connolly; Cummings; Thompson (MS)
RDTE,N	High Density Power Conversion and Distribution Equipment	$1,500,000	Sullivan; Boren
RDTE,N	High Power Density Motor Drive	$3,600,000	Murphy, Tim (PA)
RDTE,N	Highly Integrated Siloxane Optical Interconnect for Military Avionics	$1,000,000	Stupak
RDTE,N	High-Shock 100 Amp Current Limiting Circuit Breaker	$600,000	Murphy, Tim (PA)
RDTE,N	HighTemperature Radar Dome Materials	$2,000,000	Giffords
RDTE,N	High-Temperature Superconductor Trap Field Magnet Motor	$1,000,000	Carter
RDTE,N	Hybrid Propellant for Medium and Large Caliber Ammunition	$5,000,000	Boyd
RDTE,N	Hybrid Propulsion/Power Generation for Increased Fuel Efficiency for Surface Combatants	$2,000,000	Sanchez, Loretta (CA); Miller, Gary (CA)
RDTE,N	Image-Based Navigation and Precision Targeting	$800,000	Markey (MA)
RDTE,N	Improved Capabilities for Irregular Warfare Platforms	$4,000,000	Hoyer
RDTE,N	Improved Kinetic Energy Cargo Round	$1,000,000	Lee (NY)
RDTE,N	Infrared Materials Laboratory	$3,500,000	Cole

RDTE,N	Instrumented Underwater Training Systems	$2,800,000	Ros-Lehtinen
RDTE,N	Integrated Advanced Ship Control	$1,500,000	Tierney
RDTE,N	Integrated Condition Assessment and Reliability Engineering	$1,000,000	Connolly
RDTE,N	Integrated Manufacturing Systems 3D Simulation and Modeling Project	$2,500,000	Scalise; Melancon
RDTE,N	Integrated Power System Converter	$2,000,000	Murphy, Tim (PA)
RDTE,N	Integrated Power System Power Dense Harmonic Filter Design	$2,000,000	Altmire
RDTE,N	Integrated Psycho-Social Healthcare Demonstration Project	$1,000,000	Young (FL)
RDTE,N	Integration of Advanced Wide Field of View Sensor with Reusable, Reconfigurable Payload Processing Testbed System	$1,000,000	Holden
RDTE,N	Integration of Electro-Kinetic Weapons into Next Generation Navy Ships	$5,000,000	Boyd
RDTE,N	Intelligent Retrieval of Imagery	$2,500,000	Moran (VA)
RDTE,N	IP over Power Line Carrier Network Integration with ICAS	$2,000,000	McIntyre
RDTE,N	Joint Explosive Ordnance Disposal Diver Situational Awareness System	$2,000,000	Moran (VA)
RDTE,N	Joint Heavy-Lift Rotocraft Research	$1,000,000	Hoyer
RDTE,N	Joint Mission Battle-Space to support Net-Ready Key Performance Parameters	$2,000,000	Hoyer
RDTE,N	Joint Tactical Radio System Handheld Manpack Small Form Factor Radio System	$4,500,000	Wasserman Schultz
RDTE,N	Joint Technology Insertion and Accelerated System Integration Capability for Electronic Warfare	$2,000,000	Ellsworth
RDTE,N	Kinetic Hydropower System Turbine	$2,000,000	Inslee; Engel; Tonko; Towns
RDTE,N	Landing Craft Composite Lift Fan	$1,500,000	Garrett; Dent
RDTE,N	Laser Optimization Remote Lighting System	$2,500,000	Larson (CT)
RDTE,N	Laser Phalanx	$1,500,000	Crowley; Bishop (UT)

DEFENSE—Continued
[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
RDTE,N	Lighter-than-Air Stratospheric Unmanned Aerial Vehicle for Persistent Communications Relay and Surveillance	$3,000,000	Lamborn
RDTE,N	Lightweight Composite Structure Development for Aerospace Vehicles	$3,000,000	Sullivan
RDTE,N	Lithium Ion Storage Advancement for Aircraft Applications	$2,500,000	Blunt
RDTE,N	Low Frequency Active Towed Sonar System Organic ASW Capability	$2,000,000	Crenshaw
RDTE,N	Low Signature Defensive Weapon System for Surface Combatant Craft	$4,800,000	Hinchey
RDTE,N	Maintenance Free Operating Period	$2,500,000	Moran (VA)
RDTE,N	Maintenance Planning and Assessment Technology Insertion	$1,500,000	Brady (PA)
RDTE,N	Management of Lung Injury by Micronutrients	$1,500,000	Meeks (NY)
RDTE,N	Manufacturing S&T for Next-Generation Energetics	$5,000,000	Hoyer
RDTE,N	Marine Corps Cultural and Language Training Platform	$800,000	Maffei
RDTE,N	Marine Mammal Awareness, Alert and Response Systems	$3,000,000	Abercrombie
RDTE,N	Marine Mammal Detection System	$2,000,000	Smith (NJ)
RDTE,N	Marine Species Mitigation	$2,870,000	Brown, Corrine (FL)
RDTE,N	Measurement Standards Research and Development	$5,800,000	Calvert
RDTE,N	Micro-Drive for Future HVAC Systems	$600,000	Moore (WI)
RDTE,N	Military Upset Recovery Training	$1,000,000	Lee (NY)
RDTE,N	Mobile, Oxygen, Ventilation and External Suction (MOVES) System	$3,400,000	Granger; Johnson (TX)

RDTE,N	Modular Advanced Vision System	$2,000,000	Carney
RDTE,N	Mold-in-Place Coating Development for the US Submarine Fleet	$2,000,000	Taylor
RDTE,N	Moving Target Indicator Scout Radar	$1,000,000	Johnson, Sam (TX); Hall (TX); Johnson, Eddie Bernice (TX)
RDTE,N	Multi-Element Structured Filter Arrays for Naval Platforms	$4,300,000	Bonner
RDTE,N	Multifunctional Materials, Devices, and Applications	$2,000,000	Kilroy
RDTE,N	Multi-Mission Unmanned Surface Vessel	$2,500,000	Granger
RDTE,N	Nanofluidic Lubricants for Increased Fuel Efficiency in Heavy Duty Vehicles	$1,500,000	Price (NC)
RDTE,N	National Aviation Enterprise Interoperability with Carrier Strike and Expeditionary Group Forces	$4,700,000	Hoyer
RDTE,N	National Functional Genomics Center Collaborating Site	$4,000,000	Holden
RDTE,N	NAVAIR High Fidelity Oceanographic Library	$3,000,000	Rehberg
RDTE,N	NAVAIR Project for Land/Sea-Based Air Systems Maintenance and Air Worthiness	$2,000,000	Conyers; Dingell; Levin
RDTE,N	Naval Ship Hydrodynamic Test Facilities	$4,000,000	Van Hollen
RDTE,N	Navy Advanced Threat Simulator	$2,000,000	McCarthy (CA)
RDTE,N	Navy Special Warfare Performance and Injury Prevention Program for Special Boat Team 22	$2,500,000	Taylor
RDTE,N	NAWCWD Point Mugu Electronic Warfare Laboratory Upgrade	$4,000,000	Gallegly
RDTE,N	Next Generation Electronic Warfare Simulator	$2,000,000	McCarthy (CA); Ruppersberger
RDTE,N	Next Generation Manufacturing Processes and Systems	$1,500,000	Smith (TX)
RDTE,N	Next Generation Scalable Lean Manufacturing Initiative—Phase Two	$3,000,000	Young (FL)
RDTE,N	Next Generation Shipboard Integrated Power—Fuel Efficiency and Advanced Capability Enhancer	$2,000,000	Bartlett
RDTE,N	Non Traditional Ballistic Fiber and Fabric Weaving Applications for Force Protection	$2,500,000	LoBiondo; Andrews; Rothman

DEFENSE—Continued
[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
RDTE,N	Non-Gasoline Burning Outboard Engine	$1,900,000	Boyd
RDTE,N	NSWC Corona Item Unique Identification Center	$1,800,000	Calvert
RDTE,N	ONAMI Nanoelectronics, Nanometrology and Nanobiotechnology Initiative	$2,500,000	Wu; Blumenauer; DeFazio; Schrader; Walden
RDTE,N	On-Demand Custom Body Implants/Prosthesis for Injured Personnel	$2,000,000	Dingell; Levin
RDTE,N	Open Source Naval and Missile Database Reporting System	$2,400,000	Dicks
RDTE,N	Out of Autoclave Composite Processing	$2,000,000	Clay
RDTE,N	Paragon (Frequency Extension)	$3,000,000	Connolly; Moran (VA)
RDTE,N	Passive RFID Development	$1,000,000	LaTourette
RDTE,N	Persistent Autonomous Maritime Surveillance	$5,000,000	Rogers (KY)
RDTE,N	Persistent Surveillance Wave Powerbuoy System	$2,000,000	Holt
RDTE,N	Photovoltaic Rooftop Systems for Military Housing	$1,500,000	Peters; Schauer
RDTE,N	Precision Engagement Technologies for Unmanned Systems	$2,500,000	Ehlers
RDTE,N	Pure Hydrogen Supply from Logistic Fuels	$3,000,000	Murphy, Patrick (PA)
RDTE,N	Quiet Drive Advanced Rotary Actuator	$2,000,000	Sestak; Harman; Higgins; Lee (NY); Sherman; Slaughter
RDTE,N	Regenerative Fuel Cell Back-up Power	$1,700,000	Larson (CT)
RDTE,N	Sensor Integration Framework	$1,800,000	Boyd

RDTE,N	Ship Model Testing	$2,500,000	King (NY)
RDTE,N	Shipboard Wireless Maintenance Assistant	$1,500,000	Schauer; Dingell
RDTE,N	Shipboard Wireless Network	$3,000,000	Rothman
RDTE,N	Shock and Vibration Modeling of Marine Composites	$2,400,000	Towns
RDTE,N	Silicon Carbide Wafer Production—Process Development for Low Defect Power Electronics	$1,500,000	Hinchey
RDTE,N	Smart Instrument Development for the Magdalena Ridge Observatory	$2,000,000	Teague
RDTE,N	SSBN(X) Systems Development	$2,500,000	Wittman
RDTE,N	Strike Weapon Propulsion	$4,000,000	Barton
RDTE,N	Submarine Automated Test and Re-Test	$2,500,000	Moran (VA)
RDTE,N	Submarine Fatline Vector Sensor Towed Array	$2,000,000	Kratovil
RDTE,N	Submarine Navigation Decision Aids	$5,000,000	Murtha
RDTE,N	Submarine Panoramic Awareness System	$1,000,000	Sherman
RDTE,N	Submarine System Biometrics Access Control	$2,500,000	Rogers (KY)
RDTE,N	Tactical High Speed Anti-Radiation Missile Propulsion Demonstration	$1,900,000	McKeon; Connolly
RDTE,N	Technology Transfer Office	$1,500,000	Hoyer
RDTE,N	U.S. Navy Cancer Vaccine Program	$3,000,000	Jones (NC); Miller, Gary (CA)
RDTE,N	U.S. Navy Pandemic Influenza Vaccine Program	$2,000,000	McHugh
RDTE,N	Underwater Explosion Modeling and Simulation for Ohio Class Replacement Composite Non-Pressure Hull Fairing	$2,500,000	Perriello
RDTE,N	Underwater Explosives and Warhead Research	$3,000,000	Hoyer
RDTE,N	Underwater Imaging and Communications Using Lasers	$2,000,000	Wexler; Wasserman Schultz

DEFENSE—Continued
[Congressionally Directed Spending Items]

Account	Project	Amount	Requester(s)
RDTE,N	Voyage Repair Team Tool Management	$1,500,000	Adler
RDTE,N	Wide Area Sensor Force Protection Targeting	$2,000,000	Bean
RDTE,N	Workforce Requirements Planning—Team Enhancement	$1,000,000	Inslee
RDTE,N	X-49A Envelope Expansion Modifications	$4,500,000	Brady (PA); Andrews; Castle; Higgins; Larson (CT); Sestak; Slaughter
RDTE,N(MC)	Battlefield Sensor Netting	$3,000,000	Young (FL)
RDTE,N(MC)	California Central Coast Partnership Research	$3,500,000	McCarthy (CA)
RDTE,N(MC)	Dynamic Eye-Safe Imaging Laser	$1,000,000	Reichert
RDTE,N(MC)	Enhanced Small Arms Protective Insert	$2,000,000	King (NY)
RDTE,N(MC)	Global Supply Chain Management	$1,000,000	Bishop (GA)
RDTE,N(MC)	Media Exploitation Tool Integration with Intelligence C2 Systems	$1,500,000	Kosmas
RDTE,N(MC)	Near Infrared Optical Augmentation System	$2,000,000	Moran (VA)
RDTE,N(MC)	Non-Lethal Defense Technologies	$2,900,000	Murtha
RDTE,N(MC)	Remote Aiming and Sighting Optical Retrofit	$3,800,000	Granger; Johnson (TX)
WP,N	Intelligent Graphics Torpedo Test Set Troubleshooting Maintainers Aid	$5,000,000	Dicks
WP,N	Lightweight Torpedo P5U Test Equipment Modernization	$4,800,000	Dicks
WTCV,A	Arsenal Support Program Initiative	$3,000,000	Tonko
WTCV,A	Arsenal Support Program Initiative at Rock Island Arsenal	$2,000,000	Hare; Braley

EXHIBIT 19

SCRA'S ATI ANNOUNCES VANADIUM SAFETY READINESS PROGRAM FOR US ARMY

Swamp Fox

July 10, 2009

The Advanced Technology Institute (ATI), an SCRA affiliate, announces a new program for the U.S. Army that is designed to address occupational health issues and safeguard the health and safety of military, civilian and industrial workers in the critical defense sector of vanadium technology. ATI is bringing overall program management, including budgetary responsibility and technical deliverables to the one-year, $2.57M agreement, which includes performance-based contract options up to $10.5M over a five-year period.

Vanadium has a myriad of applications for military and civilian use. This important and well-established alloy is utilized in virtually every structural military application where steel products are employed. It can increase steel yield strength by more than 25 percent, allowing smaller structures to accomplish outcomes that once required more mass. For instance, vanadium microalloyed steel reduces the weight of combat and tactical vehicles and it is used in the construction of tactical bridges, material handling equipment, air and watercraft, and other in-theater steel structures.

The processing and manufacture of vanadium substances is of integral importance to the military. Since there is only limited data available about many vanadium substances, the Vanadium Safety Readiness Program will employ an assessment analysis to establish science-based occupational health standards and safe work practices. Safe air exposure limits, safe handling practices and industrial hygiene controls will be established through the program. These practices will ensure that no adverse health effects result from vanadium manufacture and use in the workplace.

"The Vanadium Producers & Reclaimers Association (VPRA) and the Vanadium International Technical Committee are both pleased that this important research program is about to commence. Our entire industry is committed to the well-being and safety of our workers, our customers and the environment," said David White, Chairman of the

VPRA Health, Safety & Environment Committee. “We look forward to partnering with such highly esteemed scientists and laboratories to develop a comprehensive health safety and environment database of knowledge on vanadium compounds.”

The program leverages a world-class team of toxicologists, scientific researchers and industry experts who are well-versed in vanadium applications, chemistry and occupational health.

ATI brings deep domain expertise in metals and advanced materials that translate into reduced costs, enhanced readiness and increased safety for its military and commercial customers. The Vanadium Technology Program, in partnership with the vanadium industry, the Army Corps of Engineers, the U.S. Tank Automotive and Armaments Command and commercial users of steel, is demonstrating the higher strength, lower cost benefits of vanadium microalloyed steel. Program case studies show that the weight of Army support structures, temporary and intermediate bridges, vehicles, trailers, barriers and buildings can be improved in protection and mobility through vanadium alloying and hot rolled steel technology.

”We are proud to see ATI once again deliver assured outcomes for the U.S. Army in support of national initiatives, and bring both greater efficiency and financial returns into this emerging market,” said Bill Mahoney, SCRA CEO . “The program will undoubtedly further advance metals technology and ensure safe practices for the health of the industry’s workforce.”
The Vanadium Safety Readiness Proposal is sponsored by the Department of the Army under Award Number W81XWH-09-2-0066. The U.S. Army Medical Research Acquisition Activity, 820 Chandler Street, Fort Detrick MD 21702-5014 is the awarding and administering acquisition office. The content of the information provided does not necessarily reflect the position or the policy of the Government and no official endorsement should be inferred.

# # #

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The Advanced Technology Institute builds international consortia to develop and implement innovative solutions for manufacturing, aerospace, automotive, maritime, metals, energy and healthcare industries. ATI-led collaborations attract world-class talent from premier companies, universities and government agencies. A private, non-profit research corporation with principal operations in Charleston, SC, ATI is an affiliate of SCRA. For more information, please visit aticorp.org (http://www.aticorp.org).

About SCRA
SCRA is a global leader in applied research and commercialization services with offices in South Carolina, Ohio and Washington, D.C. area. SCRA collaborates to advance technology, providing technology-based solutions with assured outcomes to industry and government, with the help of research universities in SC, the U.S. and around the world. For more information, please visit scra.org (http://www.scra.org).

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Jill Hirsekorn, SCRA, (843)760-3329

LOCAL NEWS
Home Telecom to bring Summerville its first tech incubator
(https://www.crda.org/news/local_news/home-telecom-to-bring-summerville-its-first-tech-incubator/)

LOCAL NEWS
Construction Commences on Charleston Tech Center in South Carolina Opportunity Zone

(https://www.crda.org/news/local_news/construction-commences-on-charleston-tech-center-in-south-carolina-opportunity-zone/)

LOCAL NEWS

The 12 Best Places to Live in 2019

(https://www.crda.org/news/local_news/the-12-best-places-to-live-in-2019/)

LOCAL NEWS

Travel + Leisure readers name Charleston No. 1 U.S. city for 7th year in a row

(https://www.crda.org/news/local_news/travel-leisure-readers-name-charleston-no-1-u-s-city-for-7th-year-in-a-row/)

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- .@HomeTelecom (http://twitter.com/HomeTelecom) announces plans to build a new incubator office space in Summerville to help foster the region's tech… https://t.co/wzt3xnWBpi (https://t.co/wzt3xnWBpi)
- ICYMI: CRDA traveled to the 2019 Paris Air Show as part of Team South Carolina this month – walking away excited ab… https://t.co/xjgae3QlVA (https://t.co/xjgae3QlVA)
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FROM OUR NEWS

HOME TELECOM TO BRING SUMMERVILLE ITS FIRST TECH INCUBATOR
July 23, 2019 (https://www.crda.org/news/local_news/home-telecom-to-bring-summerville-its-first-tech-incubator/)

CONSTRUCTION COMMENCES ON CHARLESTON TECH CENTER IN SOUTH CAROLINA OPPORTUNITY ZONE
July 18, 2019 (https://www.crda.org/news/local_news/construction-commences-on-charleston-tech-center-in-south-carolina-opportunity-zone/)

THE 12 BEST PLACES TO LIVE IN 2019
July 16, 2019 (https://www.crda.org/news/local_news/the-12-best-places-to-live-in-2019/)

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EXHIBIT 20

American Iron and Steel Institute

2017 Public Policy Agenda

Table of Contents and Summary

February 2, 2017

AISI Public Policy Priorities – Promoting a Pro-Manufacturing Agenda

Steel and other manufacturing industries are the backbone of our economy. A strong manufacturing sector creates significant benefits for society, including good-paying jobs, investment in research and development, critical materials for our national defense, and high-value exports. Yet manufacturing in North America faces significant challenges to its international competitiveness due to a host of factors, including burdensome tax rates, inadequate investment in infrastructure, increasing regulatory overreach and, most importantly, foreign unfair trade practices. These practices have resulted in massive global steel overcapacity causing a surge of steel imports into the U.S. market and job losses across the country affecting local communities. A concerted pro-manufacturing policy agenda is needed to reverse this unsustainable trend.

The impact public policies have on manufacturers must be carefully considered to ensure both economic growth and our national security. The United States cannot continue to lose its manufacturing base due to market distorting foreign competition or government policies that discourage domestic investment in productive capacity. Should this happen, millions of additional jobs would be lost and our economic strength as a nation would be further damaged. The U.S. military and our civilian national security agencies also would lose their principal source of strategic materials and our nation would become dangerously dependent upon foreign sources of supply.

To meet these critical goals, the North American steel industry strongly supports the implementation of a public policy agenda to allow U.S. manufacturers to compete in today's global economy. Key aspects of such an agenda include the following:

Industry Position: Foreign government subsidies and other market-distorting policies have resulted in massive global steel overcapacity and significant levels of steel imports, resulting in thousands of U.S. job losses and numerous plant closures. The United States must press China and other nations to eliminate their steel overcapacity and to end all subsidies and other market-distorting policies that promote steel overcapacity; enforce aggressively U.S. trade laws against dumping and subsidies; respond to foreign government currency manipulation; and defend aggressively our ability to apply non-market economy methodology to remedy injurious dumping by China.

Industry Position: AISI supports tax policy that encourages manufacturing activity in the United States and increases the global competitiveness of domestic steel producers. Congress should enact substantial reform to the tax code that includes a significant corporate rate reduction, accelerated cost recovery provisions to promote domestic capital investment, elimination of the corporate alternative minimum tax, and necessary and appropriate transition rules that allow companies to carry into any new tax system net operating losses and other tax assets they have accumulated under current law.

Industry Position: The production of steel is inherently energy intensive and the availability and reliability of energy is essential to the industry's competitiveness. The Administration should substantially revise the Clean Power Plan and other rules to ensure they do not undermine the competitiveness of U.S. manufacturers. In addition, Congress and the Interior Department should reverse ongoing federal regulatory efforts that limit production of domestic energy sources. Congress and the Administration should enact policy measures to facilitate investment in our national energy infrastructure, including production, distribution, transmission, and storage projects.

Industry Position: American steel producers have carefully sought to reduce our environmental footprint even while producing the advanced and highly recyclable steel that our economy needs. However, the simultaneous development and implementation of multiple new environmental regulatory programs at the federal and state levels have created competitive disadvantages for the industry. The Administration and Congress should act to reconsider recent EPA regulatory actions to examine the impact of these regulations on industrial competitiveness and to ensure adequate cost/benefit analysis

Industry Position: Transportation infrastructure facilitates broad economic growth and directly impacts the competitiveness of the domestic steel industry. Congress should provide for increased funding for infrastructure improvements that are directed towards long-term, multi-year projects that focus on rebuilding the nation's bridges, roads, waterways, railroads and energy infrastructure. Federal funding should be accompanied by reforms that streamline permitting to speed approval of large projects and should ensure that iron and steel used to rebuild the nation's infrastructure is produced in the United States.

Industry Position: The steel industry shares the federal government's goal of ensuring safety and health at industrial workplaces. However, recently enacted regulations may misdirect priorities and create unnecessary costs for employers that prevent optimum workplace safety and health benefits from being realized. The Administration and Congress should reconsider and reform these regulations. Congress also should enact the Voluntary Protection Program Act to authorize and improve the VPP, a key employer-employee-OSHA collaborative workplace safety program, and the new Administration should commit to a cooperative enforcement approach where federal agencies and employers work in partnership to advance workplace safety and health.

AISI Priorities on International Trade

Foreign government subsidies and other market-distorting policies in the steel sector have resulted in massive global steel overcapacity – estimated by the OECD at more than 700 million metric tons, over seven times U.S. raw steel production. This overcapacity, combined with sluggish world demand and import barriers in other markets, has resulted in significant levels of steel imports entering into the U.S. market, capturing a historically-high percentage of U.S. market share and resulting in thousands of U.S. job losses and numerous plant closures throughout the steelmaking supply chain.

Of particular note, China's steel industry remains government-owned and controlled and heavily subsidized. China continues to protect and increase its exports by manipulating its currency, raw material markets and border measures for steel and steel-containing goods. Other major offshore steel producers also continue to use subsidies, tax and trade policies, and investment restrictions to protect their markets and expand their steel production and exports. The United States must take aggressive action to combat these unfair trade practices in order to preserve and strengthen our manufacturing base.

In particular, AISI urges the new Administration to take the following actions in the first 100 days after taking office:

- ***Overcapacity –*** Press China and other nations to eliminate their steel overcapacity and to end all subsidies and other market-distorting policies that promote steel overcapacity through the newly established Global Forum on steel overcapacity and through other avenues for engagement;

- ***Section 301 –*** Instruct the U.S. Trade Representative (USTR) to initiate one or more investigations under Section 301 of the Trade Act of 1974 into the acts, policies and practices of foreign governments that contribute to the global overcapacity crisis and the repeated injurious surges of steel imports into the U.S. market;

- ***Trade Case Enforcement*** – Direct the Commerce Department and International Trade Commission to enforce aggressively and expeditiously U.S. unfair trade laws in all cases, including investigations, reviews and anti-circumvention inquiries;

- ***Currency Manipulation –*** Direct the Commerce Department to use its existing authority under the countervailing duty (CVD) law to offset the export subsidy resulting from foreign government currency manipulation and to make other administrative reforms to strengthen the effectiveness of our trade laws; and

- ***Non-Market Economy Status*** – Instruct USTR and the Commerce Department to defend aggressively at the WTO the United States' ability to apply its non-market economy methodology in antidumping (AD) investigations on imports from China, and work with other countries to maintain broad international support for the U.S. position on China non-market economy status.

In addition, AISI urges the new Administration and Congress to work together during 2017 to pursue the following initiatives to address foreign unfair trade practices and to strengthen and fully enforce our trade remedy laws both domestically and internationally:

- ***Tools against Trade-Distorting Practices*** – The Commerce Department and the USTR should use all tools available to address foreign trade-distorting practices, including aggressive enforcement of the recently strengthened U.S. trade remedy laws, WTO litigation, and appropriate bilateral and multilateral diplomatic efforts.

- ***Trade Remedy Legislation*** – The Congress should enact legislation that further strengthens U.S. trade laws and updates existing trade remedies based on new economic realities, such as remedies for currency manipulation and exporter absorption of antidumping (AD) and countervailing duties (CVD).

- ***Funding for Enforcement*** – The Congress should provide for increased appropriations for the Office of Enforcement and Compliance at the Commerce Department to ensure adequate staffing for trade remedy and anti-circumvention investigations.

- ***AD/CVD Evasion*** – Direct U.S. Customs and Border Protection to revise its interim final regulations under the Enforce and Protect Act (EAPA) to increase the transparency of its investigations into AD/CVD evasion and to facilitate greater U.S. industry participation in this process, and to continue to place an enhanced focus on commercial enforcement.

- ***WTO Dispute Settlement Reform*** – The Administration should pursue fundamental reform of the WTO dispute resolution system to address the repeated overreaching by WTO panels and the Appellate Body, especially in decisions related to AD/CVD measures.

- ***New Trade Agreements*** – Any new and updated trade agreements should strengthen North American steel and manufacturing supply chains, eliminate tariff and non-tariff barriers to U.S. exports, enhance reciprocal government procurement market access, prohibit steel-making raw materials export restrictions and discipline currency manipulation and market-distorting state-owned enterprise (SOE) behavior.

- ***NAFTA Steel Industry/Government Collaboration*** – The U.S., Canadian and Mexican governments and industries should continue to closely collaborate and leverage their excellent working relationships through the North American Steel Trade Committee, and other international fora, to enable the strongest government policies and laws against unfair trade from offshore into NAFTA and strengthen North American steel and manufacturing supply chains.

AISI Priorities on Tax Policy

AISI supports tax policy that encourages manufacturing activity in the United States and increases the global competitiveness of domestic steel producers. Other nations have been lowering their corporate tax rates in order to encourage economic growth while the United States' combined (federal plus state) tax rate is the highest in the developed world, at almost 40 percent. In addition to an overall reduction of the corporate tax rate, simplification of the tax code and a broadening of the tax base, capital investment is crucial for economic growth and job creation. Cost recovery systems, such as accelerated depreciation and full expensing, directly impact whether or not manufacturing companies will make new investments, and must be a central feature of any tax reform legislation.

AISI urges the new Administration and Congress to enact substantial reform to the tax code during the first 100 days after taking office with the following key provisions:

- ***Significant corporate rate reduction*** **–** The corporate tax rate should be reduced to 15-20 percent in order to promote the international competitiveness of U.S. industry. Studies by the Tax Foundation indicate that in order to match the corporate tax rate of China and the average of the OECD countries, the U.S. federal corporate tax rate would have to be reduced to no more than 20 percent.

- ***Accelerated cost recovery*** **–** Congress should include provisions to promote domestic capital investment and lower the cost of capital, such as accelerated depreciation, full expensing of business capital expenditures, the interest expense deduction and percentage depletion. Such provisions are essential to encourage economic growth and job creation.

- ***LIFO accounting method*** **–** Tax reform legislation should continue to permit the use of the last-in, first-out (LIFO) method of accounting which has been a widely used and accepted accounting method for decades. LIFO allows companies that are subject to rising inventory costs to be properly taxed on their real income.

- ***Elimination of the corporate alternative minimum tax*** **–** Congress should eliminate the corporate alternative minimum tax, which places an enormous administrative burden on corporations, denies companies legitimate deductions and acts as a disincentive to new investment.

- ***Necessary and appropriate transition rules*** **–** It is critical that U.S. companies be allowed to carry with them into any new tax system net operating losses (NOLs) and other tax assets they have accumulated under the current system, and that no new limitations be placed on the carryforward and carryback of NOLs.

AISI Priorities on Energy and Climate Change Policy

The production of steel is inherently energy intensive, and the industry consumes substantial amounts of electricity, natural gas, and coal and coke to make its products. The availability and reliability of supplies of these energy sources is essential to the industry's international competitiveness, especially as steelmakers in competitor nations receive subsidized energy. The domestic steel industry has made substantial gains in reducing its energy usage, as well as its environmental footprint, over the last two decades, reducing its energy intensity by 32 percent since 1990 and reducing its greenhouse gas (GHG) emissions intensity by 37 percent over the same time period. Additionally, steel products are essential for the production, distribution, transmission, and storage of all types of energy, including natural gas, oil, electricity, and renewables.

AISI urges the new Administration and Congress to undertake the following actions in the first 100 days after taking office:

- ***EPA Regulation of GHG Emissions from Electric Utilities –*** The new Administration should request the courts remand the Clean Power Plan (CPP) and the New Source Performance Standard (NSPS) for utility GHG emissions to the EPA so that the agency can review and substantially revise these rules to ensure they do not undermine the competitiveness of U.S. manufacturers.

- ***Domestic Oil and Natural Gas Production –*** Congress and the Interior Department should reverse ongoing federal regulatory efforts that limit production of domestic energy sources. In particular, Congress should use the Congressional Review Act to overturn the recent duplicative regulation of methane emissions from oil and gas production on Bureau of Land Management (BLM) lands. In addition, the new Administration should not defend the 2015 regulation of hydraulic fracturing on BLM lands during ongoing litigation. Finally, the Bureau of Ocean Energy Management (BOEM) should revise its 2017-2022 Five-Year-Program for the Outer Continental Shelf (OCS) to open additional areas for exploration and production.

- ***Energy Infrastructure –*** The new Administration should take steps to ensure the approval and completion of the Keystone XL and Dakota Access pipelines. Beyond these two projects, Congress and the Administration should enact policy measures to facilitate investment in our national energy infrastructure, including production, distribution, transmission, and storage projects. In particular, the process for pipeline approval should be streamlined and improved and the deployment of new transmission infrastructure for electricity should be encouraged. This will ensure reliable, competitive energy supplies for energy-intensive industries, and expand markets for high-value steel products that are essential for oil, natural gas and electricity production and transmission.

AISI Priorities on Environmental Policy

AISI has long identified environmental stewardship as part of our industry's strategic plan and our vision for the future. We have carefully sought to reduce our environmental footprint even while producing the advanced and highly recyclable steel that our economy needs. However, the simultaneous development and implementation of multiple new environmental regulatory programs at the federal and state levels have created competitive disadvantages for the industry, endangered manufacturing jobs and added significant costs to operations while providing only marginal environmental benefits.

AISI urges the new Administration and Congress to take the following actions within the first 100 days after taking office:

- ***Mobile Source Greenhouse Gas (GHG) Standards*** – EPA should withdraw the final determination for the light duty vehicle GHG standards for model years 2022-2025. The White House should then initiate a dialogue between EPA, National Highway Traffic Safety Administration, California Air Resources Board, the auto manufacturers and other relevant stakeholders to map out a plan for the future that establishes a common sense, implementable single national program for automobile Corporate Average Fuel Economy (CAFE) and GHG standards.

- ***Clean Water Act (CWA) Jurisdiction*** – EPA and the US Army Corps of Engineers (Corps) should draft a new Waters of the United States (WOTUS) rule to replace the current WOTUS rule that has been stayed by the U.S. Court of Appeals for the Sixth Circuit pending court review. EPA and the Corps should request that that court hold the litigation in abeyance and seek a voluntary remand of the rule to the agency, allowing it to draft a new proposal that provides a common sense, protective and workable CWA jurisdictional rule.

- ***Ozone National Ambient Air Quality Standards (NAAQS)*** – EPA should defer implementation of the new Ozone NAAQS standard by two years to allow states and impacted sources more time to prepare to meet the new standard and have a smooth transition from efforts associated with meeting the 2008 Ozone standard.

- ***Financial Assurance for Hardrock Mining*** – EPA should add iron ore mining to the list of 59 categories of mining activities excluded from financial assurance under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Sec. 108b rule. This finding is clearly supported by the data on iron ore mining risks included in the agency's docket. The EPA is required by court order to issue a final CERCLA 108b rule on hardrock mining by Dec 1, 2017.

In addition, AISI urges the new Administration and Congress to pursue the following environmental goals:

- ***Steel Sector Air Rules*** – EPA should develop steel sector air pollution rules within a reasonable timeframe that allows the industry adequate opportunity to collect and analyze its own data, and also allows time to review EPA risk assumptions and proposed additional requirements on the industry. The agency should refrain from imposing experimental and non-agency approved technology requirements that are overly burdensome on facilities and provide little added benefit over existing methods, such as the requirement to use digital opacity cameras for measuring emissions from roof vents over current methodologies. These rules should also focus solely on the source category itself and not incorporate risk from any collocated or "non-category" sources. The Integrated Iron and Steel Maximum Achievable Control Technology (MACT) rule, EAF Major Source rule, EAF Area Source rule, Coke Oven MACT rule and the Taconite Risk and Technology Review (RTR) rule are included in this group. The Integrated Iron and Steel MACT and the Coke Oven MACT rules are a part of the MACT RTR deadline case.

- ***Regulatory Reform Legislation*** – Congress should pass regulatory reform legislation to provide much needed accountability and oversight of federal regulatory agencies. This legislation could include requiring regulatory agencies to promote coordination, simplification, and harmonization of agency rules, to examine whether existing rules have contributed to the problem being addressed through regulation, and even could require a joint resolution of approval of major rules before such rules can take effect.

- ***Sue and Settle Legislation –*** Congress should pass legislation that would lessen the incentives for frivolous lawsuits which provide citizen groups the ability to have undue influence over federal regulatory agency priorities (e.g., sue and settle). This legislation could be designed to make it easier for all affected parties to take part in settlement negotiations, and to require public notice and comment on draft settlement agreements before they are filed with the court.

- ***Clean Air Act (CAA) Amendments*** – Congress should amend the CAA to modify the NAAQS review cycle and the RTR review cycle to be better aligned with the realistic pace of implementation of existing standards by EPA, states and affected emissions sources.

- ***Regional Haze Program –*** EPA should shift its posture in implementation of the Regional Haze program to allow a greater recognition of the role of states in determining compliance approaches for sources within their jurisdiction.

AISI Priorities on Transportation and Infrastructure Policy

Efficient transportation infrastructure directly impacts the competitiveness of the domestic steel industry, and manufacturing as a whole. Transportation infrastructure facilitates broad economic growth and creates significant demand for domestic steel products for projects like highways, bridges, ports, and waterways.

AISI urges the new Administration and Congress to focus on the following key actions in the first 100 days after taking office:

- ***Funding support for long-term projects –*** Increased funding of infrastructure improvements should be directed towards long-term, multi-year projects that focus on rebuilding the nation's bridges, roads, waterways, railroads and energy infrastructure.

- ***Project permitting streamlining –*** Infrastructure funding should be accompanied by reforms that streamline permitting and approval of large projects to speed project delivery time and reduce added cost associated with time in permitting.

- ***Ensure materials are produced in the United States –*** Any infrastructure plan should require that all iron and steel used to rebuild the nation's infrastructure is produced in the United States. Specifically, the domestic preference provisions should require that all manufacturing processes for iron and steel occur in the United States, consistent with the longstanding application of the existing Buy America provisions for surface transportation projects administered by the U.S. Department of Transportation.

- ***Significant long-term funding –*** The funding to rebuild America's infrastructure should derive from one or more reliable, sustainable and dedicated sources of revenue, including public funding and public-private partnerships. Funds should be directed to existing programs, such as the Highway Trust Fund, and be administered by relevant federal agencies like the U.S. Department of Transportation and the Environmental Protection Agency. The funding should be significant enough to cover long-term projects over a 10-year-period as laid out in the new Administration's 100-day action plan.

In addition to significant infrastructure spending, Congress should pass legislation providing for a single national standard for the treatment of ballast water in ships in U.S. waters that maintains exemptions for vessels travelling in limited geographic areas, such as the Great Lakes Region and St. Lawrence Seaway.

AISI Priorities on Workforce Policy

The steel industry shares the federal government's critical goal of ensuring safety and health at industrial workplaces. AISI member companies have made substantial efforts to decrease the number and frequency of workplace incidents and continue to work through AISI to share information and best practices to meet their shared goal of improving occupational safety and health. However, overly burdensome regulations may misdirect priorities and create unnecessary costs for employers that prevent optimum workplace safety and health benefits from being realized.

AISI urges the new Administration and Congress to undertake the following actions in the first 100 days after taking office:

- ***Recent Final OSHA/MSHA Regulations –*** Congress and the agencies should overturn several regulations finalized at the end of the Obama Administration. This list includes the final MSHA rule on safety examinations at metal/non-metal mining operations and the OSHA rule on ongoing recordkeeping obligations for employers.

- ***OSHA Data Modernization Rule –*** OSHA should reconsider and reform the May 2016 data modernization rule. This rule could lead to inaccurate and incomplete conclusions about safety levels in certain industries and companies and could result in sensitive company- and employee-specific information becoming public. Additionally, OSHA should ensure that the beneficial employer programs for safety incentives, executive compensation, and drug testing currently utilized by employers are not negatively impacted by the rule or existing guidance.

- ***Voluntary Protection Program (VPP) –*** Congress should enact the Voluntary Protection Program Act to authorize and improve the VPP, a key employer-employee-OSHA collaborative workplace safety program. The Administration should also demonstrate its commitment to continuing the work of the VPP.

In addition, AISI urges the new Administration to commit to a cooperative enforcement approach at OSHA and MSHA. The federal agencies and employers should work in partnership to advance workplace safety and health, rather than in an adversarial approach to enforcement and public shaming.

EXHIBIT 21

The Design and Application of Titanium Alloys to U.S. Army Platforms -2010

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ABSTRACT

Titanium alloys have long been used for reducing system weight in airframe structure and jet engine components. The high cost of titanium, however, has historically prevented the application to military ground vehicles. In recent years, the cost of titanium has fallen relative to the cost of composite and ceramic armors and titanium is now a valid option for some Army applications, whether for weight reduction or improved ballistic performance. The distinct advantages of low density, high strength, a large competitive industrial base, and well established forming and shaping techniques establishes titanium as an excellent material for many military applications. The U.S. Army Research Laboratory (ARL) has invested significant research efforts in understanding the material processing requirements for ground versus aerospace applications and this paper will provide an overview of that research. A major concurrent effort has been amending existing military specifications to allow the use of lower cost, higher oxygen content titanium alloys that meet specific ground applications. The paper will end with a review of some of the past and current applications of titanium on US Army platforms and augments previous presentations given in this forum in 2007, 2008 and 2009.

INTRODUCTION

Titanium alloys have long been used for reducing system weight in airframe structure and jet engine components. The high cost of titanium, however, has historically prevented the application to military ground vehicles. In recent years, the cost of titanium has fallen relative to the cost of composite and ceramic armors and titanium is now a valid option for some armor applications.

As early as 1950, Pitler and Hurlich [1] noted that titanium alloys showed promise as armors against small arms projectiles. By the early 1960's, Sliney [2] presented ballistic performance data for Ti-6Al-4V alloy that demonstrated significant weight reductions over steel armors for small arms threats. Little work with larger threats was conducted due to the then prohibitive cost of the titanium. Since the early 1990's, ARL has undertaken a research effort to develop baseline titanium ballistic performance data against a range of penetrators and fragments. The publication of revised military specifications with new classes of titanium alloys, processed through lower-cost plasma and electron-beam melting technology, has expanded the use of titanium for military applications

BACKGROUND

Titanium can exist in a hexagonal close-packed crystal structure (known as the alpha phase) and a body-centered cubic structure (known as the beta phase). In unalloyed titanium, the alpha phase is stable at all temperatures up to 882° C, where transformation to the beta phase occurs. This transformation temperature is known as the beta transus temperature. The beta phase is stable from 882° C to the melting point. As alloying elements are added to pure titanium, the phase transformation temperature and the amount of each phase change. Alloy additions to titanium, except tin and zirconium, tend to stabilize either the alpha or beta phase. Ti-6Al-4V, the most common titanium alloy, contains mixtures of alpha and beta phases and is therefore classified as an alpha-beta alloy. The aluminum is an alpha stabilizer, which stabilizes the alpha phase to higher temperatures, and the vanadium is a beta stabilizer, which stabilizes the beta phase to lower temperatures. The addition of these alloying elements raises the beta transus temperature to approximately 996° C. Alpha-beta alloys, such as Ti-6Al-4V, are of interest for armor applications because the alloys are generally weldable, can be heat treated, and offer moderate to high strength [3]. Ti-6Al-4V alloy can be ordered to a variety of commercial and military specifications. Extra Low Interstitial (ELI) grade plates, simultaneously conforming to MIL-T-9046J, AB-2 (aerospace) and MIL-A-46077G (armor) specifications are used in many applications. The specifications define alloy chemistry ranges, minimum mechanical properties, and, in the case of MIL-A-46077G, ballistic requirements. Typical chemical compositions of titanium plate are listed in Table 1 for a Class 1 ELI alloy; mechanical property data for a typical MIL-T-9046J, AB-2 (aerospace) plate are found in Table 2. The hardness values are representative of the plates tested; hardness is not specified in MIL-T-9046J.

U.S. rolled homogeneous armor (RHA) steel is used as the baseline for most ballistic comparisons. RHA mechanical properties are also provided in Table 2 for plate thicknesses ranging from 38-mm to 152-mm; the mechanical properties of RHA vary as a function of plate thickness due to differences in thermomechanical processing. A 38-mm RHA plate has higher strength and hardness than a 152-mm plate. Ti-6-4 Titanium has poor hardenability in thick sections and cannot be rapidly quenched. However, excellent mechanical properties can be developed into wrought plate through thermomechanical working (rolling). Titanium mechanical properties are very uniform across the plate thickness that increases the relative ballistic performance when compared to an equivalent thickness of RHA. In thick sections, titanium has significantly better mechanical properties for ballistic application than RHA.

TITANIUM MILITARY SPECIFICATION MIL-DTL-46077G

An important factor in the use of titanium alloys for military applications is Military Specification MIL-DTL-46077G that defines different classes of titanium that can be used as armor [4]. While commercial specifications such as SAE-AMS-T-9046, SAE-AMS4911 or ASTM-B265 maintain quality control through mechanical properties, chemistry and processing, MIL-DTL-46077G emphasizes ballistic response to maintain quality control; no process is specified. This specification covers the thickness ranges of 0.125”- 4.000” and was revised last on 28 September 2006. The main change from the previous specification is the expansion of the thickness range in thin sections down to 0.125”; the ballistic acceptance tables for this range have not been finalized to date and developing an acceptable ballistic test has proven difficult due to the thin cross-sections of the plate and necessity to discern quality variations due to processing.

The emphasis in recent amendments to the specification has been to incorporate new classes of titanium armor that utilize lower-cost titanium processing and alternate alloys. Table 3 provides the current four classes of titanium that can be specified under the MIL-DTL-46077G. While all four classes have the same strength and ballistic requirements, the direction has been to increase the oxygen content to a maximum of 0.30% that has allowed the use of lower-cost processing technologies such as Electron Beam or Plasma Melting for both Class 3 and 4. Armor grade titanium has a greater tolerance to oxygen content than other applications in the aerospace industry. Class 4 titanium, unlike Class 1-3, allows alternate alloys to be utilized for armor applications and has opened up new alloy designations that utilize different alloying elements; this can have additional impact on overall alloy cost by utilizing lower cost alloying elements.

Table 1. Typical Chemical Compositions for Class 1 Titanium Plates by Weight-Percent

Al	V	C	O	N	H	Fe	Ti
5.50-6.50	3.50-4.50	0.04 Max	0.14 Max	0.02 Max	0.0125 Max	0.25 Max	Balance

Table 2. Typical Titanium and RHA Mechanical Properties

MATERIAL	SOURCE	DENSITY g/cm^3	TENSILE STRENGTH	HARDNESS	ELONGATION %
Ti-6Al-4V	MIL-T-9046J	4.45	>896 MPa	302-364HB	>10
RHA	MIL-A-12560	7.85	794-951 MPa	241-331HB	11-21

Table 3. MIL-DTL-46077G Titanium Armor Specification

	Chemistry	Max. O_2 Content	Comments
Class 1	6AL-4V	0.14%	***ELI-*** 10% Elongation Min.
Class 2	6AL-4V	0.20%	***Common Armor*** 6% Elongation Min.
Class 3	6AL-4V	0.30%	***High Scrap Content*** Weld & cold temp issues
Class 4	Not Limited	0.30%	***For future developments***

BALLISTIC RESPONSE OF TITANIUM TO FRAGMENTS AND PROJECTILES

ARL has conducted extensive analysis of the ballistic response of titanium to both projectiles and fragment simulators [5-12] and more details can be found in the references. As seen in Table 2, titanium has similar strength, hardness and elongation to ballistic steel, but the density is 43% less. This strength to density ratio is the primary factor in the greater performance of titanium over ballistic steel. Figure 1 illustrates the penetration of a Ti-6Al-V alpha-beta titanium and RHA steel by a long rod penetrator at velocities from 500 m/s up to 2600 m/s. The penetration into both metals is approximately equal up to about 1700 m/s and has a mass efficiency compared to steel of 1.87 at 1000 m/s dropping off to 1.44 at 2000 m/s when the densities are considered. Even when the impact velocities approach the hydrodynamic limit where material strengths can be ignored, the penetration density law results in a theoretical performance of 1.3 times that of steel.

Microstructure and processing technology can still have a significant effect on the performance at Ordnance velocities. Figures 2 and 3 show two Ti-6Al-4V ELI plates that were beta- and alpha-beta-processed and then impacted by a 20mm fragment simulating projectile. The large difference noted in the ballistic performance between the plates tends to indicate that the failure mechanisms were in some way different. Observation of the rear plate surface failures for perforating and near-perforating impacts showed this to be the case. The

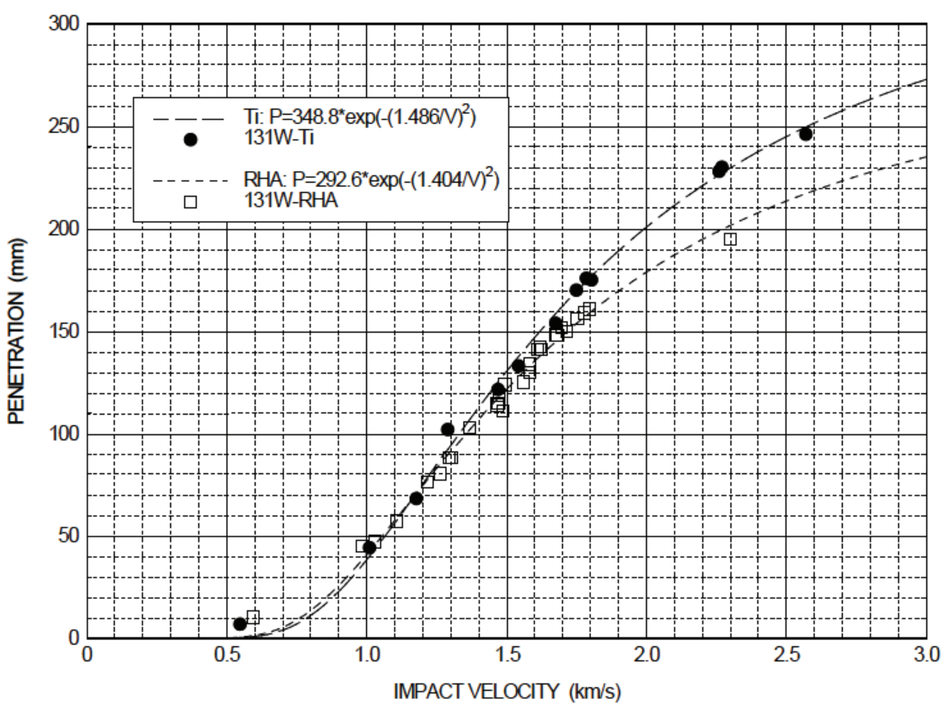


Figure 1. Penetration of a Tungsten Long Rod Penetrator into RHA and Titanium

beta processed plates failed by adiabatic shear plugging. This low-energy failure mode caused a titanium plug to be ejected from the rear surface of plate after the FSP penetrated approximately 6-mm into the plate and has been described in previous ARL work [12-14]. The plates that were alpha-beta processed failed by a mixed process of bulging, delamination, shearing, and spalling. However, this failure occurred only after the FSP had penetrated approximately 15-mm into the plate, requiring the FSP to penetrate significantly deeper into the armor than for the beta-processed plates. Rolling or annealing at temperatures above the beta transus significantly reduced the performance.

Adiabatic shear plugging is inherent in titanium as a result of shear-induced strain localizations and the low heat transfer properties of titanium. Figure 4 shows the deep penetration of a long rod tungsten penetrator into a titanium plate. The adiabatic shear bands in the sectioned plate are visible parallel to the penetration channel. The shear banding happens all along the circular penetration channel and then the titanium fragments mix with the tungsten rod fragments. In a complete perforation of the plate, the adiabatic titanium chips and penetrator debris are ejected and the penetration cavity wall appears very smooth. When an eroded penetrator comes within approximately one penetrator diameter of the rear free surface, the plate will eject a spall plug that has a larger diameter than the penetrator. This spall plug is generally not penetrated during the interaction and decreases performance. Figure 5 shows a large spall plug induced in a four inch plate that resulted in an approximate 20% loss in penetrator/target interaction. For this reason, titanium is not recommended for standalone use and low density backings, such as aluminum or composites, increase performance as the spall plug is held in place and contribute to erosion of the penetrator.

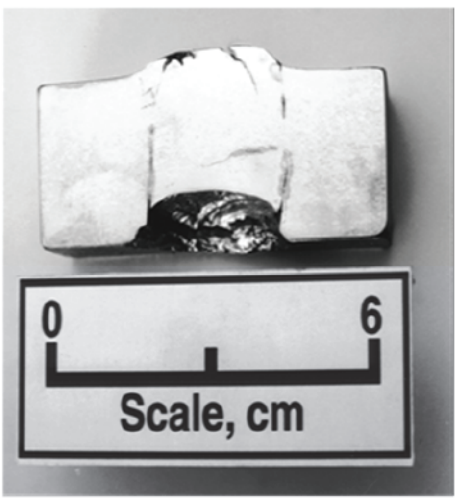


Figure 2. Cross-section of Impact Crater from 20-mm FSP for Beta Processed Plate

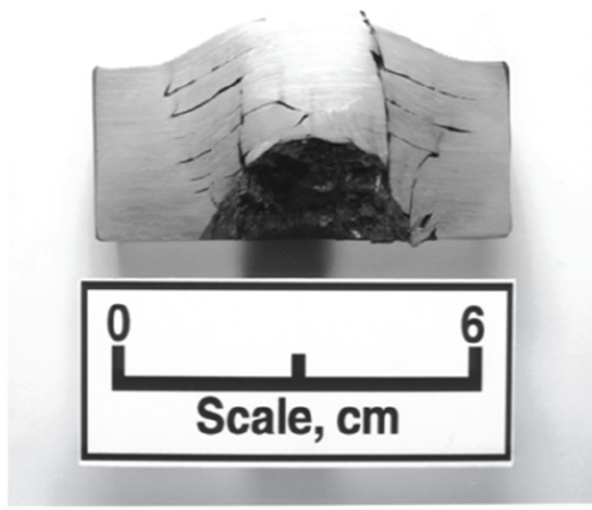


Figure 3. Cross-section of Impact Crater from 20-mm FSP for Alpha-Beta-Processed Plate

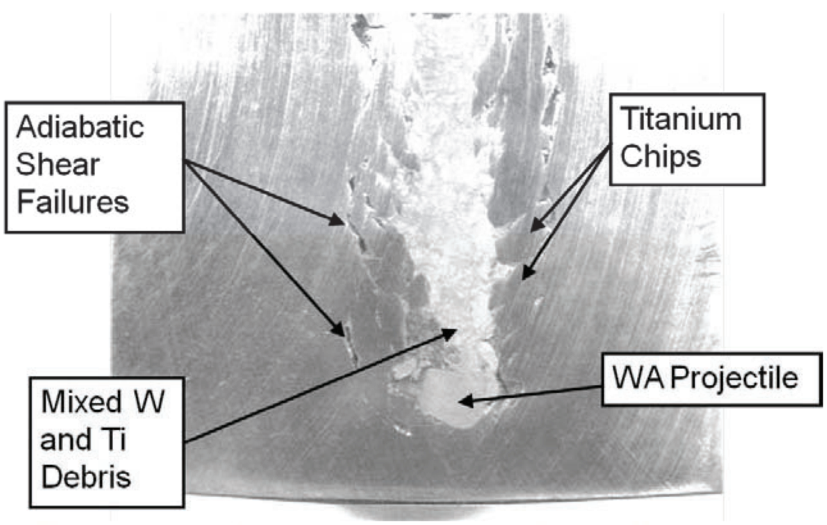


Figure 4. Deep Penetration of a Tungsten Long Rod Penetrator into Titanium showing Adiabatic Shear Bands

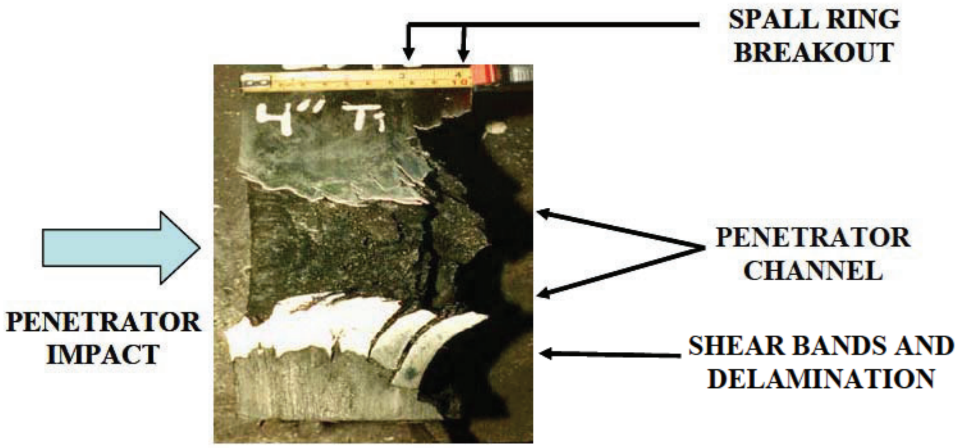


Figure 5. Spall Plug Breakout of a 100mm (4.0") Titanium Plate after Perforation by a Long Rod Penetrator

EFFECT OF MECHANICAL PROPERTIES ON BALLISTIC PERFORMANCE

The quasi-static mechanical properties of titanium are very important for most engineering applications and were included in the property requirements in MIL-DTL-46077G for Class 1 and 2 titanium. However, for armor applications, the impact of varying the mechanical properties is not apparent and processing history is more important. The most complete analysis of these effects were conducted by Burkins, Love and Wood where a set of Ti-6Al-4V ELI plates were subjected to a series of annealing temperatures and the effects on the mechanical properties were determined [13]. The results on the samples from the original single 28.5mm plate are summarized in Figure 6 where the effect of heat treating or working the plates over the beta transus temperature is obvious. The initial vacuum creep-flatten process produced ballistic plate with a performance similar to plates subjected to additional annealing below the beta transus. Plates annealed above the beta transus have a microstructure change to a Widmanstätten alpha-beta structure as seen in Figure 7. The effect on ballistic performance compared to transverse yield strength, transverse elongation and Charpy impact data are shown in Figures 8-10. The annealing step could be omitted to reduce cost or the anneal temperature could be increased to 900°C to obtain the highest performance.

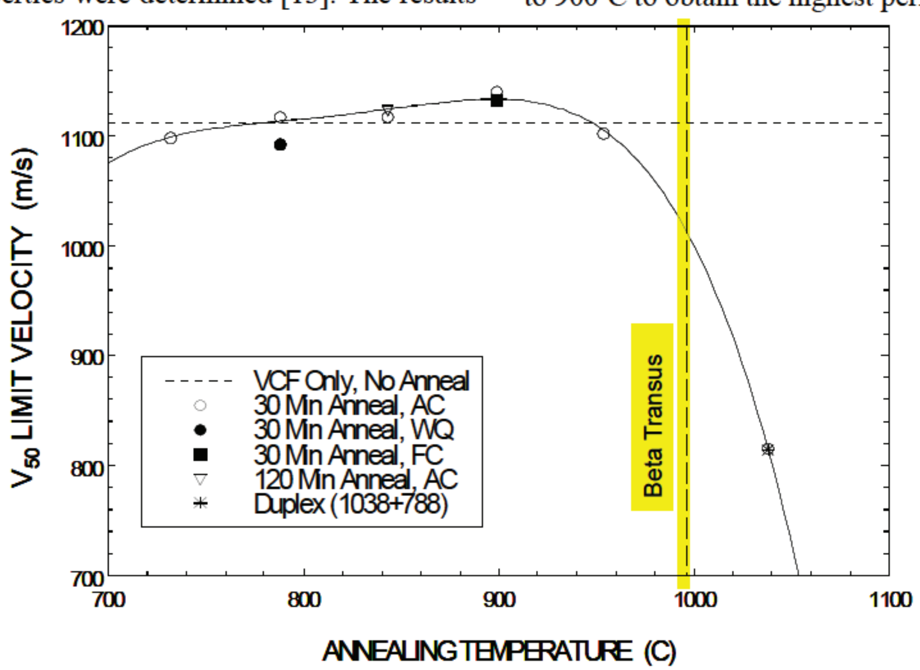


Figure 6. Effect of Annealing Temperature on Ballistic Performance

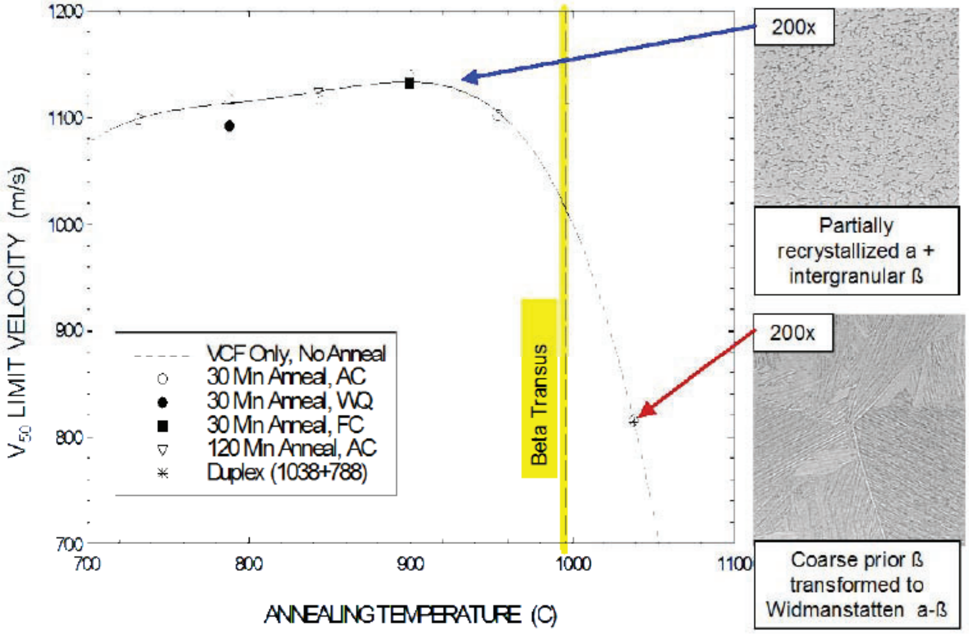


Figure 7. Change in Microstructure for Annealing over the Beta Transus Temperature

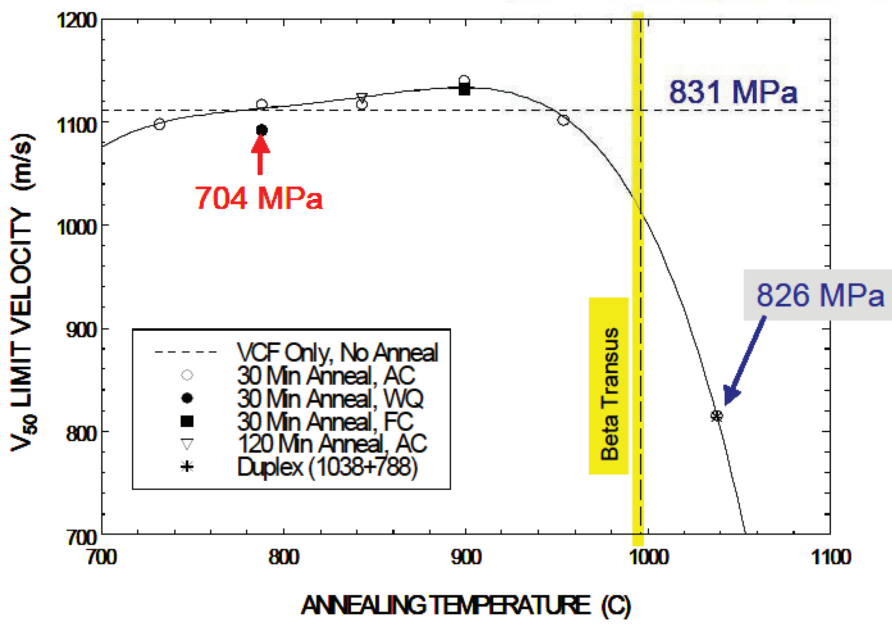


Figure 8. Change in Transverse Yield Strength with Annealing Temperature

EFFECT OF THERMOMECHANICAL PROCESSING ON BALLISTIC PERFORMANCE

In an effort to provide further data on processing of titanium armor plate, ARL and the U.S. Department of Energy Albany Research Center (ALRC) performed a joint research program to evaluate the effect of thermomechanical processing on the ballistic limit velocity of an ELI grade of Ti-6Al-4V [14-15]. ALRC obtained MIL-T-9046J, AB-2 plates from RMI Titanium Company, rolled these plates to final thickness, performed the annealing, and collected mechanical and microstructural information. ARL then tested the plates with 20-mm fragment-simulating projectiles (FSPs) and 12.7-mm armor-piercing (AP) M2 bullets in order to determine the ballistic limit velocity of each plate. The ballistic limit velocities were then compared to assess the effect of changes in rolling and heat treatment.

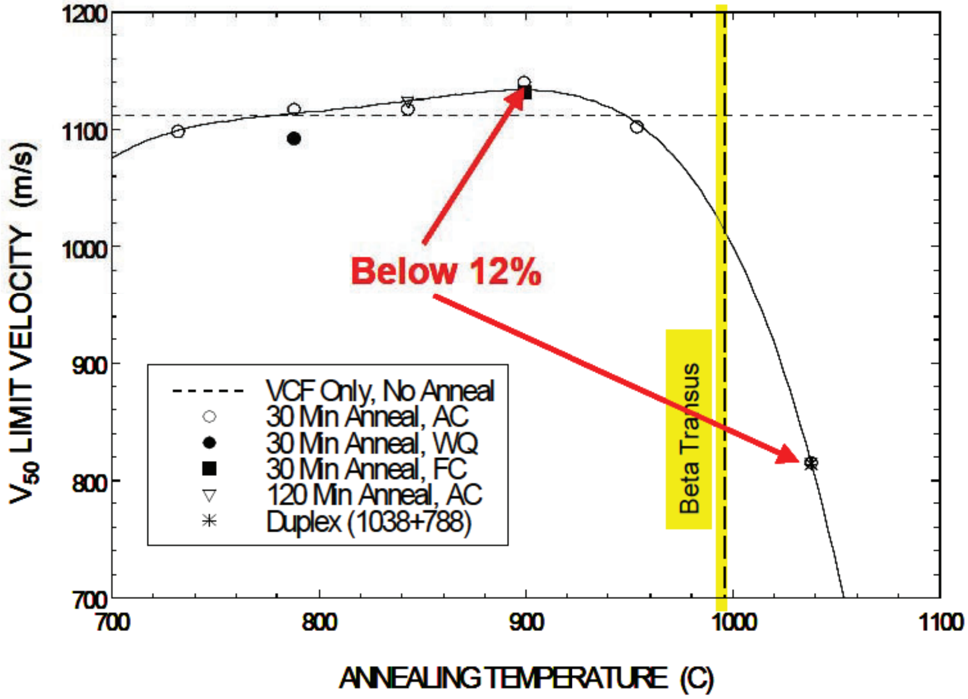


Figure 9. Effect of Transverse Elongation with Annealing Temperature

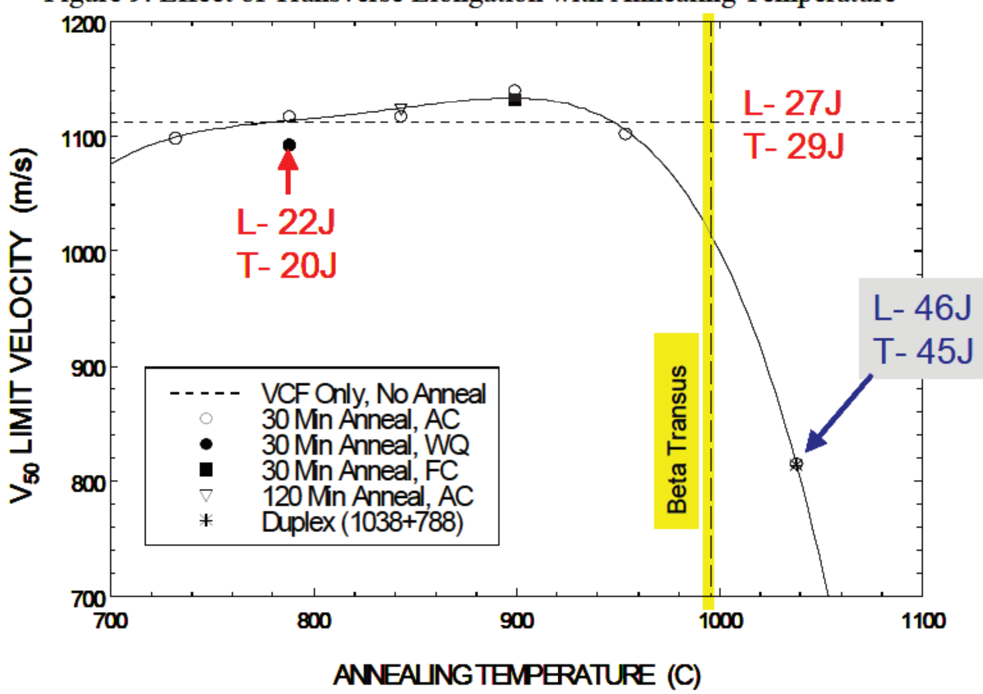


Figure 10. Effect on Charpy Impact Results with Annealing Temperature

The starting material was commercially produced 127-mm-thick Ti-6Al-4V ELI alloy plate product. Each plate was coated with a silica-based material to reduce oxygen contamination, placed into the furnace, and soaked for two hours at either 1,066° C (beta) or 954° C (alpha-beta), and step forged to 108-mm first and then 89-mm. The step forging was done without reheating. Upon completion, the plates were returned to the furnace and reheated for 20 minutes. The plates were then, either unidirectionally (straight) rolled or cross-rolled at the same temperature used in the forging operation (1,066° C or 954° C). The rolling schedule consisted of two passes at 12% reduction in thickness, two passes at 15% reduction in thickness, three passes at 20% reduction in thickness, and one final pass at the final mill setting of 25.4 mm. Each plate was reheated for 20 minutes after every second pass through the mill. Following the final pass, the plates were placed on a rack and air cooled to room temperature.

Four different annealing heat treatments were used at the completion of rolling and air cooling: (1) a beta anneal at 1,038° C for 30 minutes with an air cool (AC); (2) a beta plus alpha-beta anneal at 1,038° C for 30 minutes with an AC, followed by 788° C for 30 minutes with an AC; (3) an alpha-beta anneal at 788° C for 30 minutes with an AC; and (4) a solution treat and age (STA) at 927° C for 30 minutes with a water quench (WQ), followed by 538° C for 6 hours with an AC. As an experimental control, the final heat treatment was omitted for some of the plates. Following heat treatment, all the plates were sand-blasted to remove any remaining protective coating. All plates forged, rolled, or annealed in the beta region had a typical structure of plate-like alpha and intergranular beta with alpha at the prior beta grain boundaries. All plates forged, rolled, and annealed in the alpha-beta region had a typical structure of equiaxed alpha grains and intergranular beta.

V_{50} limit velocities were obtained for all eleven plate conditions, tested with both the 20-mm FSP and 12.7-mm APM2 projectiles. Figure 11 shows graphically the V_{50} difference for the eleven plate conditions. The required V_{50} values were derived from the acceptance tables in MIL-A-46077D. Regardless of the penetrator used, only three plates (S1, C1, and C4) passed the ballistic requirements of MIL-A-46077D, even though these three plates also failed to meet the elongation requirements of MIL-A-46077D. Beta-processed plates, either rolled or annealed at temperatures above the beta transus, had lower V_{50} ballistic limit velocities for both the 20-mm FSP and the 12.7-mm APM2. The magnitude of the effect was much greater for the 20-mm FSP (~200 m/s) than for the APM2 (~40 m/s), confirming a trend that had been indicated in prior data [12]. The plates that received no additional anneal treatment (C4 and S5) gave a ballistic performance comparable to similarly processed plates that received an alpha-beta anneal treatment (C1 and S2). For the APM2 tests, cross rolling provided no significant difference in V_{50} as compared to straight rolling (S1 vs. C1 and C5 vs. S2). For the 20-mm FSP tests, cross rolling seemed to provide a slightly

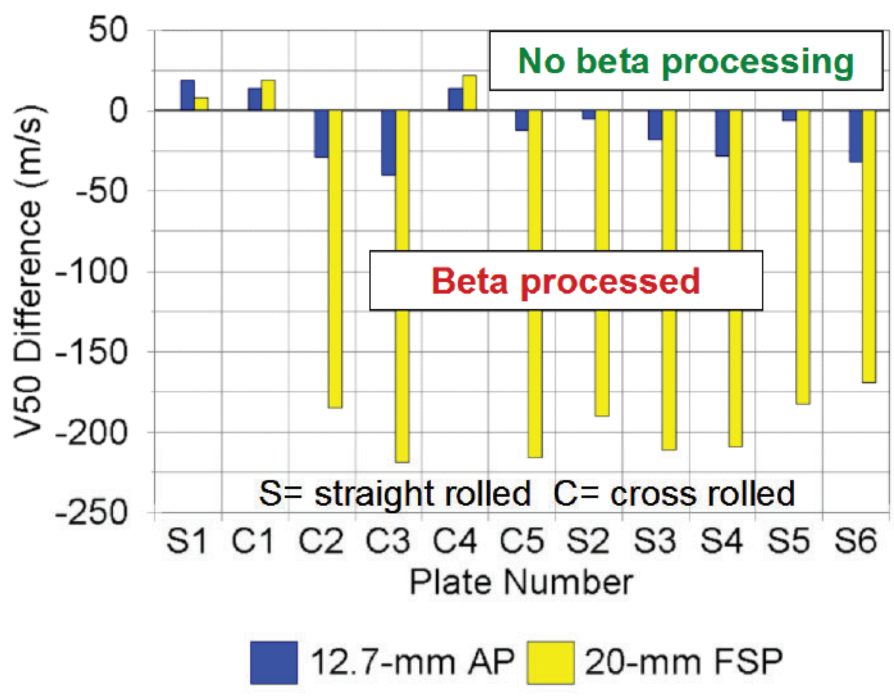


Figure 11. Beta processed Ti-6Al-4V Plate Compared to Alpha-Beta Processed Plate

higher V_{50} than straight rolling in the alpha-beta region (S1 vs. C1); however, straight rolling seemed to be slightly better than cross rolling in the beta region (C5 vs. S2). The beta-processed plates failed by a process of adiabatic shear plugging. The alpha-beta-processed plates failed by a mixed process of bulging, delamination, shearing, and spalling, which required more energy because the FSP had to burrow much deeper into the armor plate before rear surface failure occurred. The failure mode for beta and alpha-beta processed plates appeared to be the same for the 12.7-mm APM2. This observation is consistent with the relatively small differences in V_{50} performance between the beta- and alpha-beta-processed plates.

TITANIUM WROUGHT PLATE VS CASTINGS

The advantages of utilizing net shape cast titanium components for armor applications and other ballistic uses led to an examination of the ballistic performance of cast titanium as compared to wrought plate [16]. The main issue from the US Army standpoint is cost reduction by eliminating unnecessary processing. The ballistic evaluation of cast titanium utilized ASTM 367-87 Grade 5 alloy and was compared to wrought Ti-6Al-4V plate as defined in Tables 4 and 5. The mechanical properties for the cast material are lower than the wrought plate, except for the hardness and the compositions are similar. The cast titanium was also subjected to post processing procedures to include hot isostatic pressing to reduce porosity and pickling to reduce the case hardened layer and surface imperfections. The samples were impacted with armor-piercing and FSP projectiles and the results for the 20mm FSP are shown in Figure 12.

The baseline wrought data are plotted in Figure 12 as a dashed red line and the cast titanium is plotted as a solid black line. These data show the cast titanium performance to be, at best, 75% of wrought titanium and results from the reduced strengths as compared to the rolled wrought plate. The effects of post processing procedures are minimal with some possible improvement in the ballistic performance due to pickling; but the data are scattered. Conjecture would be

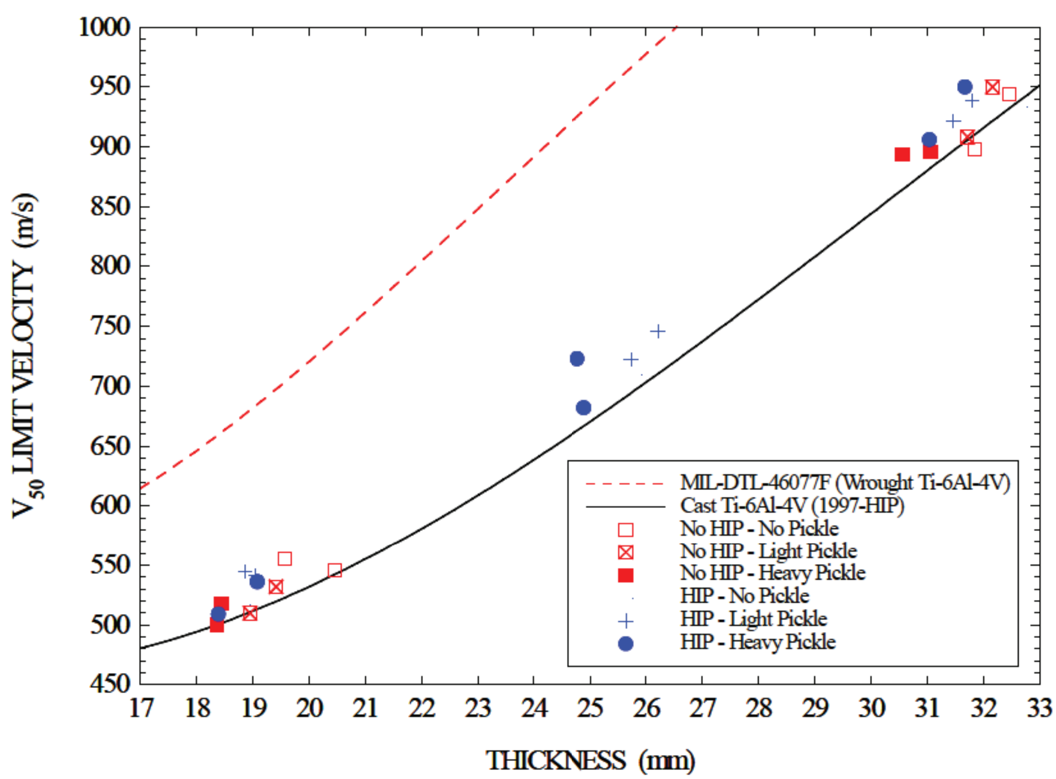


Figure 12. Ballistic Performance of 20mm FSP vs Wrought and Cast Titanium

Table 4. Comparison of Wrought and Cast Titanium Compositions

Heat #	Part ID #	Nominal Thickness (mm)	Al (%)	V (%)	Fe (%)	O (%)	C (%)	N (%)	H (%)
970139	970181	25.4	6.27	3.8	0.15	0.21	0.02	0.01	0.002
	970179	12.7							
970140	970179	12.7	6.27	3.8	0.17	0.23	0.02	0.01	0.004
	970180	19.1							
	970183	38.1							
970138	970182	31.8	6.28	3.8	0.16	0.21	0.02	0.01	0.002
	970183	38.1							
ASTM 367-87 Grade C5			5.5-6.75	3.5-4.5	0.40 max	0.25 max	0.10 max	0.05 max	0.015 max

Table 5. Mechanical Properties of Cast and Wrought Titanium

Heat #	Part ID #	Nominal Thickness (mm)	Tensile Properties			Hardness
			0.2%YS (MPa)	UTS (MPa)	Elong (%)	(BHN)
970139	970181	25.4	885	989	10.0	318
	970179	12.7				
970140	970179	12.7	900	1024	11.0	315
	970180	19.1				
	970183	38.1				
970138	970182	31.8	879	981	10.0	299
	970183	38.1				
ASTM 367-87 Grade C5			825 min.	895 min.	6 min.	365 max.

that any post process that homogenizes the surface, particularly the back of the casting could decrease crack initiation points when in tension. The use of cast components will require 20-25% thicker cross-sections over wrought plate. In complex shapes, casting may be advantageous when compared to steel castings that suffer the same issues.

SHAPED CHARGE PROTECTION OF TITANIUM

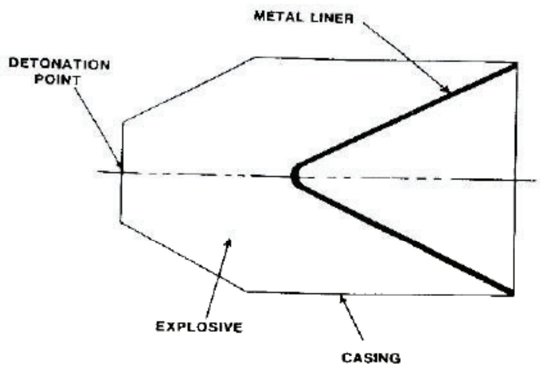


Figure 14. Shaped Charge Warhead

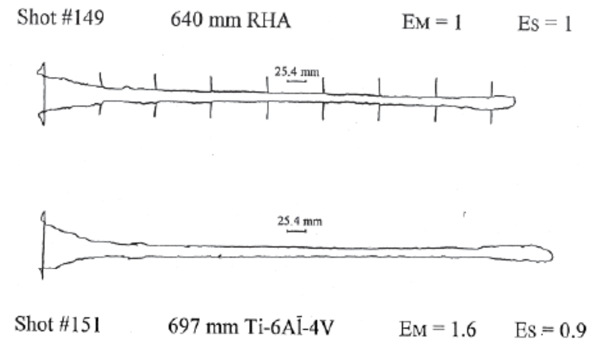


Figure 16. SC Penetration of Titanium

The primary discussion to date has related to the penetration of titanium by kinetic energy projectiles or fragments, but titanium also has excellent performance against shaped charge (SC) warheads [17]. Figure 1 showed the performance of a L/D 13 long rod tungsten penetrator as a function of velocity, with the highest impact velocity about 2.6 km/s. A typical SC is shown in Figure 14 and Figure 15 shows the sequence of flash x-rays illustrating the functioning of the warhead [18-19]. The conical copper liner is embedded in a cylinder of explosive which is detonated at the base of the explosive and the resultant detonation wave collapses the liner on the axis of the charge. This collapse causes a high velocity jet to be ejected forward. Depending on the design, the tip of the jet is traveling about 10 km/s with the tail traveling about 3 km/s. This velocity gradient causes the jet to stretch and elongate, creating very high L/D ratios. Shaped charge penetration is basically hydrodynamic where jet penetration is more a function of the relative densities of the penetrator and target and jet length; strength effects approach 0. Figure 16 compares the semi-infinite penetration of a 102mm tantalum shaped charge warhead into a stack of RHA steel and Ti-6Al-4V titanium [20-22]. The titanium had a mass efficiency 1.6 times that of the RHA, but had a space efficiency of 0.9, i.e., requires about 10% more thickness to equal the penetration into RHA. To put this in terms of pounds/ft^2, 1028 lbs of steel is needed to stop the penetration of the warhead versus 635 lbs of titanium (697mm of titanium). Overall, titanium offers excellent kinetic energy and shaped charge penetration resistance.

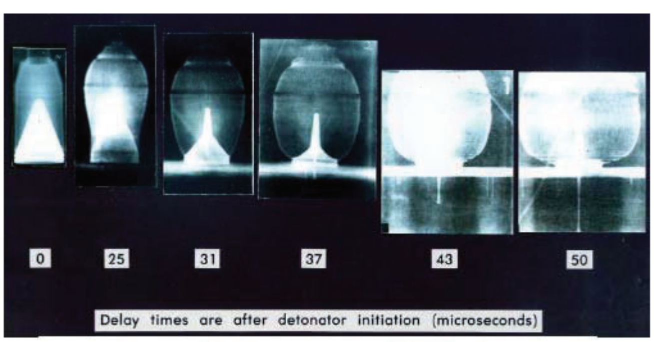


Figure 15. Formation of SC Jet

TITANIUM FORGINGS

Figure 17 shows an application of the forging of titanium for military application for ground vehicles [23]. The forging has increased strength similar to wrought rolled plate due to the mechanical working of the metal. The commander's hatch for the M2A2 Bradley is a very intricate shape and a titanium forging resulted in providing a lower weight and ballistically equivalent hatch to the previous steel hatch.

Figure 17. M2A2 Titanium Commanders Hatch

TITANIUM HOT PRESSED NET SHAPE BODY ARMOR PLATES

In 2005-2006, ARL examined the use of hot pressing net shape compound angle titanium body armor inserts in conjunction with BAE Advanced Materials of Vista, CA. The equipment used was the same hot presses used to fabricate boron carbide ceramic plates for use in body armors. Figure 18 shows a completed BAE hot pressed titanium ballistic insert [24]. Plates were fabricated from both Class 3 and 4 titanium alloys under MIL-DTL-46077G. Perciballi of ArmorWorks, Tempe, AZ also examined titanium body armor plates in 1998 [25].

TITANIUM COMPOSITES/LAMINATES

Figure 18. Hot-Pressed Net Shape Titanium Body Armor Plate

The use of titanium as a standalone armor material has ballistic disadvantages due the breakout effects of adiabatic shearing. Similar effects are found with high hard steels. For this reason, these types of metals can be backed with ductile or compliant materials as a laminate to create a much higher ballistic performance than the individual materials. This is shown in Figure 19 where a

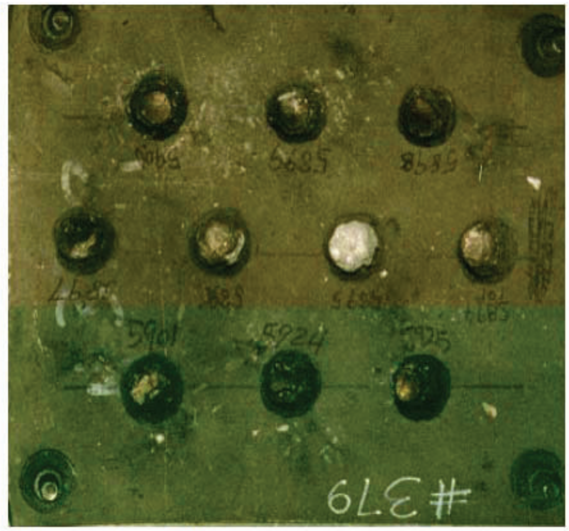


Figure 19. Multiple Impacts on a Titanium/ Aluminum Laminate

titanium plate is mechanically attached to an aluminum back plate [18-19]. ARL examined a prototype titanium appliqué on a M113A3 personnel carrier aluminum structure and had excellent ballistic performance over heavier steel based appliqués. For newer structures, the backing could also be fiber composites such as S2 glass, Kevlar Aramids, or polyethylene Dyneema/ Spectrashield composites. The harder front face erodes the projectile and the rear ductile layer captures the remaining fragments or projectile.

DUAL HARD TITANIUM

Figure 20 conceptually shows a titanium dual hard metallurgically bonded laminate similar in concept to dual hard steel. A softer rear plate can reduce spalling of the rear surface and contribute to higher performance.

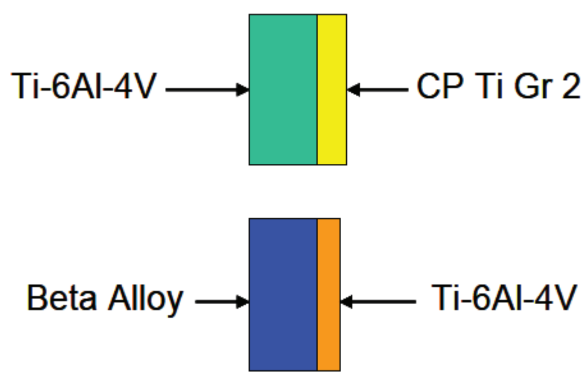


Figure 20. Dual Hard Titanium Concept

These laminates would take advantage of mechanical properties and ballistic response of the individual components to make a superior ballistic material that could be fabricated as a single plate. The earliest work in this area was undertaken between 1969 and 1976 at both Lockheed Missile and New York State University for the former US Army Materials and Mechanics Research Center, now the Materials and Research Directorate of ARL [26-29]. At that time, a Ti-3Si-Fe-0.5N front face alloy was roll bonded to a Ti-7Al-2.5Mo back plate and then heat-treated. The observation that a front hardness of 60 Rc or greater was optimum for ballistic resistance and maximum spall resistance occurred when the thickness ratio of 70/30 was noted. Today, these plates could be metallurgically bonded by rolling, diffusion bonding, hot-isostatically pressing or explosive welding. ARL has investigated all four types of bonding and found the ballistic performance can improve by10-25% depending on the threat and cross-sectional areal density [30-31]. Figure 21 shows the cross-section of a hot isostatically pressed Ti-6Al-4V/CP titanium laminate after an overmatch perforation of a fragment simulator. The penetrator impacted from the bottom and a ductile petalling failure of the CP titanium is evident without spalling. This combination was about 10% better that a single Ti-6AL-4V weight equivalent plate. This research area probably offers the best direction for ballistic application of titanium to future combat systems and these excellent older references should be revisited.

Figure 21. Hot Isostatically Pressed Ti-6Al-4V/CP Titanium Dual Hard Laminate

FUNCTIONALLY GRADED TIB/TITANIUM

The development of functionally graded materials (FGM) using ceramics and metals may offer even higher performance than dual hardness metal laminates, but the material complexity is more demanding. BAE Advanced Materials, under contract to ARL, developed a process to hot-press large near net-shape FGM tiles in a single stage utilizing titanium and titanium/titanium diboride (TiB_2) powder mixtures, forming a titanium monoboride (TiB) hard face/titanium metal substrate that grades through intermediate layers [32]. As seen in Figure 22, the TiB ceramic is formed through a reaction sintering process between the TiB_2 and titanium powders during the hot-press phase. TiB is densified as a cermet (ceramic in a metal matrix) to aid in fabrication. A major development in the process was overcoming the inherent thermoelastic properties of the constituent layers and the resultant stresses that arise from the differences in thermal expansion coefficients and elastic moduli of the layers. Analytical and finite element modeling techniques were used to determine the residual stresses and modify the processing parameters. The resultant tiles produced to date are among the largest functionally

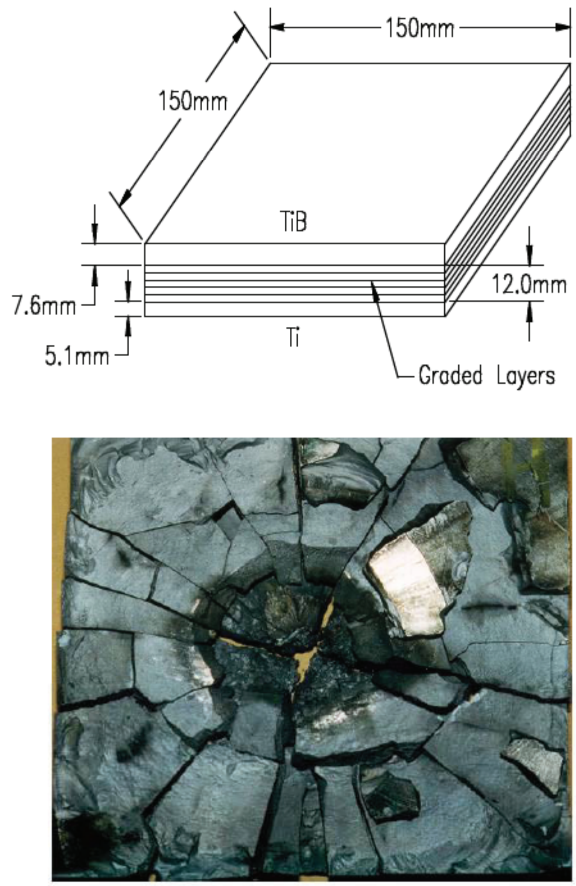


Figure 22 Functionally Graded Titanium Monoboride/Titanium Plate

gradient materials produced in the world by a practical process and represent an advancement in this technology area.

HOT ISOSTATICALLY PRESSED CERAMIC/TITANIUM MATRICES

Another more advanced ceramic laminate is hot isostatically pressed ceramic tiles in titanium matrices. The titanium matrix maintains a compressive load on the ceramic, thereby allowing full advantage of the large dynamic compressive strengths of ceramics [33]. This process has led to the left image of Figure 23 that shows the defeat of a long rod tungsten alloy penetrator by a defeat mechanism called interface dwell; the projectile is being totally consumed at the front metal ceramic interface with little damage to the ceramic. Again, then thermal expansion coefficients and elastic moduli of the layers as well as critical back plate stiffness drive this

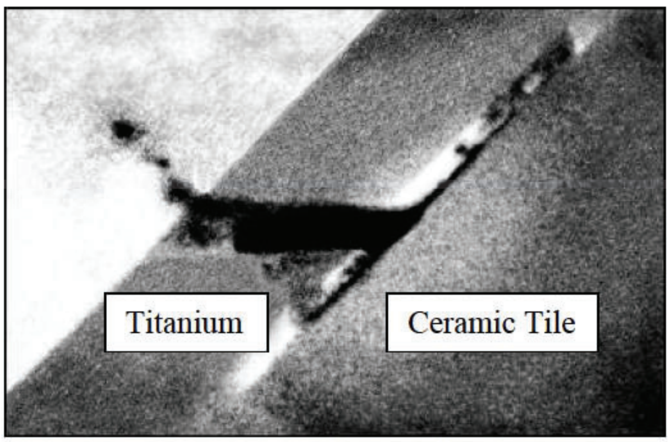


Figure 23. Interface Dwell at the Titanium/Ceramic Interface

mechanism. One fabrication method for incapsulation in a metallic structure is to hot isostatically press the titanium around the ceramic as seen in the two images of Figure 24 [34].

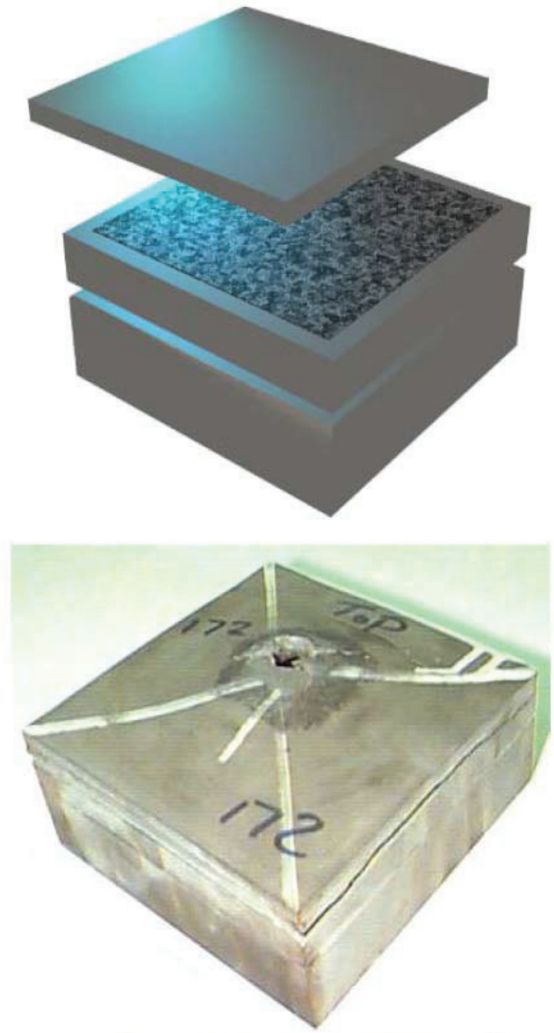
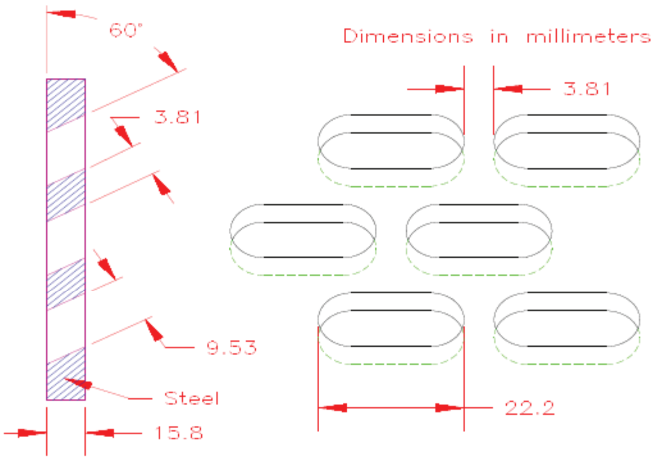


Figure 24. Hot Isostatically Pressed Ceramic in Titanium Matrices

CAST P900 TITANIUM TIPPING PLATES

The development of single plate cast P900 steel tipping plates by ARL in the late 1980's provided a significant improvement over single homogeneous steel armor plates when used as the strike face for a spaced armor or appliqué armor system. The 1991 patent provides the details of the cross-sectional design of angular holes that is still used today [35]. As seen in Figure 25, the holes are repetitively placed at a 60° angle such that the areal weight is about 50% of a solid plate. The non-homogeneous cross-section causes the projectile to tip and breakup; the disrupted fragments can then be captured in the base vehicle structure [18-19]. In 2007, ARL published military specification MIL-PRF-32269 (MR) on Perforated Homogeneous Steel Armor that set the requirements for production and acceptance of this technology [36]. Concurrently, ARL funded the development of titanium P900 using two different casting techniques to demonstrate the feasibility of producing lower weight net shape titanium castings that



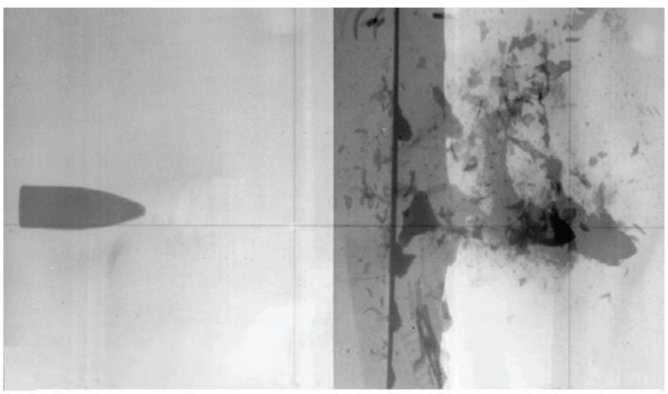


Figure 25. X-ray of a 14.5-mm Projectile Impacting a Single P900 Plate

provided the required disruption or tipping action on the impacting penetrator. The intent was to demonstrate a P900 titanium plate that met the general performance requirements of the steel military specification, but provided increased weight reduction for military platforms.

Two casting technologies were selected for prototyping the P900 plates. Figure 26 shows a 15" X 15" X 0.625" cast titanium P900 plate produced by Pacific Cast Technologies of Albany, OR that was produced using StereoLithography rapid prototyping technology and precision investment castings [37]. Figure 27 shows a 17" X 17" X 0.625" cast titanium P900 plate produced by ATI Wah Chang of Albany, OR using rammed graphite mold processing and lost foam casting technology [38]. Both companies were successful in producing plates that met the requirements of military specification and this technology needs to be further

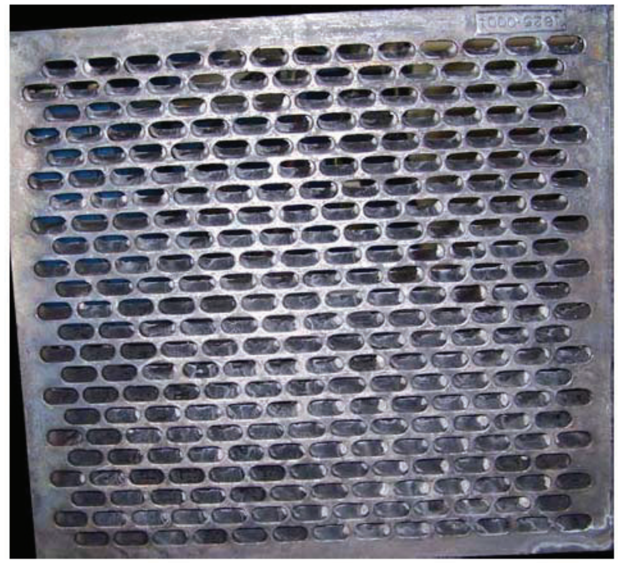


Figure 26. Pacific Cast Technologies Cast P900 Titanium Plate

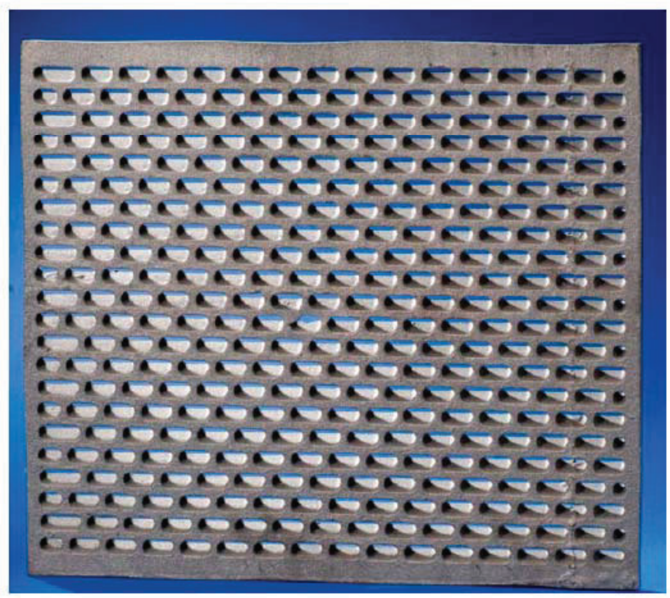


Figure 27. ATI Wah Chang Cast P900 Titanium Plate

developed using different alloys and heat treatments. Besides ground vehicle application, the ability to cast to net shape has advantages for application to aerospace protection requirements where weight is a critical factor. This was further conceptualized by ARL for application in "Perforated Fuselage Armor" that would incorporate both ballistic protection mechanisms and structural components [39].

MIL-DTL-46077G CLASS 4 TITANIUM ALLOYS

As mentioned earlier, MIL-DTL-46077G was created to provide an incentive to the titanium industry to develop non-aerospace grades of ballistic titanium [4]. The chemistries of Class 1 and Class 2 mirror that of Ti-6Al-4V ELI and standard grade 5. Class 3 allows for higher levels of oxygen and Class 4 goes a step further by removing the requirements for aluminum and vanadium. The intent is to develop non-aerospace alloys for protection requirements that can take full advantages of low-cost processing and reduced production processes that provide the required ballistic plate. Class 4 titanium must still fall into the Alpha-Beta range of alloys and meet all other mechanical and ballistic requirements for the other classes of the military specification.

The application of titanium into ground platforms has historically been greatly limited by the competition from the aerospace industry and the cyclic cost variations as demand for Class 1 and 2 Ti-6Al-4V alloys changes with production requirements. As density and strength are primary driving factors in the ballistic performance of titanium, Class 4 titanium alloys offer the potential for new ballistic applications. The development and application of non-Ti-6Al-4V alloys also offers large advantages due to the reduced use of higher cost alloying elements and lower cost electron beam or plasma beam processing. ARL considers this technical direction as the best opportunity for increasing titanium applications for ground applications in the future, whether as a standalone material or use in combination with other materials. Figure 28 shows the rear view of a production acceptance test of a 4.0" Ti-6Al-4V Class 3 plate that easily passed the MIL-DTL-46077G specification [40]. The test projectile here is a 30mm tungsten projectile and the development of the spall disk can be seen as the velocities are increased. Shot 13569 has an impact velocity just below the resultant V_{50} and the spall disk is almost fully separated.

ARL has examined a number of Class 4 titanium alloys for potential applications; examples include TIMET 62S™ and ATI 425-MIL™. The latter alloy has shown similar ballistic performance to the standard Class 2 Ti-6Al-4V alloy, but utilizes iron in place of some higher-cost vanadium as a beta stabilizer. The alloy can also be both cold and hot-worked and this capability has shown advantages in a wide variety of developmental applications. Figure 29 shows the large bend capabilities available in MIL-DTL-46077G Class 4 ATI 425-MIL™ titanium plate [41].

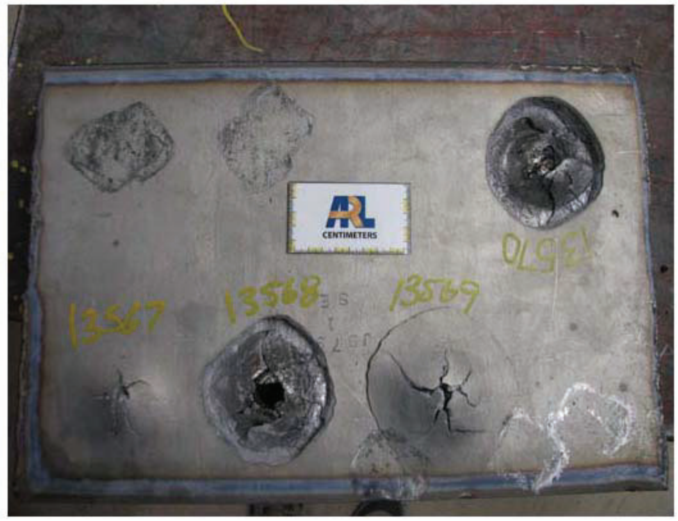


Figure 28. Production Acceptance Testing on a 4.00" Class 3 MIL-DTL-46077G Plate

Figure 29. Bend Capabilities of ATI 425-MIL™ Class 4 MIL-DTL-46077G Plate

Class 4 alloys may increase perceived production issues, such as qualification costs associated with legacy vehicle production, but this direction offers the best potential to increase applications for both commercial and military platforms.

CURRENT APPLICATIONS OF TITANIUM IN GROUND SYSTEMS

The use of titanium in military platforms has been driven by two related requirements, increased ballistic performance when used as an armor or weight reduction to increase mobility or meet tactical requirements. Either application takes advantage of the unique density and strength properties of this metal. As an armor, the performance has been documented in previous sections; however, the use of titanium as a weight reduction technique is also employed. While some effort to utilize titanium plate as appliqués on trucks in the Korean War, the earliest use of titanium for a structural application in a combat vehicle is shown in Figure 29 of a 1960 Detroit Arsenal prototype of a titanium cab on an ONTOS tracked vehicle [42]. While the research on titanium armors continue with periodic armor designs, the main drawback to the use of titanium remains the relative cost to other metals. The majority of the structure and armor components for the world's combat vehicles remain steel or aluminum based and large amounts of aluminum appliqués have been procured for add-on armor kits. The advent of low cost titanium grades and increased cost of more advanced materials such as composites and ceramics has allowed the use of titanium alloys as cost effective alternatives. The following paragraphs will illustrate some applications of titanium to currently field combat vehicles and weapon systems; the discussion is not comprehensive and some applications cannot be discussed in this forum.

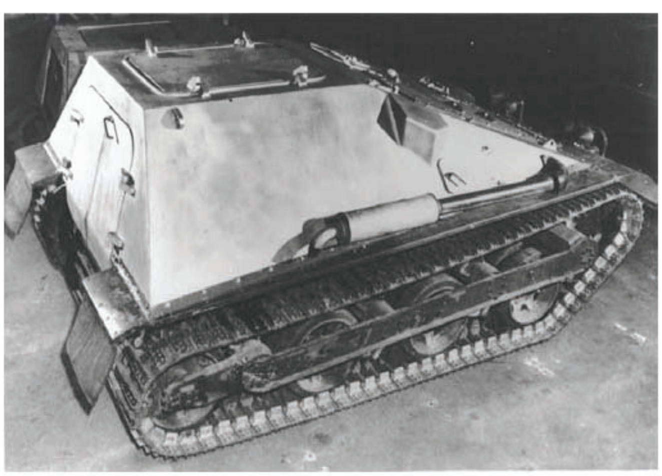


Figure 29. 1960 Detroit Arsenal Titanium Cab on an ONTOS Tracked Vehicle

One of the best illustrations of titanium on a current legacy system is shown in Figure 30 on the M1A2 Abrams tank where a concerted effort was made to reduce weight of components on the chassis [43-44]. While this weight reduction program envisioned a larger replacement of components, these four areas reduced combat weight by over 1500 lbs without loss of function or protection. Figure 31 shows the M2A2 Bradley Fighting Vehicle and two uses of titanium have been incorporated into design [43]. The commanders hatch is a titanium forging and a titanium roof appliqué was added for increased protection. The Reactive Armor Boxes on the sides were also designed to utilize titanium sheet as a replacement for sheet metal in the box construction.

The Ultra-light weight Field Howitzer, designated M777A1 in the USA, shown in Figure 32,was selected in 1997 by a joint US Army/Marine Corps initiative to replace the existing inventory of M198 155mm towed howitzers [45]. The construction of the M777A1 makes extensive use of titanium and titanium castings, enabling a weight reduction of 3,175kg (7,000lb) compared to the M198 howitzer which it replaces in the US Army and USMC inventory.

Current application of titanium is also found on two versions of the Stryker family of Vehicles [46]. Figure 33 shows the Stryker Mobile Protected Gun System and the Gun Pod is fabricated from titanium. Also shown in Figure 34 is the titanium Gunners Protection Kit on the RV and FSV versions of the Stryker. Titanium was used to reduce weight for the application

Future platforms will utilize a range of advanced light weight materials and low cost titanium has a role in providing high strength, low weight structures and components. These can be seen in a number of prototypes developed by the US Army and their contractors. Figure 35 shows the Pegasus electric drive wheeled prototype developed by BAE Systems that utilized both a lower and upper titanium welded structure [47]. The vehicle incorporated a composite rear space frame armor as well as the capability to mount a composite appliqué. This was the first full titanium vehicle prototype since the ONTOS vehicle in 1960.

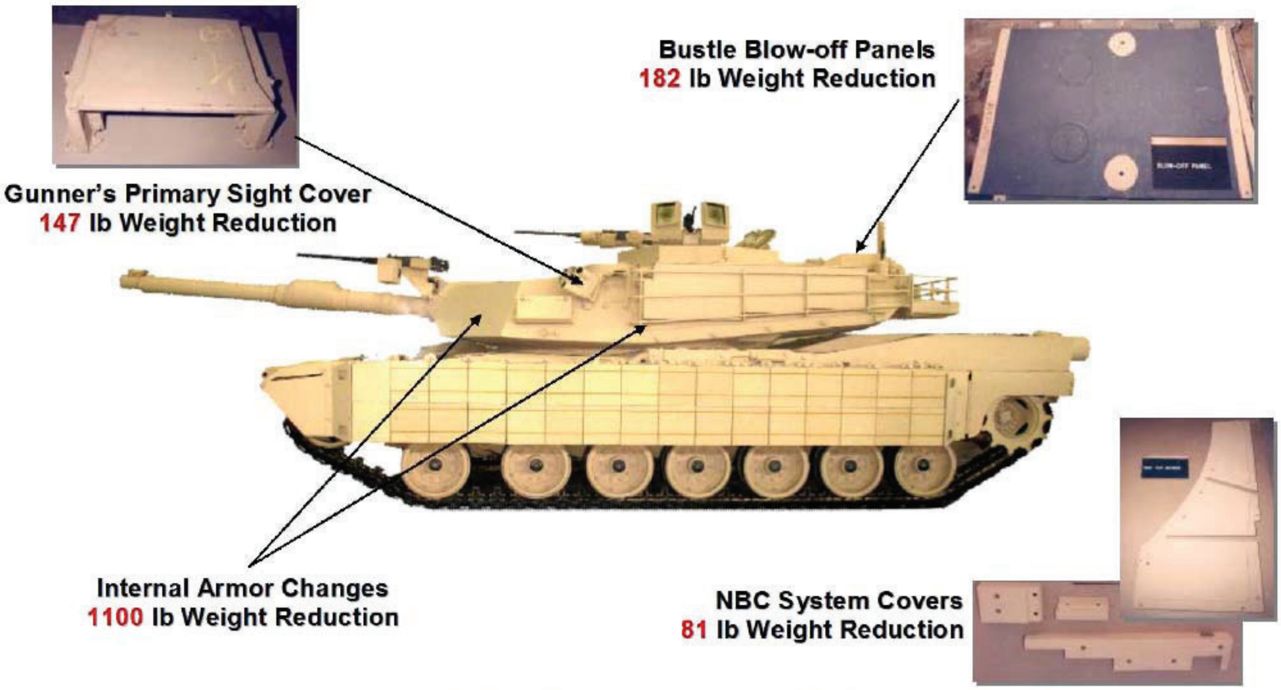


Figure 30. Titanium Weight Reduction Program for M1A2 Abrams Battle Tank

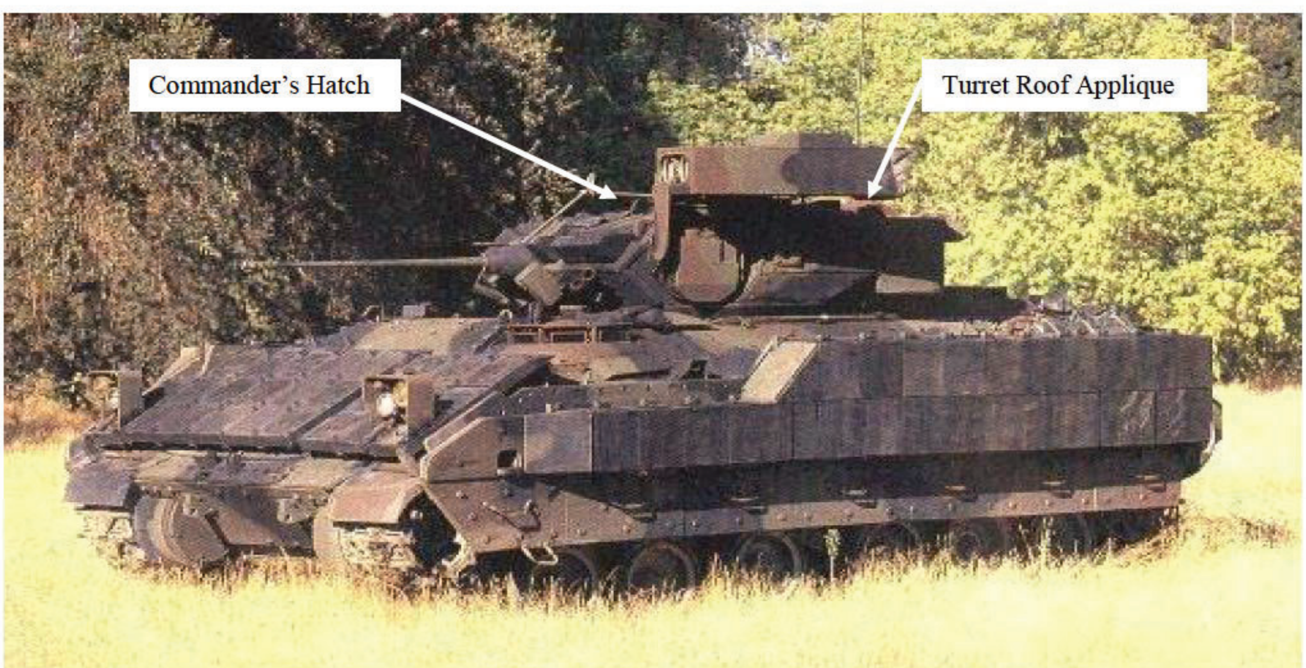


Figure 31. Titanium Commanders Hatch and Roof Applique on M2A2 Bradley Fighting Vehicle

Figure 32. M777A1 Ultra-light Field Howitzer

Figure 33. Titanium Gunners Overhead Protected Gun System on RV and RSV Stryker

Figure 34. Stryker Mobile Protected Gun System Titanium Gun Pod

Figure 35. BAE Pegasus Titanium Wheeled Prototype

The latest prototype titanium vehicle structure was an early Future Combat Vehicle hull section that was used to test composite armors (Figure 36) [48]. The lower body and nose sections were fabricated from Military Specification MIL-DTL-46077G Class 3 low cost titanium and were mated to a composite and space frame composite upper hull section. The vehicle was subjected to extensive ballistic testing and shock loading to measure the vehicle response.

Figure 36. Prototype Future Combat Vehicle Titanium Hull Section

CONCLUSIONS

This paper has provided an overview on the use of titanium alloys in military ground systems. The emphasis has been to examine the design and processing aspects in the application of this lightweight, high strength metal and emphasize cost/performance tradeoffs. With major emphasis on lightening future ground platforms, low cost grades of titanium, particularly Class 4 alloys outside the standard Ti-6Al-4V alloy family, can provide both structural and ballistic solutions. Further research into dual hard titanium offers further weight reduction and ballistic performance. Both these areas can translate into reduced material costs that make titanium more competitive as compared to other armor technologies.

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37. Photo provided courtesy of Pacific Cast Technologies, Albany, OR
38. Photo provided courtesy of ATI Wah Chang, Albany, OR
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40. ARL ballistic certification on 4.00" Titanium Plate in accordance with MIL-DTL-46077G
41. Photo provided by Larry Martin, ATI Defense, Washington, PA
42. Gooch, W., *The Design and Application of Titanium Alloys for U.S. Army Platforms*, Military Panel, International Titanium Association Titanium 2008, September 24, 2008
43. Figure provided courtesy of PEO CS&CSS, PM Abrams, Warren, MI
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46. Photos provided courtesy of Terry Dean, PM Stryker, PEO CS&CSS, Warren, MI
47. Figure provided courtesy of BAE Systems, Santa Clara, CA
48. Figure provided courtesy of BAE Systems, Santa Clara, CA

RDECOM

THE DESIGN AND APPLICATION OF TITANIUM ALLOYS FOR US ARMY PLATFORMS

TITANIUM 2010

MILITARY PANEL

Orlando, Florida

3-6 October 2010

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

William. A. Gooch
U.S. Army Research Laboratory
Weapons and Materials Research Directorate
Aberdeen Proving Ground, MD 21005-5066

THIS PRSENTATION IS UNCLASSIFIED/PUBLIC DOMAIN

Introduction

- Titanium was first examined for armor applications in 1950 by the Watertown Arsenal and Ti-6Al-4V become the main alloy of interest

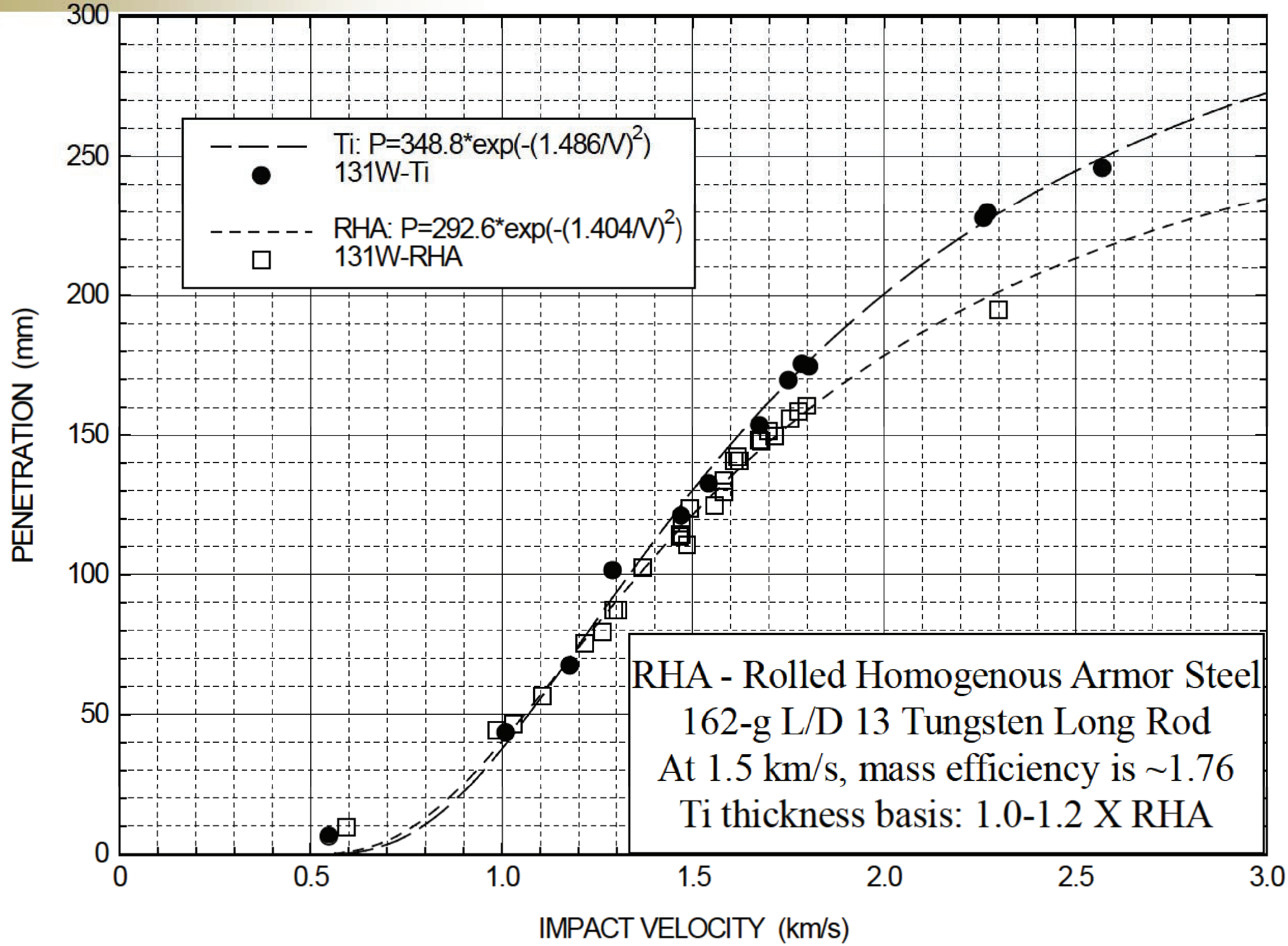
- The main advantage of titanium relates to the lower density at equal or higher strengths than rolled homogenous armor steel of equal thickness (23.2 vs 40.8 psf for 1" board foot ~43% weight reduction)

- This is the fourth year ARL has provided this Overview at the ITA and the written paper provides a detailed review of the ballistic aspects of titanium alloys

- In this short time, I would like to emphasize two technical areas that can lead to increased use of titanium alloys in the future:
  - Class 3 and Class 4 Titanium alloys under MIL-DTL-46077G
  - Dual hard titanium

- The presentation will show some new applications and end with an overview of current and proposed future applications of titanium for military ground vehicles

KE Ballistic Performance of RHA and Titanium

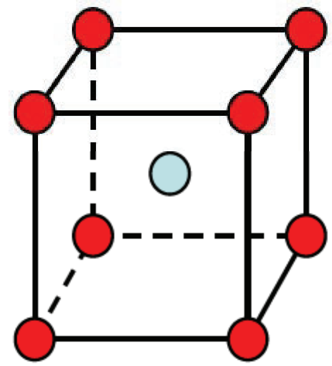


Beta Transus for Ti-6Al-4V and Processing History

Temperature ↑

Beta β

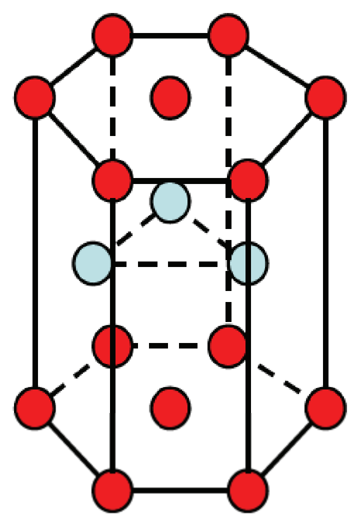
Body-Centered Cubic



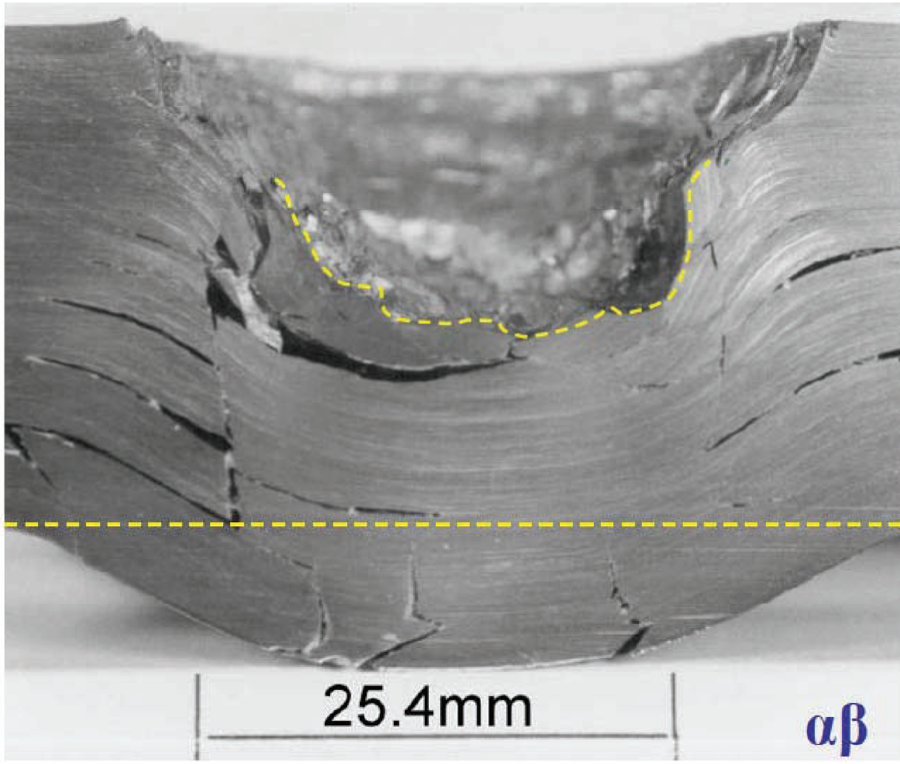
Ti-6Al-4V Beta Transus Temperature ~996°C (1825°F)

Alpha α

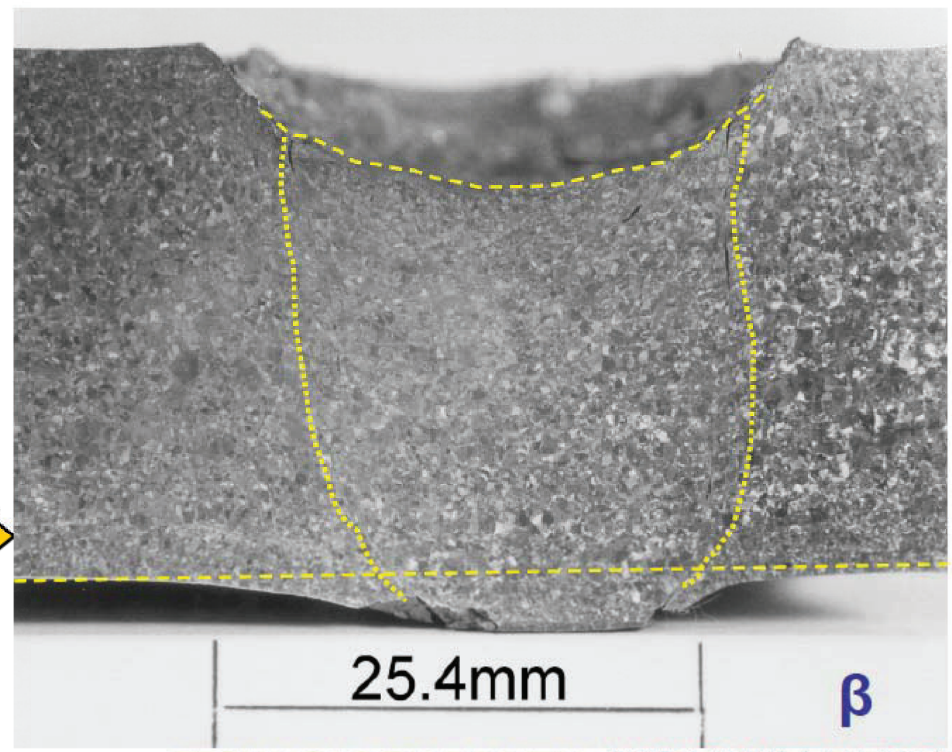
Close-packed Hexagonal



Failure Analysis of 20mm Fragment Simulating Projectile Impact

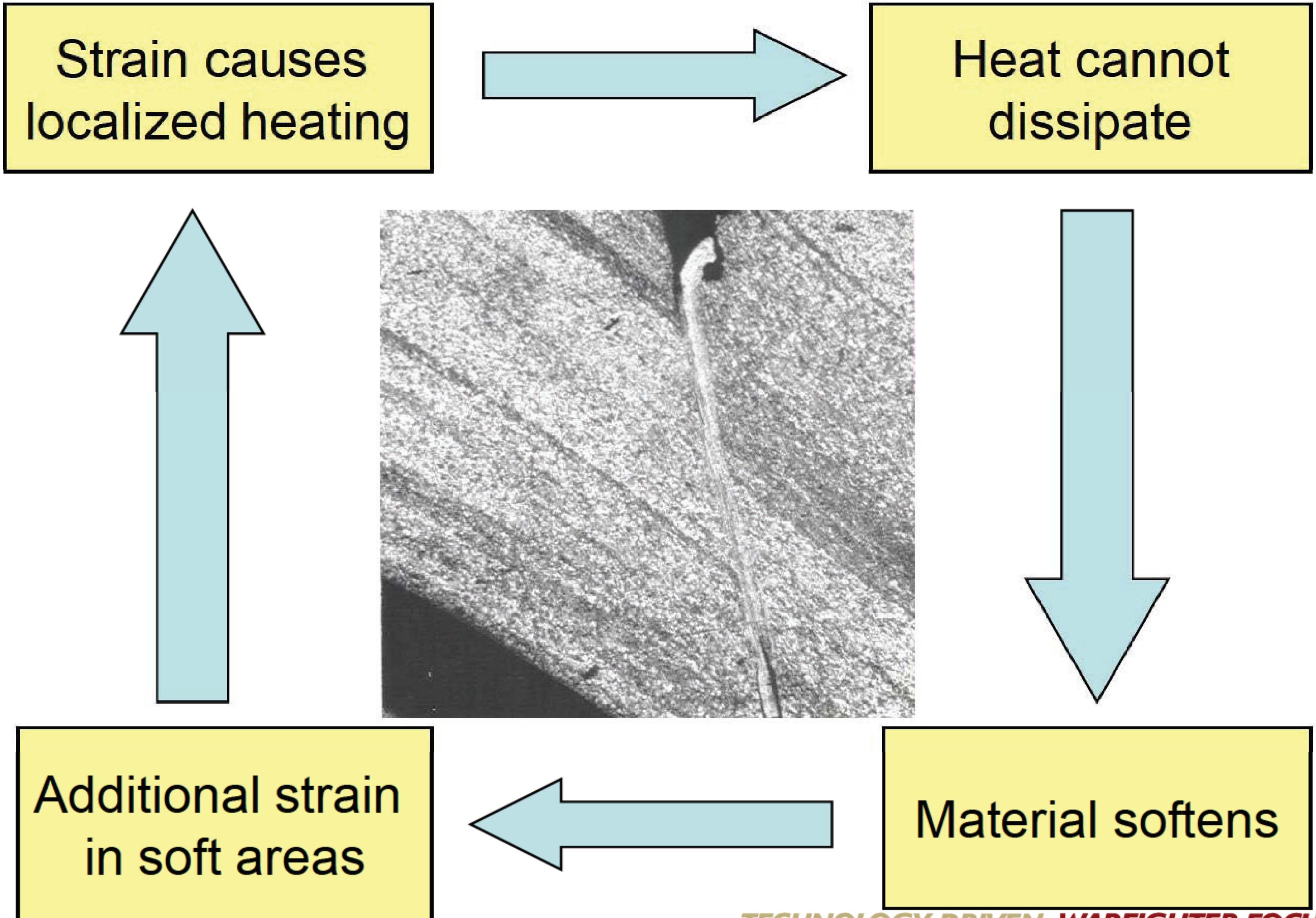


Failure by a mixed process of bulging, delamination, shearing, and spalling

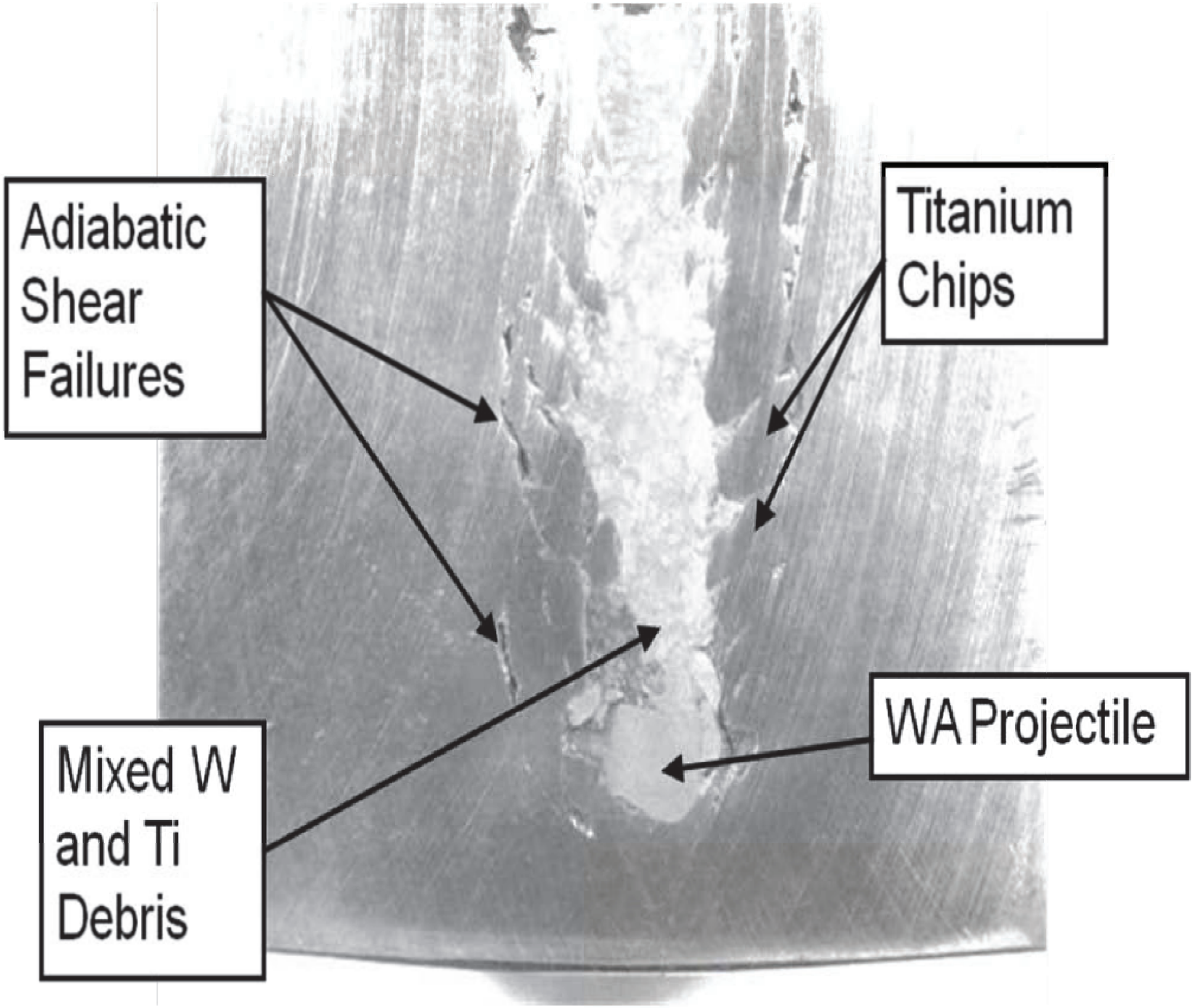


Failure by low-energy plugging

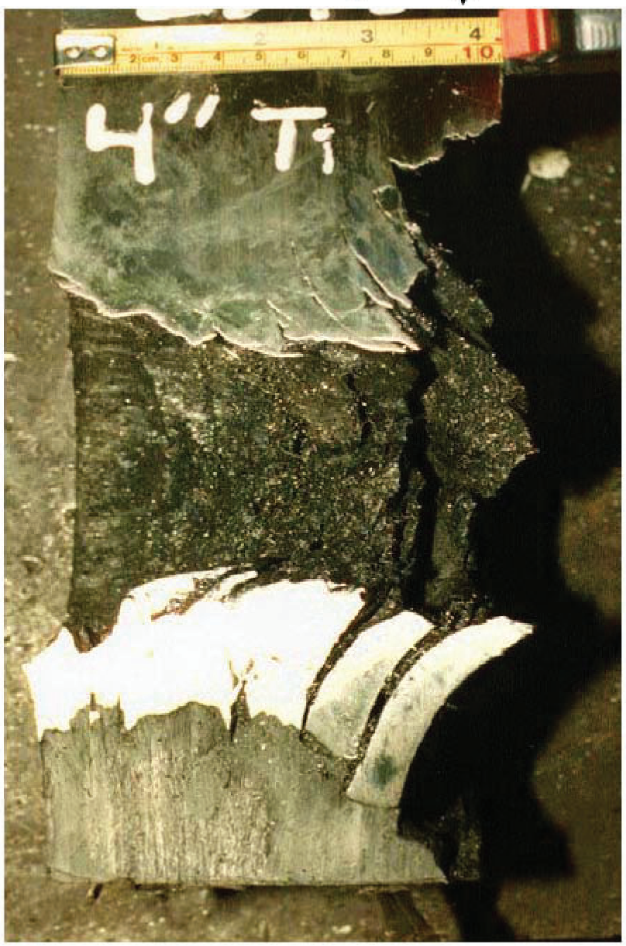
Adiabatic Shear Bands in Titanium



Deep Penetration into Titanium Showing Adiabatic Shear Bands



Spall Plug Breakout of Titanium



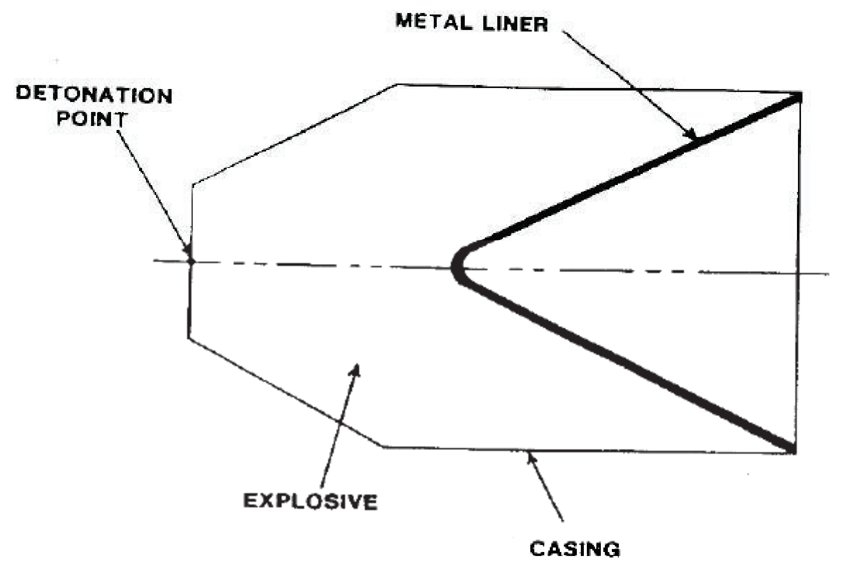
SPALL RING BREAKOUT

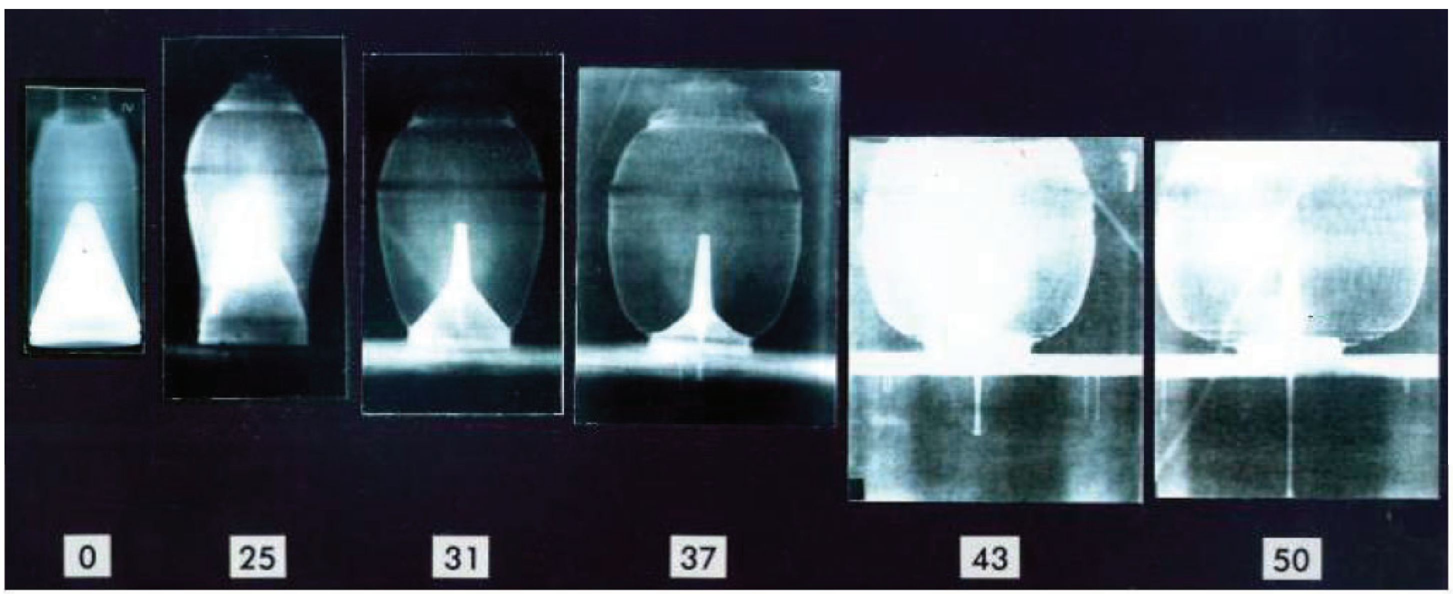
SHEAR BANDS AND DELAMINATION

PENETRATOR CHANNEL

SHEAR BANDS AND DELAMINATION

Shaped Charge Penetration

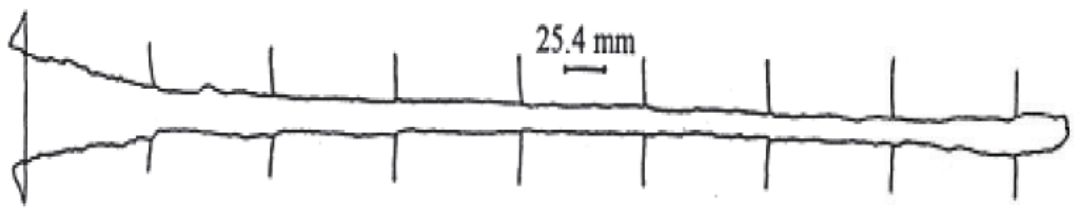




Formation of SC Jet

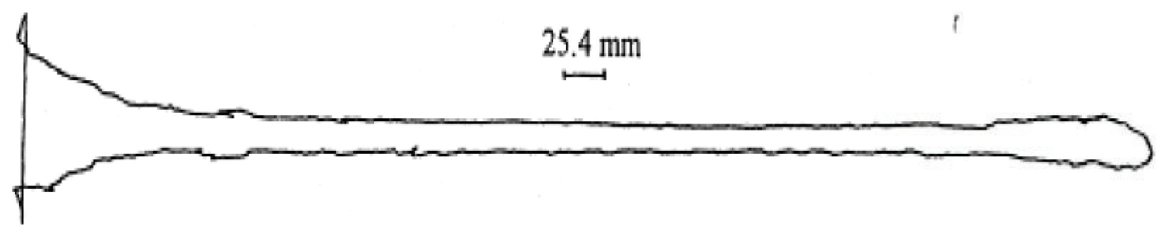
Shaped Charge Penetration into Titanium

Shot #149 640 mm RHA $E_M = 1$ $E_S = 1$



~25 inches
1028 lbs/ft²

102mm tantalum liner



~27 inches
635 lbs/ft²

Shot #151 697 mm Ti-6Al-4V $E_M = 1.6$ $E_S = 0.9$

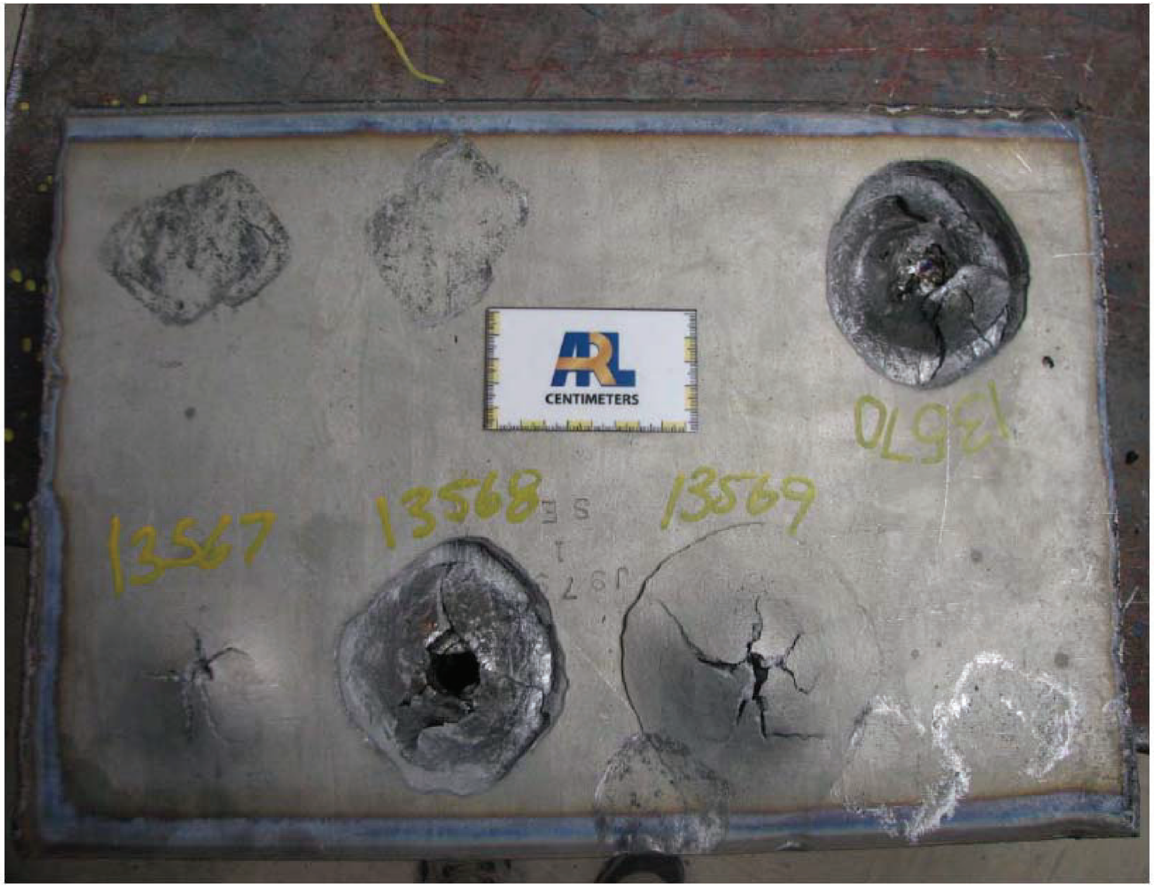
Titanium MIL-DTL-46077F & G

	Chemistry	Max. O_2 Content	Comments
Class 1	6AL- 4V	0.14%	***ELI*** - 10% Elongation Minimum
Class 2	6AL- 4V	0.20%	***Historical Armor Alloy*** 6% Elongation Minimum
Class 3	6AL- 4V	0.30%	***Higher Scrap/O_2 Content*** Electron Beam/Plasma Melting
Class 4	Not Limited	0.30%	***Lower cost alloying*** Non Aerospace Alloys

All four classes have the same minimum strength and ballistic requirements.

Expanded thickness range: 3mm-101.6mm

Emphasis 1
Class 3 and 4 MIL-DTL-46077G Plate

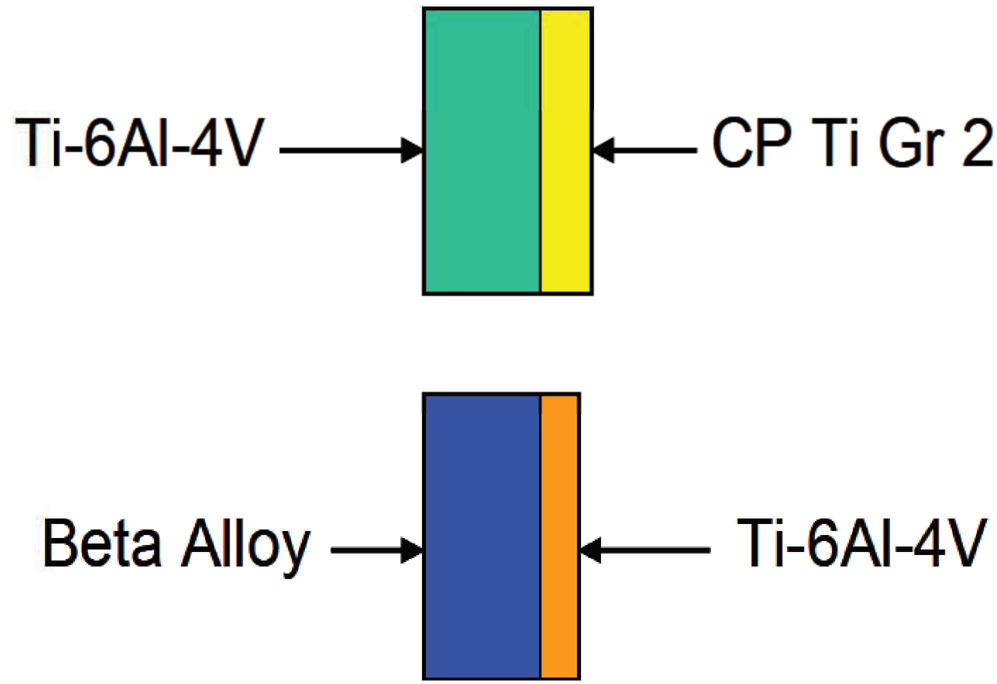


Production Acceptance Testing of a TIMET 4.00" Class 3 Plate

Bend Capabilities of ATI 425-MIL™ Class 4 Armor Plate

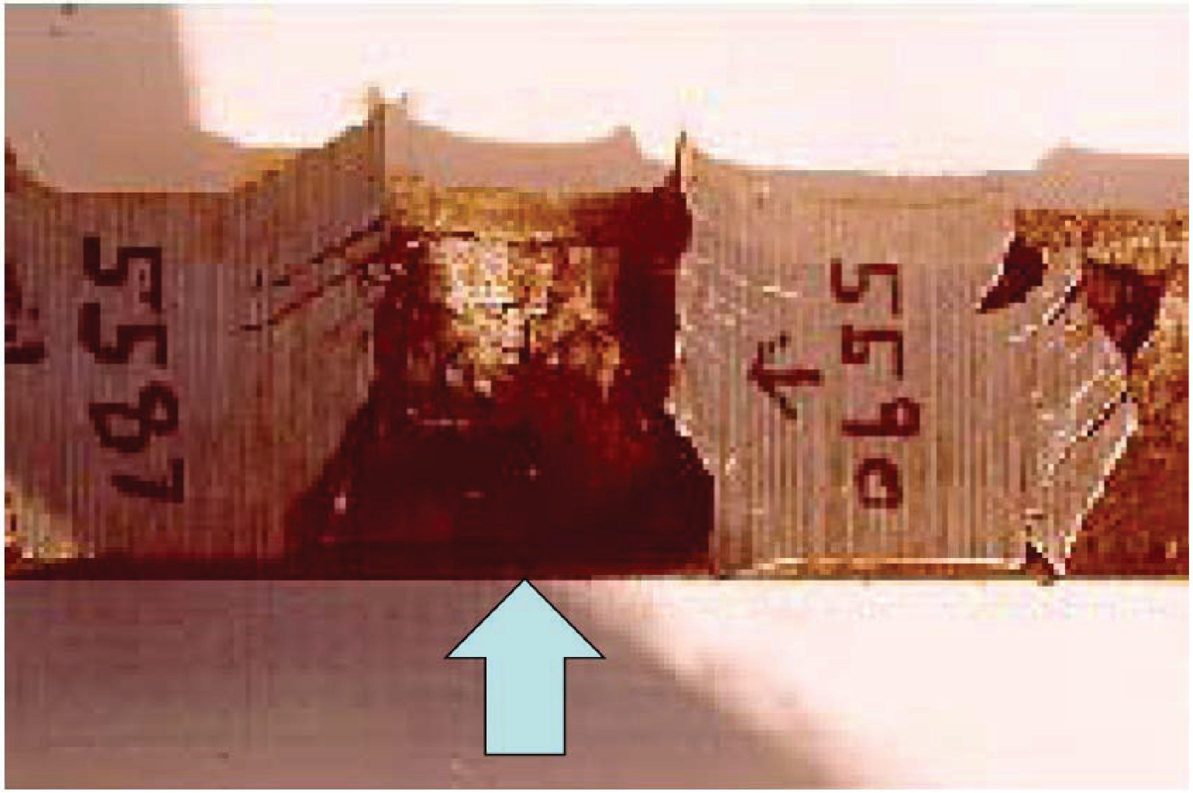
Titanium Laminates/Dual Hard Titanium

Titanium Wrought Plate Bolted to an Aluminum Rear Plate



Dual Hard Titanium Concepts

Emphasis 2
Titanium Dual Hard Armor



CP

Ti-6Al-4V

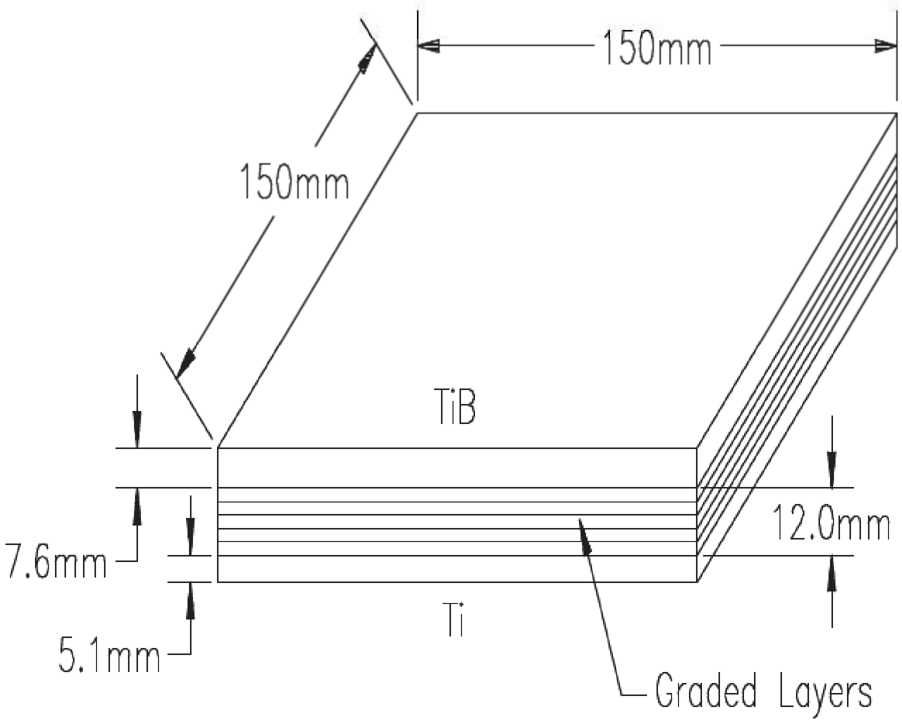
ARL Hot Isostatically Pressed Ti-6Al-4V/CP
Titanium Dual Hard Laminate

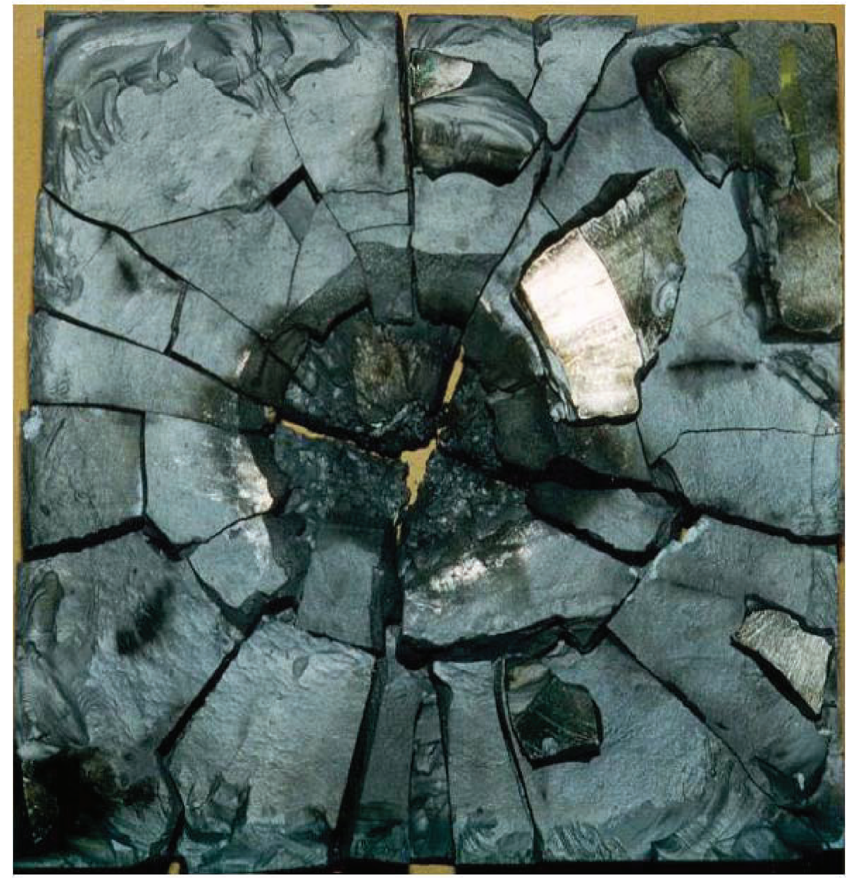
References 26-29 in paper - Dual Hard Titanium reports from 1969-1976

New Potential Applications
Titanium Body Armor Plate

BAE Advanced Materials Hot-Pressed Net Shape Titanium
Double Compound Angle Body Armor Plate

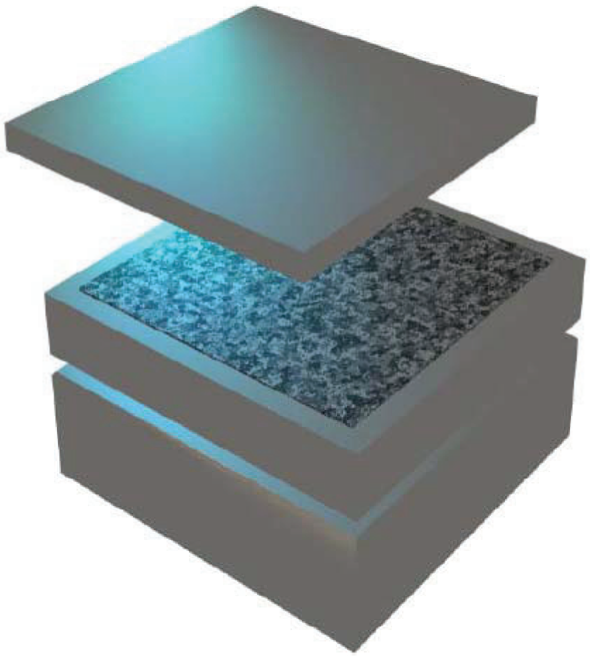
Functionally Graded Titanium Monoboride/Titanium Plate



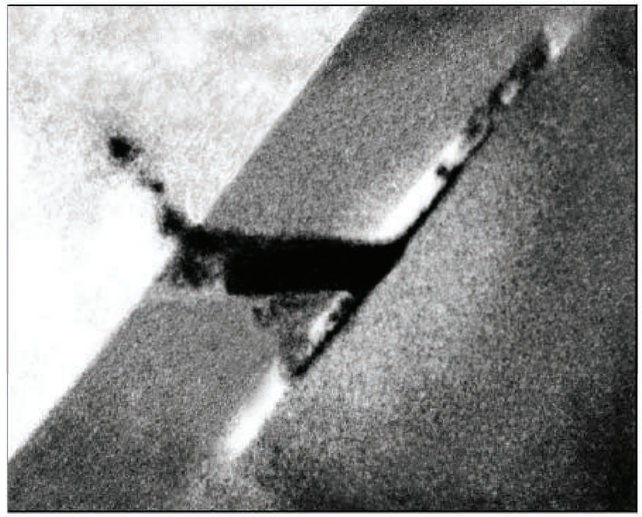


ARL & BAE Advanced Materials

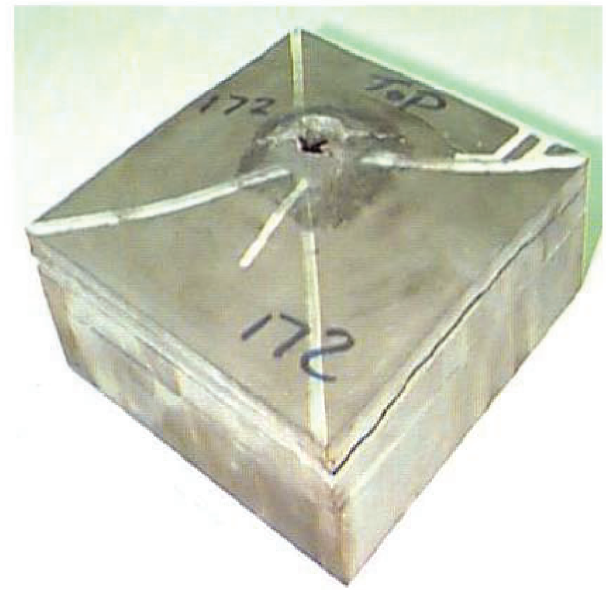
Hot Isostatically Pressed Ceramic in Titanium Matrices



Titanium/Ceramic Preform before HIP

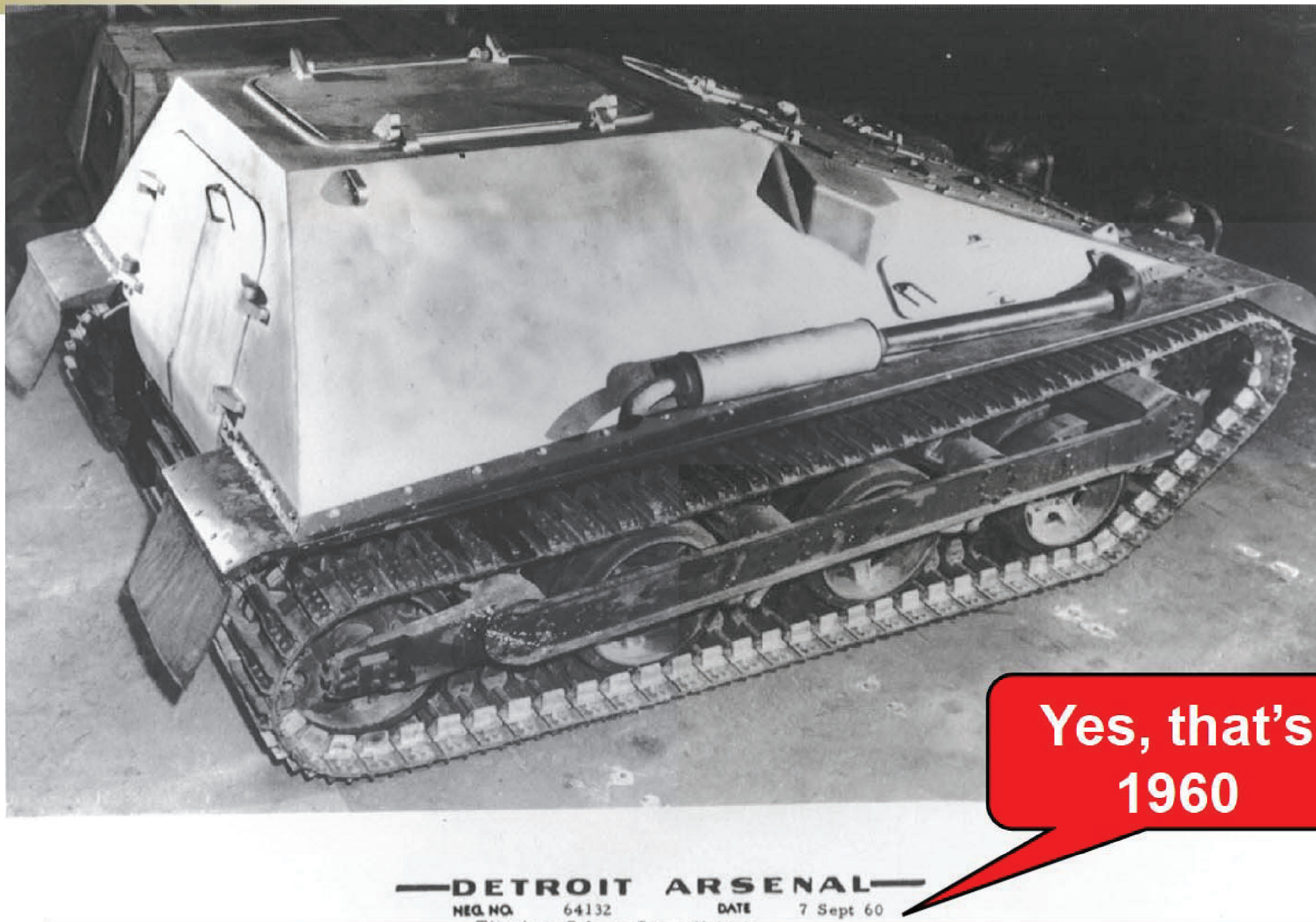


Dwell on Ceramic by Long Rod Penetrator



Post Impact Condition

Titanium Welding

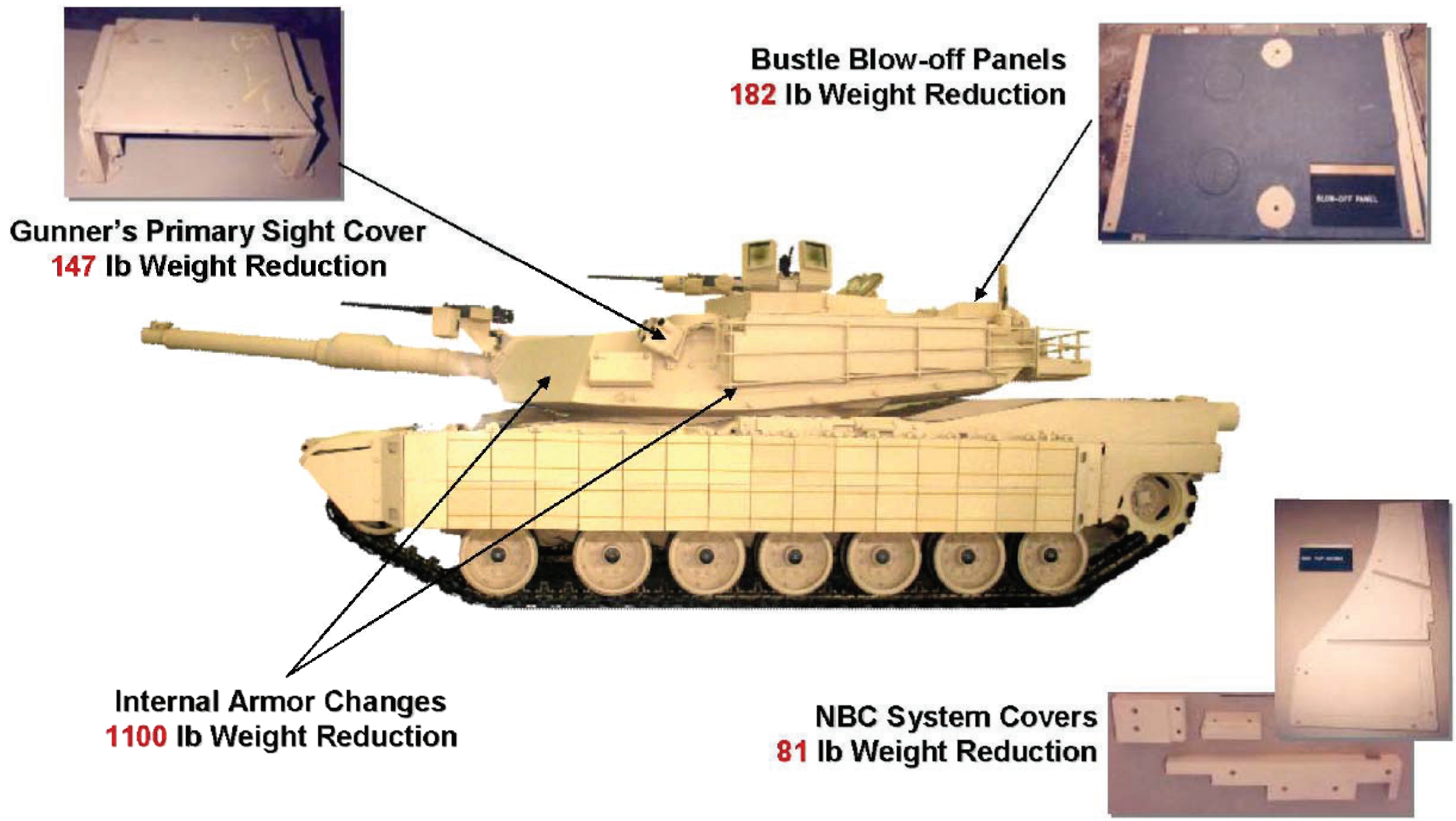


Yes, that's 1960

Titanium Welded Cab on ONTOS Vehicle

Current Applications

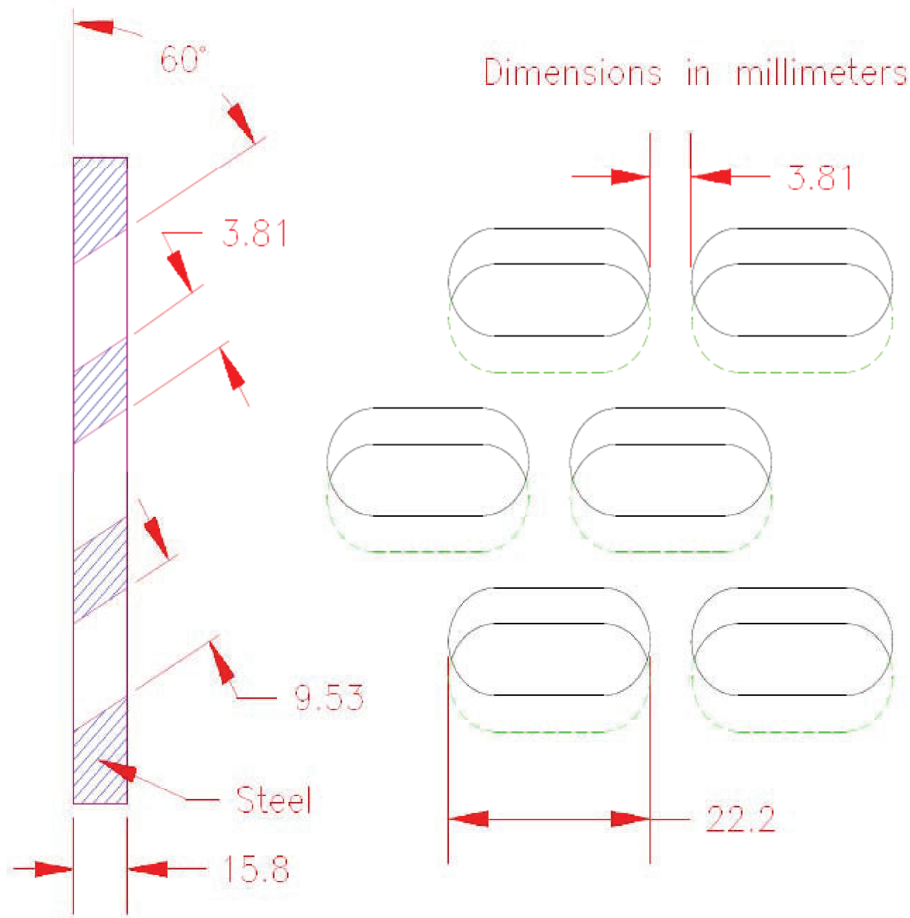
Titanium Weight Reduction Program for M1A2 Abrams Battle Tank



GDLS >1500 lbs weight savings

Forged Commanders Hatch for M2A2 Bradley Fighting Vehicle

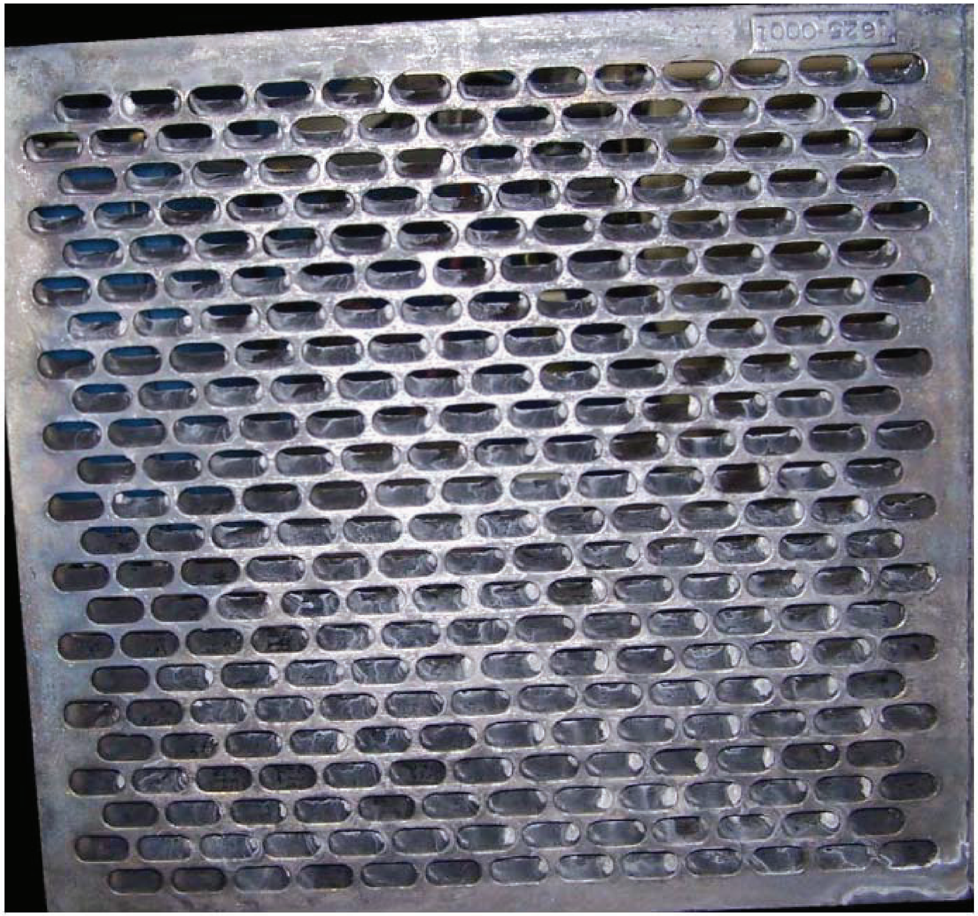
Steel P900 Tipping Plate Armors



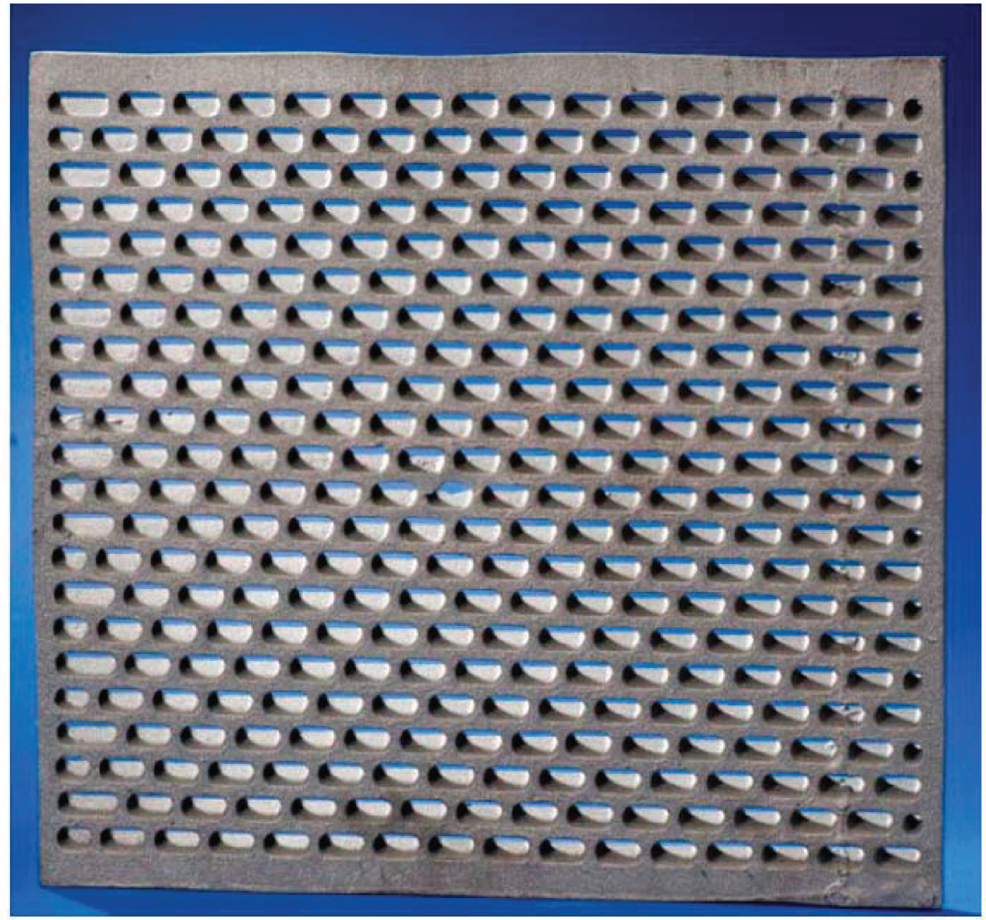
Cast P900 Tipping Plate Armor

X-ray of 14.5-mm Projectile Impacting a Single P900 Plate

New Application
Titanium P900 Armors



Pacific Cast Technologies
Cast P900 Titanium Plate



ATI Wah Chang Cast
P900 Titanium Plate

Current Applications

Ultra-light Weight M777A1 Towed Howitzer
Utilizes Extensive Titanium Castings and Plate

>7000lbs savings over M198

New Applications
Stryker Family of Vehicles

Titanium Commanders Cupola on RV and FSV Stryker Systems

Titanium Gun Pod on Stryker Mobile Protection Gun System

Courtesy – PM Stryker

Prototype Applications

BAE Pegasus Titanium Wheeled Prototype

Courtesy - BAE Santa Clara

Prototype Applications

Future Combat Vehicle Titanium Hull Prototype

BAE/TARDEC/ARL

Conclusions

- This presentation provided a cursory overview of the technical investigation of titanium for military ground applications.
- The written paper has expanded technical detail and references
- The main advantage of titanium relates to its lower density at equal or higher strengths than rolled homogenous armor steel of equal thickness.
- Military Specification MIL-DTL-46077G increased the thickness range and defined Class 3 and 4 alloys that provide equal protection at lower processing costs through increased oxygen levels, greater scrap content, advanced processing technology and reduced alloying.
- The development of Dual Hard titanium offers higher KE performance at equal weight and needs to be re-examined again.

Thank you

EXHIBIT 22

RENEWABLE ENERGY WORLD

New Navy Smart Microgrid Project Will Test Vanadium Flow Battery Storage

The Smart Microgrid project will focus on developing applications and use-case scenarios to optimize power consumption at military bases, college campuses, industrial parks and other institutions, according to the companies.

December 2, 2014

By Andrew Burger
na

California -- The California Energy Commission (CEC) and U.S. Navy (USN) are teaming up to spur deployment of grid-integrated local renewable energy resources and advanced energy storage solutions. On December 1, Imergy Power Systems announced that its ESP30 series vanadium-flow batteries will be used in a CEC-sponsored Smart Microgrid project hosted by the Navy at its Mobile Utilities Support Equipment (MUSE) Facility in Port Hueneme, California.

Foresight Renewable Solutions is responsible for the engineering, design and construction of the USN-MUSE smart microgrid. If all goes well, the demo project will serve as a model for smart microgrid deployments at U.S. military installations and civilian communities in California and beyond.

Scheduled to be tested from Summer 2015 to the end of the year, the smart microgrid demo system will consist of up to 150-kW of solar PV capacity and a 100-kW/400-kWh energy storage solution based on Imergy's ESP30 vanadium-flow batteries, Foresight Renewable Solutions' CEO Carlos Pineda said. The GELI (Growing Energy Labs, Inc.) Energy Operating System (EOS) will manage the smart microgrid's operations.

Foresight was awarded the $1.7-million CEC grant last year, coming out on top among 30 candidates vying for the project award. Matching funds from participants will bring the total budget to $3 million.

“The grant was for newer technologies on the verge of commercial deployment. Imergy's flow battery disaggregates power conversion and energy storage, providing for incremental additions of storage capacity if needed. It also uniquely provides cost-effective bulk energy storage and fast-response ability to enhance power quality," Pineda explained.

Disaggregating Energy Storage and Conversion

The CEC's selection process was extensive, Pineda said, entailing "an extensive review...to determine a strong community partner (including military bases) and the potential for the technology to increase renewable energy penetration."

Lower energy costs and sustainable energy security, reliability and resiliency — not only for the MUSE facility but for electric grid operators — rank at the top of the list of the smart microgrid project's anticipated benefits. As Imergy explained in a press release, "The Smart Microgrid project will focus on developing applications and use-case scenarios to optimize power consumption at military bases, college campuses, industrial parks and other institutions."

Integrated with a solar PV system with generating capacity of as much as 150-kW and the GELI EOS, three Imergy ESP30 series vanadium-flow batteries will comprise the core of the MUSE smart microgrid. Each ESP30 has a 50-kW power/200-kWh energy storage capacity.

Four key attributes will provide the basis for assessing the CEC-USN smart microgrid's performance:

- **Demand charge management**: The project will demonstrate how well the system can release short bursts of energy when demand peaks occur, enabling users to reduce their electricity bills by lowering their utility demand charges;
- **Load shifting**: The project will prove how well the system can shift load from higher cost times of day to lower cost times of day, enabling users to reduce their electricity bills by shifting load to times when electricity prices are lower;
- **Solar firming and ramp rate control**: The project will show how well batteries can smooth out the jagged nature of solar power production, helping solar power systems provide more consistent power throughout the day;
- **Island mode**: The project will demonstrate how well a photovoltaic (PV) solar system and battery storage, disconnected from the grid, can provide energy for a user's critical loads during a given time period, enabling similar systems to be securely deployed at remote, mission critical facilities.

The Battery Technology

According to Dr. Herve Mazzocco, Imergy's director of business development, the company's vanadium-flow batteries are more efficient, flexible and will in short order prove to be more cost-effective than conventional, fossil-fuel grid assets for balancing out fluctuations in grid power demand and supply, particularly as penetration of renewable energy generation assets continues to grow.

Imergy's vanadium-flow battery systems, Mazzocco highlighted, can ramp up or down and pass through full charge-discharge cycles in a matter of milliseconds as compared to minutes for natural gas "peaker" plants, delivering electricity at utility-scale over periods of four, six and even eight hours.

Besides enabling grid operators to integrate more intermittent renewable energy from solar and wind generation assets, these attributes are also of critical importance when it comes to recovering to grid outages and failures — in other words, they can significantly enhance grid resiliency and reliability.

Imergy's vanadium-flow battery technology is also scaleable, Mazzocco said, making it better suited to meet grid-scale needs. Further, the batteries last longer than advanced energy storage solutions based on Li-ion batteries, he said.

The fact that Imergy uses recycled vanadium from environmental waste in manufacturing its advanced battery storage systems adds to the MUSE smart microgrid's advantages and benefits vis-a-vis conventional alternatives. A transition metal, ample supplies of vanadium exist. The majority of vanadium is used in structural steel alloys. It also alloyed with titanium in the manufacture of jet engines and air frames, as well as in alloys used in nuclear reactors.

Integrating Renewables and Enhancing Energy Security, Grid Reliability and Resiliency

Distributing advanced energy storage systems both on the utility and customer sides of the grid could well be the missing piece of the puzzle that accelerates the transition from fossil-fuel to renewable energy-based energy system and “green” economy. Navigant Research predicts that annual global revenues for energy storage systems for the grid and ancillary services will grow from $675 million in 2014 to $15.6 billion in 2024.

California and the U.S. military are at the forefront of a wave of early adopters. Passage of AB2514 in October 2013 requires California's three investor-owned utilities to acquire 1.3 gigawatts (GW) of power storage capacity by 2020.

Renewable energy resources supply 12 percent of the Navy's total annual energy needs at present. That's due to increase to at least 20 percent over the course of the decade. “Microgrids at military bases could help the military lower energy costs, expand their use of renewable energy, and reduce their dependence on diesel and grid connectivity for mission critical assignments,” Imergy highlights in its press release.

The CEC-USN microgrid will be the first field-test of Imergy's ESP30 vanadium-flow battery system in the U.S. Similar installations that entail integrating solar PV and Imergy's vanadium-flow battery system are under way in India and will be up and running before the CEC-Navy microgrid system is operational, Mazzocco said.

Vanadium-flow battery storage technologies such as Imergy's ESP30 address multiple issues grid operators are facing as environmental, industry regulations and market conditions change and greater amounts of renewable energy generation capacity come online, he elaborated.

“To solve these multiple problems you need fast response, large capacities and long lived assets, and that's what we provide. In the end, the bottom line is that we deliver a solution that is safe, that lasts long, that is affordable and compares favorably to traditional fossil fuel-based grid assets.”

Lead image: Lighthouse at Port Hueneme, California via Shutterstock

EXHIBIT 23

MENU

New device hides, on cue, from infrared cameras

Tunable material developed at Harvard boasts nearly 100% absorption on demand

November 26, 2012

Cambridge, Mass. - November 26, 2012 - Now you see it, now you don't.

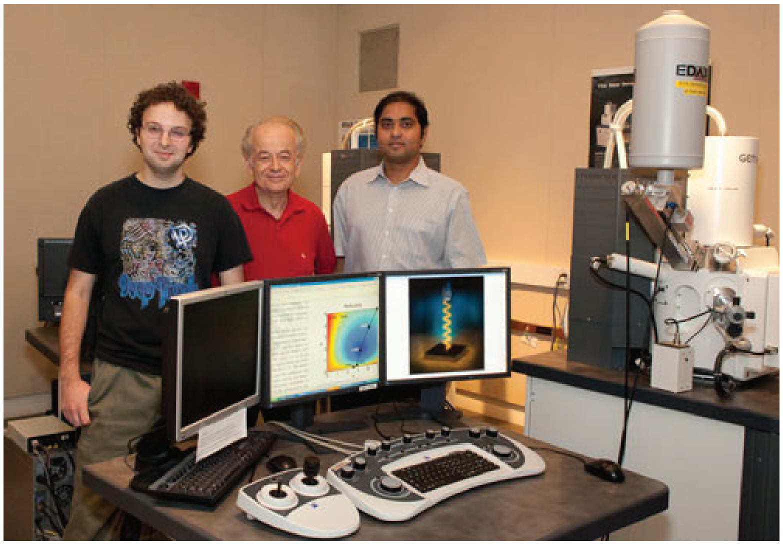
A new device invented at the Harvard School of Engineering and Applied Sciences (SEAS) can absorb 99.75% of infrared light that shines on it. When activated, it appears black to infrared cameras.

Composed of just a 180-nanometer-thick layer of vanadium dioxide (VO_2) on top of a sheet of sapphire, the device reacts to temperature changes by reflecting dramatically more or less infrared light.

Announced today in the journal ***Applied Physics Letters***, and featured on its cover, this perfect absorber is ultrathin, tunable, and exceptionally well suited for use in a range of infrared optical devices.

Perfect absorbers have been created many times before, but not with such versatile properties. In a Fabry-Pérot cavity, for instance, two mirrors sandwich an absorbing material, and light simply reflects light back and forth until it's mostly all gone. Other devices incorporate surfaces with nanoscale metallic patterns that trap and eventually absorb the light.

"Our structure uses a highly unusual approach, with better results," says principal investigator **Federico Capasso**, Robert L. Wallace Professor of Applied Physics and Vinton Hayes Senior Research Fellow in Electrical Engineering at SEAS. "We exploit a kind of naturally disordered metamaterial, along with thin-film interference effects, to achieve one of the highest absorption rates we've ever seen. Yet our perfect absorber is structurally simpler than anything tried before, which is important for many device applications."



Mikhail Kats, Federico Capasso, and Shriram Ramanathan used unusualmaterials and interference effects to create a perfect absorber. They are pictured here in a scanning electron microscopy imaging suite at the Harvard Center for Nanoscale Systems. (Photoby Caroline Perry, SEAS Communications.)

With collaborators at Harvard and at the University of California, San Diego, Capasso's research group took advantage of surprising properties in both of the materials they used.

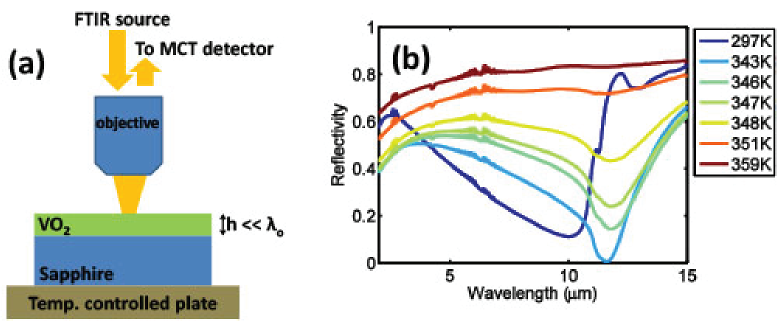
Vanadium dioxide is normally an insulating material, meaning that it does not conduct electricity well. Take it from room temperature up to about 68 degrees Celsius, however, and it undergoes a dramatic transition. The crystal quickly rearranges itself as the temperature approaches a critical value. Metallic islands appear as specks, scattered throughout the material, with more and more appearing until it has become uniformly metallic.

“Right near this insulator-to-metal transition, you have a very interesting mixed medium, made up of both insulating and metallic phases,” says coauthor **Shriram Ramanathan**, Associate Professor of Materials Science at SEAS, who synthesized the thin film. “It’s a very complex and rich microstructure in terms of its electronic properties, and it has very unusual optical properties.”

Those properties, when manipulated correctly, happen to be ideal for infrared absorption.

Meanwhile, the underlying sapphire substrate has a secret of its own. Usually transparent, its crystal structure actually makes it opaque and reflective, like a metal, to a narrow subset of infrared wavelengths.

The result is a combination of materials that internally reflects and devours incident infrared light.



Left: This diagram shows the experimental setup used for measuring the reflectivity of the vanadium-sapphire device. The vanadium oxide layer is only 180 nanometers thick, much thinner than the wavelength of the incident infrared light. *Right*: At just the right temperature (light blue line), the reflectivity of the device drops almost to zero (99.75% absorbance) for infrared light at a wavelength of 11.6 microns. (Illustrations courtesy of Mikhail Kats.)

"Both of these materials have lots of optical losses, and we've demonstrated that when light reflects between lossy materials, instead of transparent or highly reflective ones, you get strange interface reflections," explains lead author Mikhail Kats, a graduate student at SEAS. "When you combine all of those resulting waves, you can coax them to destructively interfere and completely cancel out. The net effect is that a film one hundred times thinner than the wavelength of the incident light can create perfect absorption."

The challenge for Capasso, Ramanathan, Kats, and their colleagues was not only to understand this behavior, but also to learn how to fabricate pure enough samples of the vanadium dioxide.

“Vanadium oxide can exist in many oxidation states, and only if you have VO_2 does it go through a metal-insulator transition close to room temperature,” Ramanathan explains. “We have developed several techniques in our lab to allow exquisite compositional and structural control, almost at the atomic scale, to grow such complex films. The resulting phase purity allows us to see these remarkable properties, which otherwise would be very difficult to observe.”

Because the device can be easily switched between its absorbent and non-absorbent states, thepossible applications are quite wide ranging and include bolometers (thermal imaging devices) with tunable absorption, spectroscopy devices, tunable filters, thermal emitters, radiation detectors, and equipment for energy harvesting.

“An ideal bolometer design needs to absorb all of the infrared light that falls on it, turning it to heat, and correspondingly its resistance should change a lot per degree change in temperature,” notes Kats. “In principle, our new perfect absorber could be used to make incredibly sensitive thermal cameras.”

Harvard's **Office of Technology Development** has filed patent applications on the novel invention and is actively pursuing licensing and commercialization opportunities.

###

This work was supported in part by the Defense Advanced Research Projects Agency (DARPA). The researchers were also supported by a graduate research fellowship from the National Science Foundation; the Agency for Science, Technology, and Research in Singapore; the Office of Naval Research; the Jeffress Memorial Trust; and the Air Force Office of Scientific Research.

Additional coauthors include **Dmitri Basov**, a physics professor at UCSD; postdoctoral fellow Patrice Genevet and graduate student Romain Blanchard, at Harvard; Deepika Sharma, a former visiting student at Harvard; Jiao Lin and Zheng Yang, former postdoctoral fellows at Harvard; and M. Mumtaz Qazilbash, a former postdoctoral fellow at UCSD.

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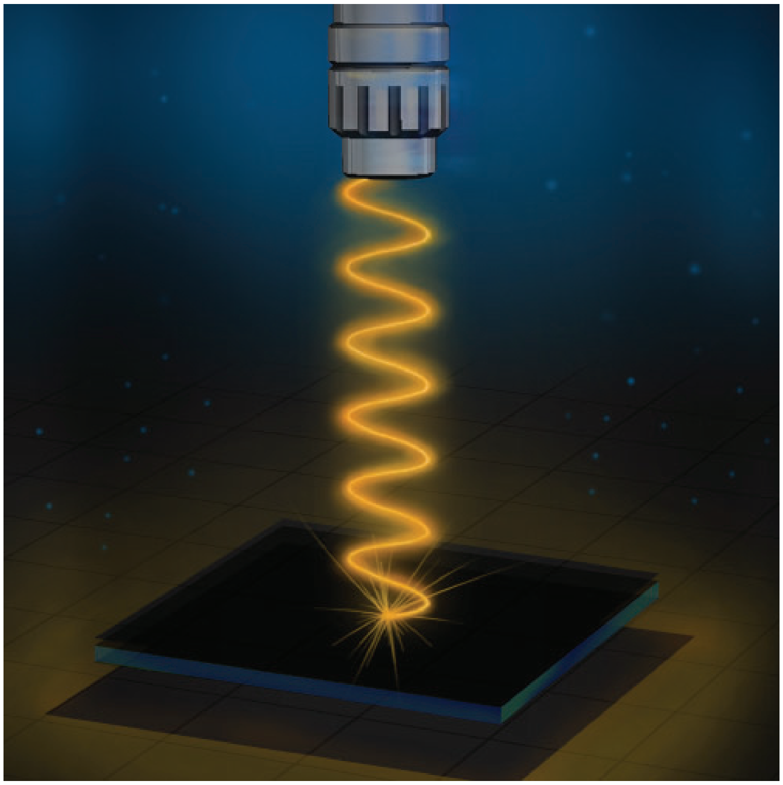

Artist's rendition of the experimental setup used to measure the reflectivity of the vanadium-sapphire device. (Modified from an illustration by Kirill Nadtochiy.)

PRESS CONTACT

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RECENT NEWS

EXHIBIT 24

EVRAZ NIKOM

Mníšek pod Brdy, Czech Republic

EVRAZ Nikom is engaged in production of ferroalloys and corundum material. It converts the vanadium oxide produced by Vanady Tula into ferrovanadium, the major vanadium product used by the steel industry to increase strength and hardness. EVRAZ Nikom manages to produce about 4,600 metric tons of ferrovanadium per year that are shipped to steelmakers globally.

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Vanadium

- EVRAZ Vanady Tula (/facilities/evraz-vanady-tula/)
- EVRAZ Stratcor (/facilities/evraz-stratcor/)
- EVRAZ Nikom

EXHIBIT 25

2014 HISTORICAL FERROVANDIUM IMPORTS FOLLOWING SUNSET OF RUSSIAN ANTIDUMPING ORDER

CALCULATION OF RUSSIAN AND CZECH REPUBLIC 2014 FERROVANADIUM U.S. IMPORT QUANTITIES AS CLASSIFIED UNDER TARIFF CODE 7202.92.00

Imports For Consumption | Monthly data for 2014

Country	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Czech Republic	component pounds	354,364	305,031	396,100	266,946	216,657	425,842	319,110	284,176	246,506	354,926	170,652	343,168	3,683,477
Canada	component pounds	190,124	115,187	175,470	190,327	69,269	141,190	186,460	208,449	102,023	238,227	160,889	139,716	1,917,332
South Korea	component pounds	-	52,704	236,199	171,006	64,086	169,716	174,617	-	109,473	75,211	156,312	33,841	1,243,163
Austria	component pounds	154,070	-	64,084	164,665	43,074	42,086	26,940	43,883	108,787	40,660	115,866	57,166	861,281
Japan	component pounds	19,762	20,199	20,477	20,704	20,318	20,040	20,040	20,199	20,040	20,437	33,949	-	236,163
Australia	component pounds	35,265	-	-	-	-	-	-	35,902	19,220	-	60,351	-	150,739
Russia	component pounds	35,400	17,639	35,545	-	-	-	-	-	35,671	8,920	-	-	133,174
South Africa	component pounds	-	-	10,697	-	-	-	-	-	-	-	-	-	10,697
Singapore	component pounds	-	-	-	-	-	-	-	-	-	4,414	-	-	4,414
Germany	component pounds	-	295	-	-	-	882	-	-	-	-	-	-	1,177
Total	component pounds	788,985	511,055	938,571	813,648	413,404	799,757	727,167	592,608	641,719	742,793	698,019	573,891	8,241,617
Russia and Czech Republic														3,816,652

Country	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Czech Republic	Customs Value	3,321,855	3,056,954	4,073,002	2,932,843	2,421,774	4,711,192	3,560,898	3,076,217	2,668,438	3,842,092	1,847,314	3,714,819	39,227,398
Canada	Customs Value	2,334,673	1,495,723	2,172,413	2,342,633	899,922	1,918,852	2,109,571	2,692,144	1,361,191	2,893,874	1,996,022	1,635,478	23,852,496
South Korea	Customs Value	-	590,694	2,692,729	1,989,269	767,588	2,011,113	2,043,569	-	1,245,090	843,490	1,743,131	383,859	14,310,532
Austria	Customs Value	1,650,779	-	777,356	1,950,161	886,398	866,076	554,443	559,211	1,691,250	467,805	1,292,423	674,236	11,370,138
Japan	Customs Value	208,318	214,472	219,148	213,129	214,008	221,573	227,118	222,077	208,120	220,291	212,078	-	2,380,332
Australia	Customs Value	407,938	-	-	-	-	-	-	447,827	226,675	-	698,046	-	1,780,486
Russia	Customs Value	399,813	204,815	412,747	-	-	-	-	-	401,634	102,364	-	-	1,521,373
South Africa	Customs Value	-	-	123,261	-	-	-	-	-	-	-	-	-	123,261
Singapore	Customs Value	-	-	-	-	-	-	-	-	-	45,022	-	-	45,022
Germany	Customs Value	-	16,439	-	-	-	25,298	-	-	-	-	-	-	41,737
Total	Customs Value	8,323,376	5,579,097	10,470,656	9,428,035	5,189,690	9,754,104	8,495,599	6,997,476	7,802,398	8,414,938	7,789,014	6,408,392	94,652,775
Russia and Czech Republic														40,748,771

Country	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Czech Republic	US$/component pound	9.37	10.02	10.28	10.99	11.18	11.06	11.16	10.83	10.83	10.83	10.83	10.83	10.65
Canada	US$/component pound	12.28	12.99	12.38	12.31	12.99	13.59	11.31	12.92	13.34	12.15	12.41	11.71	12.44
South Korea	US$/component pound	-	11.21	11.40	11.63	11.98	11.85	11.70	-	11.37	11.22	11.15	11.34	11.51
Austria	US$/component pound	10.71	-	12.13	11.84	20.58	20.58	20.58	12.74	15.55	11.51	11.15	11.79	13.20
Japan	US$/component pound	10.54	10.62	10.70	10.29	10.53	11.06	11.33	10.99	10.39	10.78	6.25	-	10.08
Australia	US$/component pound	11.57	-	-	-	-	-	-	12.47	11.79	-	11.57	-	11.81
Russia	US$/component pound	11.29	11.61	11.61	-	-	-	-	-	11.26	11.48	-	-	11.42
South Africa	US$/component pound	-	-	11.52	-	-	-	-	-	-	-	-	-	11.52
Singapore	US$/component pound	-	-	-	-	-	-	-	-	-	10.20	-	-	10.20
Germany	US$/component pound	-	55.65	-	-	-	28.69	-	-	-	-	-	-	35.45
Total	US$/component pound	10.55	10.92	11.16	11.59	12.55	12.20	11.68	11.81	12.16	11.33	11.16	11.17	11.48

Source: USITC Dataweb HTS Nos.7202.92.00

Note, August 2014 Czech Republic per unit import amount used to estimate the September through December 2017 Czech Republic import quantities.

EXHIBIT 26

VANADIUM IMPORT STATISTICS

IMPORT VOLUME

Product	Unit (Pounds)	HTS	2016	2017	2018	Jan. - July 2018	Jan. - July 2019	Annualized 2019
Ferrovanadium (1)	Contained Vanadium	7202.92.00	6,065,505	7,744,884	8,004,046	4,439,592	4,334,232	7,430,111
Vanadium Carbonitrides (2)								
South Africa	Contained Vanadium	2849.90.50	3,191,246	3,213,258	2,750,396	1,574,947	1,893,354	3,245,750
China	Contained Vanadium	2849.90.50	131,538	196,865	266,100	134,241	86,876	148,930
Vanadium Oxides (V2O3 & V2O5)	Contained Vanadium	2825.30.00	6,886,893	7,826,632	10,364,979	6,299,688	5,316,479	9,113,963
Vanadates	Contained Vanadium	2841.90.10	689,466	769,867	857,690	431,363	119,149	204,255
Total All Products			**16,964,648**	**19,751,507**	**22,243,211**	**12,879,831**	**11,750,089**	**20,143,010**
Percent Volume Increase/(Decrease)					**31%**			

(1) Suppressed Czech Republic volume amounts are estimated based upon average unit value of imports from Canada, Austria and Russia.
(2) Contained vanadium amount assumed to be 78 percent of shipment weight.

IMPORT VALUE (CIF)

Ferrovanadium	US Dollars	7202.92.00	48,580,993	95,903,726	231,457,718	114,149,480	123,214,109	211,224,187
Vanadium Carbonitrides								
South Africa - Nitrovan	US Dollars	2849.90.50	22,845,457	39,126,916	78,149,025	34,530,641	77,547,257	132,938,155
China - Vanadium Carbonitrides	US Dollars	2849.90.50	4,315,310	6,241,394	9,373,064	4,645,146	2,605,878	4,467,219
Vanadium Oxides	US Dollars	2825.30.00	36,005,144	64,525,616	176,951,239	92,891,898	86,126,175	147,644,871
Vanadates	US Dollars	2841.90.10	4,522,689	6,338,674	17,623,649	7,869,589	2,712,238	4,649,551
Total			**116,269,593**	**212,136,326**	**513,554,695**	**254,086,754**	**292,205,657**	**500,923,983**
Percent Value Increase/(Decrease)					**342%**			

Source: USITC Dataweb.

EXHIBIT 27

ENTIRE EXHIBIT NOT SUSCEPTIBLE TO PUBLIC SUMMARY

EXHIBIT 28

ENTIRE EXHIBIT NOT SUSCEPTIBLE TO PUBLIC SUMMARY

EXHIBIT 29

ENTIRE EXHIBIT NOT SUSCEPTIBLE TO PUBLIC SUMMARY

EXHIBIT 30

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Environmental regulation and competitiveness in the mining industry: Permitting processes with special focus on Finland, Sweden and Russia ☆

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ABSTRACT

This paper investigates to what extent and under what circumstances environmental regulation can be designed and implemented to jointly achieve positive environmental outcomes and sustained competitive strength in the mining industry. First the paper provides a conceptual analysis of the impacts of environmental regulations on mining competitiveness, including a discussion of how the environmental-competitiveness trade-off can be affected by various regulatory design and implementation strategies. Methodologically we distinguish between the flexibility, predictability and stringency of the regulations, and in a second step these analytical concepts are illustrated in the empirical context of the environmental permitting processes in Finland, Sweden and Russia. An important result is that in these countries there has been a lack of timeliness and predictability in the environmental regulations (e.g., uncertainty about the interpretation of the legislation, delays due to appeals etc.). These problems can in part be addressed by, for instance: (a) allocating more resources to the regulatory authorities; (b) establishing more consensus-based regulatory interactions between the mining industry and the authorities; and (c) introducing more standardized procedures and road maps for environmental impact assessments, permit applications and not the least for how to interpret specific legal rules in the context of mining.

Introduction

Background and motivation

This paper addresses the relationship between environmental regulation and competitiveness in the mining industry. Mining poses significant environmental challenges. It generates large volumes of, for instance, waste rock, tailings, acid mine drainage, airborne dust and other contaminants, which are deposited on land and in the air and water. For these reasons mining is the focus of increasingly stringent environmental regulations. Still, while environmental impact assessments and permits are needed to address any negative impacts, and promote the adoption of environmentally benign production processes, these regulations may also increase the time, costs and risks associated with opening and operating mines. In this sense there appears to exist a trade-off in that while it is important to control pollution from mining operations, such regulations may also lead to less mining investments, pollution leakage (i.e., increased emissions abroad) and lost employment opportunities to the local and regional economy. This paper argues, though, that in many instances this trade-off is complex and highly dependent on the specific design and implementation of the regulations.

Previous research on mining competitiveness and environmental regulations tends to suggest that the geological potential and overall political stability of host countries rank higher than environmental regulations (as well as other mineral policies) when companies are deciding on the location of exploration activities and mining development investment (e.g., Johnson, 1990; Wilkerson, 2010; Tole and Koop, 2011). Still, the majority of this previous work primarily addresses the overall impacts and/or the stringency of the regulations (e.g., comparing specific emission performance standards etc.), while less attention has been paid to the ways in which the environmental permitting processes—and the associated legal rules

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* Corresponding author.

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0301-4207/

—have been designed, interpreted and implemented in practice (see further *Previous research on mining competitiveness and environmental policy*). Other social science research on industrial pollution control has shown that a number of regulatory design issues could significantly influence the companies' prospects for complying with stringent environmental regulations while at the same time avoiding significant negative impacts on the competitiveness of the industry.

These issues concern, for instance, the flexibility granted to the industry in terms of selecting the appropriate compliance measures as well as the time granted to adapt the new requirements (e.g., Bergquist et al., 2013). Different regulatory approaches also differ in the sense that some rely on cooperation and consensus between the relevant authorities and industry, while others tend to be based on more conflict-ridden frameworks (e.g., Lundqvist, 1980; Löfstedt and Vogel, 2001). Environmental permitting processes are typically based on case-by-case assessments of new mines and/or production expansions at existing ones; the outcomes of these processes may therefore be highly dependent on, for instance, interpretations of the legal rules, timely regulatory decisions as well as on the regulators' competence concerning technological solutions and their costs. Such factors will influence the outcomes of the permitting process both in terms of the decision whether or not to allow mine development, and regarding the specific requirements of the granted permit. Any uncertainties associated with the process will in turn affect the risks faced by companies prior to investment.

The importance of the design and implementation of environmental regulations for the mining industry's costs, risks and profitability is evident when considering the expressed concerns of mining professionals. While the critique sometimes concerns the stringency of the regulations (i.e., permit requirements that are perceived to impose excessive costs following changes in the production process), it is more often pointing towards a lack of timely and predictable decision-making processes. For instance, in Sweden the mining permitting process has been claimed to be unpredictable, subjective, too slow, and in lack of coordination across different regulatory authorities (e.g., Aaro et al., 2012). In the USA and Canada mining managers and professionals have raised concerns that more stringent environmental regulations (e.g., the greenhouse gas regulations in California) in combination with permitting delays could induce the industry to start operations in developing countries (e.g., PwC, 2012; Cervantes et al., 2013; Wyatt and McCurdy, 2013).

The above suggests that there is no simple and straightforward environment-competitiveness trade-off, and that there may be scope for achieving more favorable environmental outcomes without jeopardizing the industry's competitiveness through different policy designs and implementation strategies. In this paper we address this challenge both conceptually but also by examining the permitting processes of mining operations in Finland and Sweden, in part also referring to experiences from the Russian mining sector.

Objectives and scope

The overall objective of this paper is to investigate to what extent and under what circumstances industrial pollution regulations can be designed to jointly achieve positive environmental outcomes as well as sustained competitive strength in the mining industry. Specifically, the paper provides:

- An analytical framework addressing the impacts of environmental regulations on the mining sector's competitiveness, and how the environment-competitiveness trade-off can be affected by various regulatory design and implementation strategies.
- An empirical illustration of how this framework can be employed in the empirical context of the environmental permitting processes—and the resulting pollution control requirements—in Finland, Sweden and Russia.

Mining companies are affected by several types of environmental regulations (Eggert, 1994), but in this paper we primarily focus on the pollution control requirements stipulated under the permitting conditions for new mines and/or for production expansions at existing mines. This also means that little explicit attention is devoted to, for instance, the issuance of concession permits and the regulation of land use issues (see Williams (2012) and Tiess (2011) for recent reviews). In addition, we also do not address the competitiveness impacts of different market-based policy instruments, such as various pollution charges and the European Union's Emissions Trading Scheme (EU ETS).

Tiess (2011) emphasizes the importance of exchange of experiences of mining regulation between different countries, and our choice of case countries should be of interest for several reasons. First, together Finland, Sweden and Russia are important suppliers of both non-ferrous minerals and iron ore, especially in a European context. For instance, over 90% of the European Union's production of iron ore stems from Sweden. In all three countries the interest in continued mining development has been high during the recent decade due to elevated price levels. Second, though, surveys of mining professionals and managers show that these actors' perception of the investment environment—including the uncertainties surrounding the environmental regulations—differ significantly across Sweden and Finland on the one hand and Russia on the other. For instance, both Sweden and Finland are at the top of the Fraser Institute's ranking of mining countries, while Russia is not perceived to offer particularly stable regulatory conditions for mining companies (Wilson and Cervantes, 2014). This is in part illustrated in Fig. 1 showing the impact of environmental regulation uncertainty (e.g., the stability of regulations, the consistency and timeliness of the regulatory processes, and whether regulations appear to be based on scientific knowledge or not) on investment propensity in the three countries.

Third, even though Finland and Sweden both offer relatively stable environmental regulations from the perspective of global mining representatives and also have fairly similar permitting processes, our analyses will show that some design features differ. Some of these features are potentially important from a competitiveness point-of-view. Interesting changes have also occurred in the environmental permitting processes over time, and in the empirical analysis we address a number of important characteristics of the Swedish regulatory approach during the 1970s and 1980s. This approach was in large based on a policy–style seeking cooperation

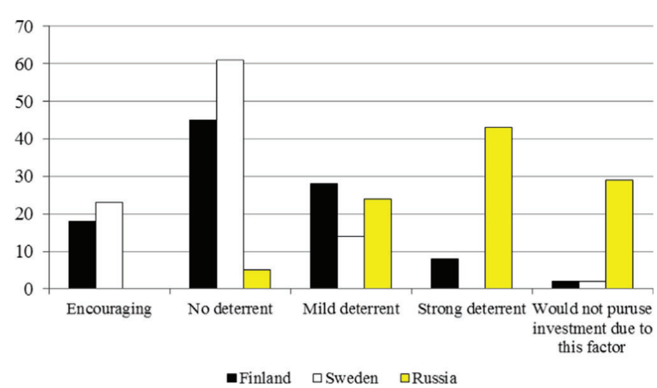

Fig. 1. Mining companies' view on the uncertainty concerning environmental regulation (percentage shares of the respondents). Source: Wilson and Cervantes (2014).

and consensus between the regulators and the industry (e.g., Lundqvist, 1980). For instance, the experiences demonstrate the importance of flexible standards for emissions coupled with often extended compliance periods, and taking into account parameters such as local environmental impacts, potential for technological innovation as well as long-term competitiveness. During this regulatory era the emissions of a large number of pollutants (e.g., sulfur, COD, heavy metals etc.) were radically reduced in Swedish industry, without however significantly compromising its competitiveness (e.g., Bergquist et al., 2013; Söderholm and Bergquist, 2013).

Methodological approach and empirical material

Based on a review of the existing empirical literature and on a conceptual analysis of the environment-competitiveness trade-off, we develop a simple analytical framework that can be used to investigate three important features of the environmental permitting process. These include: (a) the predictability and timeliness of the regulatory decision-making process from the perspective of prospective investors; (b) the compliance flexibility in terms of required pollution reduction measures and the time granted to comply with these; and (c) the stringency of the permit conditions (e.g., emission standards), including how these may be tightened over time. In a second step these three analytical concepts are illustrated and exemplified in the empirical context of the environmental permitting processes—and the resulting pollution control requirements—in Finland, Sweden and Russia. This provides an opportunity to learn from both good and bad experiences.

In large the analysis relies on an investor eye-view of the legal rules; it employs both case law and analytical jurisprudence for determining the content and function of the law. This also includes analyses of specific mining permitting processes in the three countries. In addition, we rely on secondary sources, including reports by company representatives (e.g., Granberg, 2013), as well as personal interviews with companies that have applied (or are about to apply) for a permit. The analysis of the early Swedish permitting process relies on permitting process documents held at the archives of the County Administrative Board and the National Archive of Sweden. This material is rich in the sense that it contains: (a) the permit application of the individual company, including detailed technical descriptions; (b) reports and decisions from the relevant authorities; (c) accounts of the negotiations between the authorities and the individual company during the assessment process; and (d) subsequent reports over related tests (of various pollution abatement methods) and the nature of the regulatory requirements.

Outline of paper

The paper proceeds as follows. In the next section we briefly review the empirical literature on the relationship between environmental regulation and competitiveness in the mining industry, and discuss how this paper contributes to this literature stream. *Theoretical remarks and analytical framework* provides a simple analytical framework addressing the impact of environmental regulation on mining competitiveness. Most importantly, it identifies and discusses a number of factors that will affect this relationship and the trade-offs involved. The next section provides a brief background to the environmental regulation systems in Finland, Sweden and Russia. *The environment-competitiveness challenge in mining permitting cases* reports our findings from illustrating the stringency, predictability and flexibility of these countries' environmental permitting processes, including examples from past and present mining cases. Finally, A final section provides a number of concluding remarks as well as some avenues for future research.

Previous research on mining competitiveness and environmental policy

The empirical literature on the relationship between environmental regulation and mining competitiveness tends to define competitiveness as the capacity of regions and countries to attract investment in new and/or expanded mining operations. The key question has thus been to what extent the environmental regulations (e.g., including the conditions of the permits) have affected the expected costs and revenues of mining investment, and in turn the willingness to invest in new mining ventures across the world (e.g., Tole and Koop, 2011; Rémy, 2003; Wilkerson, 2010). Often the focus has been on key differences among developed versus developing countries.

Mining investment and environmental regulation: results from the literature

Overall the empirical research on mining investment and environmental regulations shows that geological potential and political stability are the most important factors determining the locational choice of mining companies. Mineral policies also matter, although in general environmental regulations have not constituted a major impediment to investment. This was shown already by Peck et al. (1992) who surveyed 32 multi-national mining companies. Similar results have been obtained in more recent research. Wilkerson (2010), McNamara (2009) Annandale and Taplin (2003) also highlight the role of political stability. For instance, Wilkerson (2010) argues that mining companies tend to locate in countries where government functions in a stable and smooth way, thus providing a safe business climate. Moreover, Tole and Koop (2011) use a dataset going back to 1975 in order to analyze where the world's largest gold mining companies have chosen to locate new mines, and whether the stringency of environmental regulations has affected this decision. The authors show, using econometric techniques, that gold mining companies have tended to locate in regions close to their head offices and in regions where corruption levels are low. These companies prefer to locate in regions that can offer a low-risk, secure, transparent and stable business environment. In other words, rather than seeking out countries where environmental regulation is lax, mining firms are primarily searching for countries that provide an overall stable government.

At the same time the politically stable countries also tend to be those with the strictest environmental regulations. Thus, although environmental legislation may act as an impediment to exploration in some regions and can entail delays of the start-up process, the largest mining companies tend to be subject to environmental regulation practically in all places they choose to locate their mining operations. For this reason one is unlikely to detect a close negative empirical relationship between environmental regulation stringency and mining investment.

A number of empirical studies investigate and comment on this relationship in more detail. Annandale and Taplin (2003) address the effect of environmental permitting processes on proposed mine development projects internationally, and they present the results of a survey among 200 mining company executives in Australia and Canada. The responses indicate that a substantive majority of mining companies do not perceive the environmental permitting process as an impediment to investment and it may even encourage investment activity. This was particularly the case among the Australian companies, while the Canadian executives overall expressed more concern over the negative impacts of the permitting process. Tole and Koop (2011) report similar results following their econometric analysis of the locational choice of multi-national gold mining companies. Specifically, they show that strict environmental regulation did not affect the location decisions and it could even attract investment. This is reflected in the fact that gold mining firms seem to be more inclined to invest in regions with a clean environment, although their results are less robust for this finding.

Rather than being intimidated by strict environmental regulation, mining companies may be looking for it, or at least for the factors that the existence of such regulation represent, such as stable political and legal institutions.[1] Companies prefer to commence operations in countries where the environmental regulatory framework is clear and consistent as well as non-discretionary (see also Rémy, 2003). The role of regulatory stability is further accentuated in the Fraser Institute's annual assessment of the attractiveness of different mining nations for investment. In these assessments mining professionals are asked to evaluate how uncertainty regarding environmental regulations (e.g., the stability of the regulations, the consistency and timeliness of the regulatory processes, whether regulations appear to be based on science or not, etc.) affects their willingness to invest in different regions or countries. This assessment shows, for instance, that in developed countries environmental regulations are generally less of a deterrent to investment than is the case in the developed world.

Regulatory stability is particularly important for mining given the cyclical nature of minerals markets with widely fluctuating output prices, thus providing narrow investment 'windows' and forcing a certain time table for new investments. Results from the Behre Dolbear Group's annual assessment of the performance of different mining countries add to this picture (Wyatt and McCurdy, 2013). One of the factors that they consider is the average time it takes to obtain a permit decision. According to Wyatt and McCurdy (2013) delays in the permitting process are a global problem, and it will be affected by, for instance, requirements for public consultation, adversarial trials and opposition and intervention by various stakeholder groups and NGOs. For instance, in parts of the USA delays in the permitting process have posed a substantive risk to mining operations, and lead times of 7–10 years before new mines can start operating are common.

Most previous research, though, do not 'decompose' the environmental regulatory framework in order to separate between, for instance, the stringency of the imposed permit conditions (e.g., performance standards) on the one hand and other design and implementation features on the other. The latter includes, for instance, the uncertainties created by the lack of timeliness in the regulatory decision-making process. Previous research also lacks a set of comparative studies of regulatory design and implementation in different countries.

A contributing explanation for the non-existent (and sometimes even positive) relationship between environmental regulation and mining development is that differences in compliance costs across countries may be relatively unimportant to the multi-national mining companies since these companies tend to adopt the same technological and environmental standards independent of where they choose to operate. This is in turn due to a number of factors, including that: (a) the most modern and cost-effective mining processes are generally the most environmentally friendly ones; (b) environmental standards are becoming stricter worldwide, it thus makes sense for the industry to adopt strict environmental standards early on, rather than having to readjust later on; and (c) international mining companies are exposed to scrutiny and pressure from the public, banks and the shareholders to pursue appropriate environmental conduct (Peck et al., 1992; Rémy, 2003). The mining technologies used also have to comply with the environmental standards adopted in countries with strict regulations since much of the market potential for metals and minerals are found in these same countries.

Furthermore, McNamara (2009) notes that multi-national mining companies, independent of their size, are affected by something that resembles an international consensus on environmental matters, and they are also increasingly influenced by various self-regulatory industry codes and standards. The companies wish to maintain a good corporate image, and they therefore shy away from situations that could evoke scandals that will make clients, customers and the public lose trust in them (see also World Bank and International Finance Corporation, 2002).

Hilson (2000) argues that while the multi-national mining companies often use the same environmental standards independent of where they are operating, this is not likely to be true for small companies in the developing world. Small local mining operations in poor countries are likely to be the ones primarily affected by, and benefitting from, a lack of stringent environmental regulations. However, small mining companies are also more often dependent on credit, so this is likely to be particularly prevalent in regions and countries in which international banks, development organizations etc. are not pushing for increased environmental conduct (Rémy, 2003).

Nevertheless, while it may not be an obvious advantage for countries to implement slack environmental regulations in order to attract foreign mining investment, at least not in the long-run, this does not imply that costs and productivity of mining companies are not affected by environmental regulations. Most notably perhaps, while companies may well adapt to stricter environmental regulations in the long-run, the intermediate period can be both long and burdensome and involve significant costs and investment in order to comply with the environmental regulations. This implies that the dynamics of the regulatory impacts, including how the responsible authorities interact with the industry and other regulatory design issues, will be important for addressing the environment-competitiveness dilemma at the company level.

Additional lessons from the industrial pollution control literature

While issues relating to regulatory design and implementation have not been adequately addressed in the previous social science literature on mining and the environment, previous research on differences in environmental regulatory systems across countries (e.g., Lundqvist, 1980; Jänicke, 1992; Bergquist et al., 2013) suggests that the presence of negotiated policies in some countries has facilitated the environmental transformation of important industrial sectors. Long-term collaborative interaction among companies and regulators can make use of decentralized knowledge and create legitimacy for the policy outcomes. In contrast, more conflict-ridden regulatory systems have tended to produce poorer results in terms of reduced industrial emissions. In this context, comparative studies have argued that since the early 1970s the U.S. environmental regulatory approach has been largely adversarial while the corresponding regulations in many European countries have been more consensual (Brickman et al., 1985; Lundqvist, 1980).[2]

[1] McNamara (2009) argues that it is typically easier for a large multi-national mining company with its headquarter in, for instance, Australia to carry out mining activities in a similar regulatory culture with strict environmental standards, as opposed to starting businesses in a country with lax environmental regulations but completely different legal institutions and rules of conduct.

[2] The flip-side of this coin is that the transparency of the U.S. system has been—and may still be— higher than in Europe. The European model has historically been more trusting and led by centralized elites. Over time, though, the two systems have tended to converge and adopted similar features (Löfstedt and Vogel, 2001).

Furthermore, previous theoretical and empirical research also suggests that environmental regulations that provide flexibility over time in identifying, developing and demonstrating new technology will stimulate innovation, and permit industrial firms to coordinate pollution prevention measures with productive investments (e.g., Lindmark and Bergquist, 2008; Bergquist et al., 2013). In the environmental economics literature a lot of attention has been devoted to the incentive-based policy instruments, such as pollution charges and emissions trading schemes (Goulder and Parry, 2008). There are, however, also important differences in the regulations typically required as a result of individual permits. For instance, emission standards that are technology- rather than performance-based will risk to force the diffusion of suboptimal technologies. Lindmark and Bergquist (2008) compare the regulatory strategies to reduce emissions of several heavy metals from two metal smelter plants in Canada and Sweden, respectively. These authors show that the Swedish regulatory approach during the 1970s and 1980s differed from the Canadian one in that it relied exclusively on performance standards as opposed to technology standards. This made it easier for the Swedish plant to experiment with different compliance strategies, and to choose the most efficient ones. In the end this resulted in both better economic and environmental performance compared to the Canadian competitor.

Previous research also emphasizes the importance of intertemporal flexibility in the compliance process. For instance, Sartorius and Zundel (2005) as well as Nentjes et al. (2007) have emphasized that the regulatory 'time-strategy' may constitute an important issue in environmental regulation. For instance, longer compliance periods imply a less rapid emission reduction, but at the same time companies have time to reduce uncertainty and compliance costs by engaging in R&D and technology demonstration activities.[3]

Theoretical remarks and analytical framework

The competitiveness-environment relationship

There is no generally established definition of the competitiveness of industrial companies. In this paper we follow Tilton (1992) and relate competitiveness to the ability to gain and maintain market shares, thus suggesting that a company with a declining market share is losing its competitiveness. Tilton also notes that since mineral commodities often are relatively homogenous and standardized, the competitiveness of mining companies is largely based on costs of production. If these costs are not low enough there would be little scope for making normal long-run profits.

In order to investigate the impact of environmental regulation on competitiveness one must therefore analyze: (a) to what extent and in what ways these regulations influence companies' direct and indirect costs and productivity (i.e., crowd out other productive investments); as well as (b) if and how these cost increases can be passed on to the firms' customers (so-called 'cost pass-through') without a resulting loss in revenues. Mining companies in the developed world typically operate in global markets with intense competition for relatively homogenous products, and they therefore have relatively limited scope for passing on increased costs to the customers. In the following we will therefore focus on the impact of regulations on mining companies' costs and productivity.

Environmental regulations imply that the companies' productive resources must be allocated to invest in pollution abatement at the expense of other investments. Although such requirements often can be motivated from society's point-of-view they raise the cost of opening and operating new mines. Fig. 2 shows different ways in which production costs may be affected, both directly and indirectly. The direct costs include the extra costs associated with, for instance, new equipment, administration (including new staff), production interruptions and the purchase of more expensive factor inputs. These costs can also be 'hidden' and not easily detected for an external evaluator (e.g., Joshi et al., 2001). One example of this is where the regulation leads to more frequent production stops, which in turn leads to a decrease in supply reliability. A new regulation can also imply that a mining operation needs to substitute one factor input (e.g., fuel) for another; even if the new input factor has the same price as the replaced one this may result in lower profits due to inferior product quality. The lost revenues of such impacts can be difficult to assess in advance.

The indirect costs arise since the environmental regulations may crowd out other productive investments in capital and/or innovation, and this leads to a lower long-run profitability. If a new pollution standard requires a company to make other priorities in its R&D budget and spend more money on environmental innovation, the direct effect on the company's costs may be negligible. Still, since less attention is now paid to conventional R&D there may be negative impacts on the competitiveness in the long-run. Another example of indirect costs is the costs that are often referred to as general equilibrium costs. For instance, if an environmental requirement is imposed on the mining industry, this may influence the costs and prices faced by other sectors (e.g., those that sell inputs to mining companies).

The notion that environmental regulation has negative impacts on industrial competitiveness has also been challenged. Much of this discussion has centered on the so-called Porter hypothesis (Porter and van der Linde, 1995), essentially arguing that 'properly-designed' environmental regulations will: (a) stimulate environmental innovation (the weak version of the hypothesis); and (b) increase not only the environmental performance but also the economic performance (i.e., profits, productivity etc.) of industries (the strong version). According to Porter and van der Linde (1995) properly-designed environmental regulations should adhere to three principles. First, the regulations must create maximum opportunities for compliance and innovation, leaving the specific technology choices and compliance strategies to industry and not to the regulator. Second, the regulatory process should leave as little room as possible for uncertainty at every stage. Third and finally, the environmental regulations should foster continuous

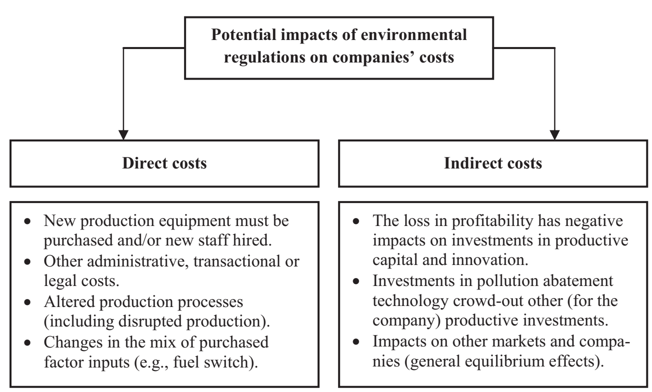

Fig. 2. Categorization of the impacts of environmental regulation on the industry's costs. Sources: based on Jaffe et al. (1995) and Brännlund and Lundgren (2009).

[3] The importance of the timing of policy and repeated regulator-firm interactions is emphasized also in Mohr (2006) and in a number of industry case studies. For instance, Kivimaa (2007) investigates the environmental policy–innovation linkages in the Nordic pulp, paper and packaging industries, and concludes that credible regulations that are gradually tightened over time will tend to encourage environmental innovation in production processes.

environmental improvements rather than locking in any particular technology.

In general, there is strong empirical support for the weak version of the Porter hypothesis (e.g., Ambec et al., 2011, Ford et al., 2014; Lanoie et al., 2011; Söderholm and Bergquist, 2013). This is far from controversial; regulatory decisions that force companies to undertake pollution abatement investments will provide incentives to search for and develop new and cheaper abatement technology. The strong version of the Porter hypothesis is much more controversial, and contrasts with the above notion of increased costs and lower industrial productivity following the introduction of environmental regulations. However, the empirical support for this hypothesis is limited (e.g., see the review by Brännlund and Lundgren, 2009). Although there may be single cases where one ex post may observe non-insignificant productivity improvements following the implementation of stricter regulations, this does not imply that the introduction of stricter regulations is motivated *ex ante*. At the company level there are likely to exist several—not yet identified—productivity-enhancing measures that could be undertaken if companies allocated enough resources (e.g., staff hours) to identify these. Still, in a world of scarce resources the relevant question is not whether such search efforts generate new ideas and solutions or not, but instead whether the search efforts that are being induced by the environmental regulations generally lead to more significant productivity improvements compared to the corresponding search efforts that companies do initiate themselves (e.g., Jaffe et al., 1995).

In this paper we do not provide explicit tests of the Porter hypotheses. Instead we address the issue of how environmental regulations should be designed and implemented to potentially ease up the tension between regulatory pressure and competitiveness. In this context Porter's criteria for properly designed regulations are of significant interest.

The importance of environmental regulatory design and implementation

We identify and discuss three features of environmental regulations that could affect the prospects for addressing both environmental and competitiveness concerns in the permitting process. These are briefly summarized and exemplified in Fig. 3. Here we distinguish between regulatory issues that arise before the permit is granted (*ex ante*), and the design and implementation of the regulations in the case where the permit is granted (ex post).

Mining is a capital intensive industry and many of the concerns about competitiveness associated with environmental regulations could emerge in the form of a lack of predictability and timeliness prior to the regulatory decision. For a mining company capacity expansions (or replacements) are keys to its future competitive strength. However, due to the cyclical nature of minerals markets, the mining industry has typically faced narrow investment windows, i.e., periods characterized by high prices and favorable conditions for loan financing. Moreover, the competitive environment has led to an increased demand for efficiency improvements and high capacity utilization rates. This includes, for instance, the adoption of lean manufacturing techniques and just-in-time inventory systems (Humphreys, 2000). This can in turn greatly increase the importance of a producer's capacity to demonstrate itself as a consistent and reliable supplier. Significant delay in the permitting processes—e.g., due to a lack of staff and resources at the regulatory authorities and/or generous opportunities for local stakeholders to participate (and appeal) in the process—may threaten this reputation.

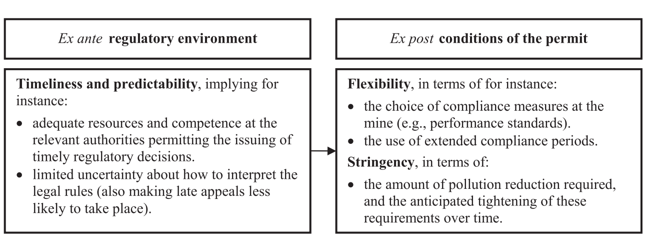

Fig. 3. Environmental permits and competitiveness: critical issues.

However, while the source of money, the timing of repayment of loans, the need to make a profit etc., tend to force a particular timetable (and outcome), the mining industry must also acknowledge the business risks associated with tense community relations. Over time the industry has witnessed an increased demand for a more inclusive mining sector that embraces the rights of people, and involves more direct participation in decision-making processes at the regional and local level (e.g., Söderholm and Svahn, 2014). For these reasons several companies and governments in mineral-rich countries have embraced the need for mineral ventures to gain a 'social license' to operate, i.e., a broad approval and acceptance of society towards these ventures that goes beyond the requirements of formal licenses. Typically this requires early and constructive dialogs with important stakeholders and the local population to avoid future appeals and delays in the process (Prno, 2013).

Another issue that may influence the predictability of the outcome of the permitting processes is if the legislation provides the authorities with a substantial degree of discretion to interpret how the rules should be interpreted and put into practice (e.g., concerning the conditions for obtaining a permit). For instance, if the legal rules provide very vague guidelines for how to assess specific cases, this could provide room for late appeals and lengthy licensing processes. Often the legal rules are deliberately vague; one could argue that they have been formulated so as to provide scope for promoting the interest of both economic development and environmental protection over time. However, legal rules should also aim to clarify "what applies" in a particular situation (Pettersson and Söderholm, 2014). In the absence of clear *ex ante* guidelines mining investments risks may be significantly exacerbated.

Flexibility concerns how the conditions of the permit are set, first of all to which extent they rely on technology prescriptions or on performance-based emission standards. Performance or technology standards have been the main policy instruments to regulate industrial pollution in most countries (e.g., Ashford and Caldart, 2008). However, the economic impacts of these are likely to differ significantly. Individual mines typically differ in terms of their pollution abatement costs, and these costs are not likely to be known with any certainty prior to investment. Still, mining companies normally know far better than the regulating authorities what it will cost to abate emissions at the mine. They also have few incentives to reveal this information to the regulator. This is known as information asymmetries. In such a setting performance standards are likely to be more cost-effective, since these leave it to the individual company to identify the relevant compliance measures. Technology standards instead dictate what specific processes or solutions that companies must use; by design this type of regulation provides little leeway to undertake other potentially more efficient measures.

Since the future costs of pollution abatement technology are uncertain, companies need to develop and test new and more efficient technological solutions in order to comply with increasingly stringent regulations. Given the uncertainties involved in the R&D and technology demonstration process, flexibility is important also in terms of the time allowed for complying under the permit conditions (Nentjes et al., 2007). For instance, the capital stock of the mining industry is durable and replacing industrial equipment will be costly and time-consuming. For this reason extended compliance periods could help to ease the environmental-competitiveness trade-off. This type of dynamic flexibility provides companies with time to experiment and test new technologies, and avoid errors in the compliance process.[4] However, in countries relying heavily on strict environmental quality standards (e.g., the use of maximum allowable concentrations), such adjustment periods may be difficult to implement since they may lead to non-compliance in the short-run.

Finally, the stringency of the regulations is clearly relevant from a competitiveness perspective. In most countries the environmental permitting processes involve also an assessment of the presence of "excessive costs" (e.g., Sorrell, 2002), but there exists no well-established methodological approach to assess such impacts in individual cases. In our investigation we primarily address the issue of regulatory stringency from a dynamic perspective, and in the context of Porter's criterion that the regulations should foster continuous environmental improvements. In the presence of firm-regulator information asymmetries, though, this is often difficult to achieve in practice, and may involve difficult trade-offs. The incentive effects of performance-based emission standards will deteriorate over time, e.g., as less costly abatement technologies are introduced. For this reason, there will be calls for a gradual tightening of the standards, but in determining the new values, the authorities require substantial knowledge about future abatement costs. If they underestimate these costs, the limit values may be very stringent with potentially detrimental effects on the economic performance of industrial activity. In contrast, if the costs are overestimated, the implemented emission standards will be too lax, thus resulting in weak incentives for mining companies to improve their environmental performance.[5]

Again, an important regulatory tool for resolving this competitiveness–environment trade-off is the allowed compliance period. A longer compliance period implies a less rapid emission reduction, but at the same time firms have time to reduce uncertainty and compliance costs by engaging in R&D and demonstration activities. It may also be important for the authorities to invest in know-how on industry-specific pollution abatement technology to bridge information asymmetries between plant owners and the regulating authority. The use of a consensus-based regulatory strategy, including regular and constructive dialogs between the regulator and the industry (e.g., concerning time plans, compliance methods etc.), could also assist in this process.

Background to pollution control legislation in Finland, Sweden and Russia

In all three case countries the environmental permitting of mining operations is (and has also historically been) based on case-by-case assessments. The permitting processes are however complex, typically involving the application of a large number of rules, distributed among several different laws and levels of authority, as well as environmental impact assessments and consultations with various stakeholders. In this paper, though, we focus solely on the most important legal rules pertaining specifically to industrial pollution control. A more comprehensive presentation and assessment of the permitting of mining operations in Finland, Sweden and Russia are provided by Pettersson et al. (2014) (see also Tiess, 2011).

In Sweden, besides an exploitation concession (in line with the Minerals Act), it is also necessary for mining operations to obtain an environmental permit in accordance with the Environmental Code (1998:808). An environmental impact assessment (EIA) is required, and the resulting regulations and conditions (e.g., emission standards) rely heavily on the criteria outlined in the Code, including, for instance, the precautionary principle and the requirements for Best Available Technique (BAT). The decisions concerning the specific conditions of the environmental permit (if granted) are taken by the regional Land and Environmental Courts.

The Swedish permitting process for industrial plants prior to the advent of the Environmental Code in 1998 is also of interest from an environment-competitiveness point-of-view, and below we address a number of important features of this earlier regulatory approach. The legal rules outlined in the 1969 Environmental Protection Act were overall very similar to those of its successor (the Environmental Code). However, the 1969 Act envisaged a permitting process that was based on a policy–style seeking cooperation and consensus between the regulators and the industry (Bergquist et al., 2013; Lundqvist, 1980). The process was administrated by the Franchise Board of Environmental Protection (FBEP), and the permits had to be reassessed and renewed every 10 years on the basis of what was considered BAT at the time. In *The environment-competitiveness challenge in mining permitting cases* we illustrate how this regulatory approach relied on flexible performance standards implemented in combination with extended compliance periods. In these ways it provided scope for environmental innovation, and permitted the affected companies to coordinate pollution abatement measures with productive investments.

In Finland the permitting process is overall similar to the Swedish one. The main legal document concerning the prevention of air and water pollution is the Finnish Environmental Protection Act (EPA 86/200), and similar to Sweden it is based on general principles such as BAT, the principle of caution and care, the polluter pays principle etc. Some environmental issues are addressed also in the Finnish Mining Act (621/2011). All permit applications must include a comprehensive EIA, which is then reviewed by the Regional State Administrative Agencies. These also grant the permit and stipulate the permit conditions.

Moreover, since both Sweden and Finland are Member States of the European Union a number of EU Directives also affect the environmental regulation of the mining industry. For instance, an integrated pollution prevention approach based on individual performance standards for industrial plants has been the core of the so-called IPPC Directive (Directive 2008//EC) and in the more recent Industrial Emissions Directive (Directive 2010/75/EC), the latter repealing the IPPC Directive as of January 1, 2014. Moreover, public participation is required in both the Swedish and the Finnish EIA procedures, but such deliberations were more limited in Sweden during the 1970s and 1980s (e.g., Lundqvist, 1980). Until the 1990s Swedish industrial pollution regulation only involved a few networks of actors.

In Russia the exploitation of mineral resources is based on a licensing regime, and the main legislation consists of the 1992 Subsoil law. According to this legislation any company that holds the user rights has certain obligations, including, for instance, the prevention of the accumulation of industrial or domestic waste in catchment areas and in places where groundwater is used for drinking. Moreover, the mining operations must also comply with certain technical (including environmental) standards. These should be agreed by a special committee prior to approval. This committee is established by the Federal authority for administration of the State fund of Subsoil resources, and it includes representatives of the State mining supervision and executive authorities in the field of environmental protection.

[4] The notion that the costs of innovation can be reduced by extending the R&D period has been illustrated in, for instance, Kamien and Schwartz (1982) and Viscusi et al. (2005).

[5] It can be noted that in this situation, performance standards are likely to perform worse than market-based instruments (e.g., emission charges, markets for tradable allowances etc.). This is because under a performance standard the company will have no incentive to perform beyond the pre-determined limit value, while market-based instruments generally induce plant owners to conduct low-cost abatement beyond this level (since this reduces charge or allowance payments). See, for instance, Goulder and Parry (2008).

Prior to the permit decision an EIA must be conducted, and this involves several other legal Acts, e.g., the Environmental Protection Act. These include substantive provisions in relation to the environment, and prescribe, for instance, precautionary measures, emission limit values and environmental quality standards. The plant-specific emission limit values have typically been derived from environmental quality standards using modeling software (e.g., maximum allowable concentrations for over 200 pollutants have been prescribed) (Organization for Economic Co-operation and Development (OECD) 2006). Companies pay a fee exceeding these limit values. Still, in spite of these formal requirements the room for neglecting important pollution problems can be significant in Russia (e.g., Pettersson et al., 2014). Since 2014 the Russian Ministry of the Environment has been preparing for a fundamental change in the regulatory system, with a stronger emphasis on getting companies to invest in BAT.

The environment–competitiveness challenge in mining permitting cases

Introduction

Our analytical framework pinpoints a number of conditions under which the environmental permitting can provide scope for achieving improved environmental performance with minor negative repercussions for the competitiveness of the mining industry. These include, not the least, flexibility in terms of compliance measures, the use of compliance periods to permit demonstration and tests of new abatement technology, clear legal guidelines for how to address different conflicts of interest, and high regulatory competence. The remainder of this section investigates the regulatory approaches in Finland, Sweden and Russia under the context of these conditions.

Regulatory efficiency: timeliness and predictability

Permitting delays in the mining development phase is a global concern, and the least frequent delays are typically found in developed mining countries such as Australia, Canada and Chile (Behre Dolbear (BD), 2014). In all of our three countries, though, critique has been raised about the long timeframes involved in obtaining permits, and measures have been undertaken to shorten the permitting process. This includes allocating more resources (staff) to the relevant authorities. None of the countries have however introduced prespecified time limits within which a decision has to be made. In Sweden the average time for mining cases administered at the Land and Environmental Court has been about 2 years (over the time period 2002–2011), but it has also varied a lot across single cases (reaching a maximum of 55 years in one case) (SweMin, 2012). In Finland the waiting time at the Regional State Administrative Agency before mining development can commence has been 1–3 years (Wilson and Cervantes, 2014).

The impacts of such extended processes, it has been argued (e.g., by representatives of some Swedish and Finnish mining companies), include a reduced ability to supply the customers with the planned output of mineral products. In Sweden one relatively recent example of this is the permitting process for a new tailings pond at Hötjärn supporting Boliden's mine operations (Granberg, 2013). This project was delayed several years; a permit was first granted in 2007 but then followed appeals and in November 2011 the case was brought to the Supreme Court of Sweden. The Court rejected the last appeals, and Hötjärn could be taken into operation. The consequences of the delay was reduced mine output over the period. In general, the lack of timeliness could also lead to increased uncertainty about whether the mining operations will be able to benefit from high output prices (this also increasing the prospects for loan financing).

In Sweden the government has allocated more resources to the regulatory authorities with the aim to reduce permitting delays. In Finland the environmental permit is granted by regional authorities (the Regional State Administrative Agency). Also in this case the authorities experience a lack of resources, making it harder to monitor and enforce the regulations (Korvela, 2013). Still, given the cyclical nature of the mining industry it may often be difficult for these authorities to plan staff requirements over extended time periods.

Public participation in the decision-making processes is an important issue in the Finnish and Swedish permitting processes, and the Nordic mining companies often have an incentive to outperform the legal requirements on this account (i.e., to gain a social license to operate). However, these ambitions may also clash with the demand for timeliness. Deliberations with stakeholders must often take time in order to be meaningful. In the earlier Swedish permitting process, this was in part facilitated by more limited public participation, and thus a more expert-based assessment of impacts and conditions (Lundqvist, 1980). In order to save time and avoid late appeals it has become increasingly important for the Nordic mining companies to establish close relations with important stakeholders at an early stage in the permitting process (e.g., Granberg, 2013).[6]

The timeliness of the permitting process appears not only to be a matter of having more staff at the regulatory authorities. It is also related to the predictability of the regulations in terms of how to interpret the legal rules. Vague guidelines create uncertainties, and appeals may come late in the process, thus further extending the timeframes involved in obtaining a permit. A recent example of such regulatory uncertainty is the experiences of the Swedish state-owned iron ore producer LKAB in the community of Svappavaara. In this case the company was first (in 2010) granted a permit by the Land and Environmental Court to undertake mining activities. This decision was however appealed by the Swedish Environmental Protection Agency on the grounds that the new operations had to be judged in conjunction with existing (refining) facilities. This argument was later endorsed by the so-called Environmental Court of Appeal, which thus rejected the company's original application since, the Court argued, it was too narrow in scope. A new application had to be prepared, and this caused a three-year delay in the process. In November 2013, a new permit could be issued by the Court.

While this type of integrated environmental assessment often is motivated for environmental reasons, the problem here is that LKAB was given little opportunity to *ex ante* anticipate the Courts' views and their ultimate verdicts on the planned operations (see also Pettersson and Söderholm, 2014). In these types of assessments the Swedish legal text provides limited guidelines for how to determine the scope of the permit application. In Finland (as well as in Russia) similar requirements for integrated environmental assessments exist. However, so far this type of ruling has not caused any permitting delays in the Finnish mining sector.[7]

[6] In cases where such early deliberations are not initiated, intense conflicts can take off. For instance, Beowulf Mining's planned iron ore project in Kallak in the north of Sweden has seen intense protests by Sami groups and environmental activists. This conflict has even reached the news headlines in other countries. See, for instance, the article at BBC News website in July, 2014 (http://www.bbc.com/news/business-28547314).

[7] In Sweden the performance standards that will form part of industrial firms' permit conditions often differ depending on the location and on the extent to which different expert authorities (e.g., the Swedish Environmental Protection Agency) raise concerns about a particular issue or not. This is in some contrast to Finland and Russia where there has sometimes been a greater reliance on predetermined standards, e.g., for noise. While the latter adds predictability to the

Finally, the Russian regulatory system has overall lacked both timeliness and predictability. According to Behre Dolbear (BD) (2014), Russia is one of the countries where permitting delays cause some of the most significant risks to international mining ventures. Part of this problem can be found in the EIA process following the requirement to discuss critical issues with stakeholders. There are examples where companies have had to start the EIA process from scratch because of absent deliberations.

Moreover, there has been a high level of ambiguity in the distribution of competence across different levels of authority. Although the regional governments have the mandate to decide on the local regulatory requirements and how these should be applied, the federal state system adds additional complexity (e.g., Beare, 2009).[8] In general significant consultations with regional authorities are needed, and the staff members from different authorities are not always well-coordinated. Since the regulations in this area are fairly recent and tend to be under constant revision (see also *Background to pollution control legislation in Finland, Sweden and Russia*), regulators still have not fully adapted to the new rules. In some cases the Russian authorities have been uncertain about how the environmental legislation should be implemented. There is even a need for standardization and classification of the terminology used in legal documents (e.g., Saliyeva and Popov, 2014).

In some respects, the environmental requirements for mining operations in Russia have often been stricter than in other developed mining countries such as Canada (e.g., dry-stacked gold tailings in some jurisdictions) (Cervantes et al., 2013). One reason is that the plant-specific emission limit values have been based on environmental quality standards that in turn are very stringent even making some prescribed limit values technically unfeasible (OECD, 2006). Still, in practice these strict requirements will typically not be enforced. Mining companies are expected to contribute to the social and economic development of the community (e.g., Sadykov, 2011), and for this reason the authorities may implement less stringent regulations to avoid disruptive social impacts (e.g., lay-offs etc.). For a foreign mining company these types of negotiated deals can be difficult to handle, and they also create uncertainty about future requirements once a new mine has been put into place.

Compliance flexibility in terms of technology choices and adjustment periods

Flexibility and firm discretion in identifying the most suitable pollution abatement technology are important prerequisites for efficient compliance and technology adoption outcomes. In all three countries there is a relatively frequent use of performance rather than technology standards under the permitting conditions, e.g., emission limit values.[9] Still, technology standards may also be used. One of the Finnish mining companies expressed that a stronger emphasis on technology standards would likely have serious negative impacts on operations due to the associated lack of flexibility. In Sweden the emphasis on compliance flexibility was even stronger before the advent of the Environmental Code. During the 1970s and 1980s the BAT-requirements were also then mandatory, but the FBEP consistently avoided technology standards in favor of individual performance standards.

With a combination of tough performance standards and extended compliance periods, the companies may also face intertemporal flexibility. In both Finland and Sweden there is legal room for imposing extended compliance periods, thus allowing companies to develop and demonstrate new technology. However, today this does not appear to be used consistently in any of the countries. In Finland the absence of longer compliance periods has even created problems for the mining industry. Specifically, in 2009 Agnico-Eagle Finland (AEF) started its gold production, and in 2012 the company initiated a new permitting process in order to be able to increase production. Based on the EIA the company, among other things, proposed an emission limit value for sulfate at 5000 mg/l (to be enforced in late 2016 at the earliest). However, the permit conditions stipulated a limit value of 2000 mg/l, coming into force already in 2014. Moreover, the conditions also stated that a limit value of 1000 mg/l should be used from 2017 and onwards. Due to these stringent regulations and the short compliance period, AEF has appealed the permit decision. The company argues that reaching such low emission levels will take considerable time. First it needs to identify a method with which it is possible to reach the stipulated sulfate levels, then test this in the lab, do pilot testing and finally resolve the technical solutions and planning.

Again, the earlier Swedish permitting process provided greater scope for inter-temporal flexibility. This was evident in the permitting of the LKAB and Boliden operations during the 1970s and 1980s. For instance, LKAB obtained a compliance period of 2 years in the late 1970s in order to investigate how appropriate protective measures against the emissions of dust following the production increase at the company's pellet plant should be carried out. The FBEP justified this decision with the argument that this question could not be answered until the rebuilt pellet plant had been tested in practical operation. Even in the presence of economic downturns, such as in 1978 when LKAB (facing the advent of the second oil crises) was forced to put a pellet plant on standby, the company was instructed by the FBEP to continue the investigations. In this case the testing concerned the emissions of dust, fluorine and sulfur compounds from the plant. At the same time the Board also stated that given the uncertain economic prospects at the time it was not reasonable to tighten the conditions further since this could imply that LKAB made extensive investments that in the end could prove superfluous.

The compliance periods could also involve several parallel investigations regarding different pollution abatement measures. In 1974, Boliden planned to expand production at its Laisvall mine, and as part of the permitting process it investigated advanced new as well as improved existing purification of the company's waterborne emissions. In addition, at the request of the authorities Boliden also investigated the possibility to recover the wastewater instead of letting it out. Ultimately, in 1986 when the final permit was issued, it would prove that the proposed treatment plant—based on, for instance, sulfide precipitation—and in part tested and developed by the company, implied such low levels of heavy metals in the fish that it was no longer justified to consider the possible recovery of the wastewater. The total compliance period was 10 years. No similar or related strategy for addressing regulator–company interactions and the balancing act between environmental and economic outcomes over time appears to exist in the current regulatory systems in Sweden, Finland or Russia.

(*footnote continued*)
permitting process it may however also lead to unreasonable outcomes in individual cases (i.e., too strict in some cases and non-binding in others). This difference in the standard-setting has also been detected when comparing other industrial activities, such as the regulation of Swedish and Danish wind power plants (e.g., Pettersson et al., 2010).

[8] OECD (2006) notes that in Russia, the relations between the federal level and the regions have remained unclear. In the early 2000s an additional administrative layer was added, and this further increased the level of ambiguity.

[9] In Russia this is however not the case for the maximum allowable concentrations for pollutants. Equal concentrations are typically prescribed across the entire country in spite of fundamental differences in, for instance, geography, climate, landscape, geology etc. Even the reference concentrations for a particular location may exceed the maximum allowable concentrations. This adds to the problem of unattainable emission limit values, which was discussed in *Regulatory efficiency: timeliness and predictability*.

The prospects for implementing more stringent regulations over time

In striking a balance between tough environmental regulations on the one hand and competitiveness on the other, one must also consider the prospects for providing continuous incentives for improved environmental performance over time. In some countries the prospects for introducing re-assessments of existing permits are limited, if not only for a lack of resources at the responsible authorities. Moreover, regulator–company information asymmetries make it difficult to implement standards that are not based on either an underestimation or an overestimation of the compliance costs. The efficient tightening of, for instance, emission standards over time may therefore require substantial investment in regulatory engineering competence. By allowing longer compliance periods, thus reducing investment uncertainty and permitting flexibility in R&D and demonstration strategies, the affected companies could also cope with the increased uncertainty associated with more ambitious standards in the future.

Reassessments of existing environmental permits appear to take place more frequently in Finland and Russia compared to Sweden (where they are rare, primarily due to a lack of adequate regulatory resources and staff). Still, in the previous Swedish permitting processes the permits had to be reassessed and renewed every 10 years on the basis of what was considered BAT at the time. In Russia permits are granted for a 5-year period. Companies have also paid a fee (fine) for emissions that are above the standard, thus implying that they would have an incentive to perform beyond the predetermined limit value (Söderholm, 2003; OECD, 2006). With the planned reforms of the Russian regulatory system, though, there may be an increased emphasis on requiring investments in BAT rather than paying for excess emissions.

While the experiences of permit reassessments are generally not well-documented one may note that there is evidence of concerns about the regulatory competence concerning industrial production processes and pollution abatement options. In Finland concerns have been raised about the need for more interaction between the supervisory and permit-issuing authorities on the one hand and the mining companies on the other. This could help in reaching a consensus on how to interpret and implement the permit (as well as in identifying any necessary revisions to the permit conditions). The lack of engineering competence in the permitting process was also brought up in Finland with respect to the AEF mine and the sulfate regulations.[10] A similar critique has been directed at the Swedish environmental authorities in connection to mining permit processes (e.g., Aaro et al., 2012; Granberg, 2013). For instance, permits may be revoked on procedural and formalistic grounds while less attention, it is sometimes argued, has been devoted to the technical issues (e.g., pollution abatement technology and its costs).

One may note that in part the lack of competence and resources at the regulatory authorities can be attributed to the unanticipated minerals boom in the early 2000s. At the end of the 1990s the global interest in mining investment increased rapidly and regulatory authorities were largely unprepared for this. This has been evident also in other well-developed mining countries. For instance, in Canada the government has invested about US$ 160 million in order to improve the capacity of agents and departments that form part of the regulatory process that mining companies have to go through (Government of Canada, 2010).

Bergquist et al. (2013) shows that during the 1970s and 1980s, the Swedish authorities were able to implement gradually stricter emission limit values for industrial plants (e.g., in the metal smelting industries), without this having serious negative impacts on profits and industrial productivity. This required, though, substantial investment among regulatory and other government (and semi-governmental) authorities (e.g., the Swedish Environmental Protection Agency, the Swedish Institute for Water and Air Protection) in know-how on industry-specific pollution abatement technology to bridge information asymmetries between plant owners and the authorities. Central to this development was the exchange of information between the regulatory authorities and the companies. The Swedish Environmental Protection Agency and the County Administrative Boards (i.e., the regional governments) participated in the investigations and planned the investigation work in collaboration with the company, and then also followed the work through frequent site visits. Over time the authorities—including the FBEP—gained improved information and knowledge about the abatement opportunities and costs at the individual plants. New knowledge, e.g., developed in joint public–private research programs, was then effectively used by the regulatory authorities in upcoming permitting processes.

In the absence of clear-cut ambient environmental quality standards the FBEP also had the opportunity to alter the permit requirements as new knowledge was advanced. This typically took place when the permits were updated, and in the Laisvall (Boliden) case the abatement requirements were radically tightened during the time period 1974–1986. In addition, although LKAB put its pellet plant on standby due to the weak market situation (in 1978) the company continued to evaluate different methods for reducing the dust emissions. Under the supervision of the Swedish Environmental Protection Agency during the standby period, the FBEP later on, in 1979, could tighten the requirements of the 1976 permit concerning dust emissions, from 0.9 kg/t to 0.5 kg/t. Overall, this meant a reduction of dust emissions from 4.6 kg/t real emissions in 1975 to conditions, based on a technology that was not yet in commercial operation, of only 0.5 kg/t emissions in 1979.

Finally, the extended compliance periods fostered continuous environmental improvements, and permitted the companies to combine productive investments with pollution abatement measures. The regulatory system's legitimacy was also increased. This type of flexibility in terms of compliance and time strategies has not formed part of many other countries' regulatory approaches (see also Yarime, 2007; Lindmark and Bergquist, 2008).

A comparative summary

Table 1 shows a condensed comparison of how the flexibility, the predictability/timeliness and the stringency of environmental regulations have tended to play out in the permitting of mines in Finland, Sweden and Russia. The results revealed some important similarities and differences across the three countries, the latter even when comparing Finland and Sweden that have adopted very similar environmental legislations.

The paper has illustrated that overall in all three countries—and regardless of some important differences across these—a lack of timeliness and predictability in the environmental regulations has constituted a significant obstacle to new and/or expanding mining operations. The uncertainties facing mining companies concern thus both the time it takes to get a permit, but not the least the nature of the conditions laid out in the permit (if granted). In Russia these uncertainties are overall more prevalent, and related to significant lack of coordination among different levels of authority. In Sweden and Finland the regulatory framework is significantly clearer and more stable over time. However, in these countries investment uncertainties have arisen due to a lack of: (a) *ex ante* guidelines for how to interpret specific legal rules;[11] and (b) adequate resources at

[10] This issue was also raised in connection to the so-called Talvivaara nickel and zinc mine in the eastern part of Finland. It has experienced numerous environmental challenges since its start, and one of the most recent problems was a toxic water leak in November 2012 (Korvela, 2013).

[11] In Sweden the Swedish Geological Survey (2013) provides an in-depth description of the mining permitting process in the country. This presents some

Table 1
Comparative assessment of environmental permitting in Finland, Russia and Sweden.

	Finland	Russia	Sweden (1970–1990)	Sweden (Present)
Regulatory efficiency (i.e., timeliness) and (*ex ante*) predictability	Concerns over delays in permitting process.Regulators experience a lack of resources. Public participation important part of EIA.Some uncertainty concerning permit conditions. Some use of pre-determined emissions standards.	Permitting delays big investment barrier.Uncertainties about how to interpret rules.Public participation important part of EIA.The lack of regulatory coordination (federal vs. regional level) leads to uncertain permit conditions.	Permitting delays not considered a problem.Lack of regulatory resources not a problemPublic participation was restricted.Expert-based dialogue between regulators and the industry led to less uncertainty about permit conditions.	Concerns over delays in permitting process.Regulators experience a lack of resources. Public participation important part of EIA.Concerns about uncertain permit conditions. Less use of pre-determined emissions standards).
Flexibility in terms of compliance measures and adjustment period	BAT, and most often emissions rather than technology standards. Legislation permits extended compliance periods, but this is not used consistently.	BAT, and most often emissions rather than technology standards. No systematic use of compliance periods (but sometimes less stringent regulations for social reasons).	BAT, and consistently emissions rather than technology standards. Consistent use of extended compliance periods (2–3 years), as well as adaptation to market conditions.	BAT, and most often emissions rather than technology standards.Legislation permits extended compliance periods, but this is not used consistently.
Prospects for gradually implementing more stringent regulations without jeopardizing the competitiveness	Re-assessments of existing permits.Concerns over lack of regulators' technical competence, and calls for expert-based and consensus-seeking regulatory approach.	Permits granted for a 5-year period. Companies pay a fee for emissions above the standard. Overall, though, monitoring and enforcement have not been strict.	Re-assessments of existing permits. Substantial regulatory technical knowledge and intense exchange of information. This permitted gradually stricter regulations.	Limited re-assessment of existing permits.Concerns over lack of regulators' technical competence, and calls for expert-based and consensus-seeking regulatory approach.

the regulating authorities. In all three countries public participation is an important part of the EIA process, and this has occasionally caused delays in the permitting process (e.g., due to late appeals).

In terms of flexibility all three countries tend to provide mining companies with quite a lot of discretion in terms of choosing compliance strategy. Hence, performance rather than technology standards (based on BAT) are employed in most cases. However, there appears to be less emphasis on granting dynamic flexibility through the use of compliance periods. This is in contrast to the earlier Swedish industrial pollution control system during the 1970s and 1980s, when performance standards were consistently implemented in combination with extended compliance periods as well as with public support for joint state-industry R&D projects. In this way the earlier Swedish regulatory approach provided scope for environmental innovation and permitted the affected companies to coordinate pollution abatement measures with productive investments.

The permitting process for industrial plants in Sweden during the 1970s and 1980s could also in other ways be considered a best-practice regulation from an environment-competitiveness point-of-view. It was consensus-based, and relied heavily on substantial regulatory technical knowledge and intense exchange of information, ultimately permitting the gradual implementation of more stringent regulations without jeopardizing the competitiveness of the industry. The scope for achieving this is less favorable today, and this applies to all three countries. For instance, in present Sweden there is a lack of re-assessment of permits as well as of regulatory resources and in Russia strict monitoring and enforcement activities are generally not taking place. Both in Finland and Sweden industry representatives are frequently requesting a more expert-based and consensus-seeking regulatory approach.

An important weakness of the earlier Swedish system, though, was the limited role of stake-holders and the public in the decision-making process. On the one hand this expert-dominated process could lead to reduced uncertainties about the timing and the content of the design and implementation of the regulations, but on the other hand it could also result in a serious lack of legitimacy. For mining companies it has over time become increasingly important to acknowledge that the permitting process must take a certain amount of time in order to establish good relations with local stakeholders and address any related concerns. This therefore requires early preparations to avoid appeals, which otherwise could lead to an even more extended legal process.

(*footnote continued*)
clarifications of the legislation, but it does, however, still leave room for different interpretations of specific legal rules (e.g., the scope of the integrated environmental assessment).

Concluding remarks and avenues for future research

The nature of mining development requires a substantial degree of risk-taking that needs to be recognized and rewarded. At the same time the environmental impacts of mining may be significant, and there is a need for regulations that tend to increase the time, costs and risks associated with bringing a mine into production. Costs may arise because of expenditures on EIAs and on implementing the required changes in the production process. In addition, and perhaps even more importantly, significant risks coupled with the timeliness and the content of the permit arise from the perspective of the company prior to mining. This suggests that there is a need for extending the time horizons of the regulations as well as emphasizing a simple, rule-based process for granting permits that—as far as possible—minimize investor uncertainty and enhances predictability.

The main message of this paper is that the environment-competitiveness trade-off is highly dependent on the design and implementation of the regulations, and that there often is scope for achieving positive environmental outcomes without seriously jeopardizing the long-run competitiveness of the mining industry. The regulations must then address the predictability and the timeliness of the regulatory decision-making process, as well as the flexibility in terms of required pollution reduction measures and the time granted to comply with these. The problems encountered in, for instance, the Swedish and Finnish permitting processes can in part be addressed by: (a) allocating more resources and competence to the regulatory authorities; (b) introducing new governance and administrative tools for improving cooperation and information exchange between the industry and the authorities; (c) a more consistent use of stringent performance standards in combination with extended compliance periods; and (d) introducing more standardized procedures and road maps for EIAs and permit applications, as well as for how to interpret specific legal rules. These general recommendations are likely to be valid also for other developed mining countries.

Future research addressing the relationship between tougher environmental requirements and competitiveness is however needed. This research needs to go beyond the formal legal rules, secondary sources, companies' perceptions etc., and focus even more on learning from and comparing the experiences of regulatory design and implementation across countries. In addition, the environmental regulations of the mining industry are becoming tougher and more complex over time, in part as a result of new layers of legislation. This is perhaps particularly evident in the Member States of the European Union, where the recently adopted EU Industrial Emissions Directive (IED) aims at tightening, harmonizing and clarifying the relevant BAT requirements. The competitiveness impacts of forthcoming BAT requirements require further scrutiny. Finally, additional research is also needed on the regulation of mine closure and rehabilitation. This regulation also tends to vary from country to country depending on public policies and industry practices (e.g., the use of reclamation bonds in some countries), and inter-country comparisons would be meaningful. For instance, a critical issue is how to determine the size of a reclamation bond (Gerard, 2000), and the resulting impact on environmental performance and competitiveness.

Also in the above cases, specific design and implementation issues are deemed to be important, thus making the analytical framework presented in this paper a useful tool. It provides a qualitative recognition of key issues in addressing the environment-competitiveness trade-off in regulatory decision-making, issues that could also be increasingly recognized in future econometric work attempting to operationalize environmental regulations.

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EXHIBIT 31

Mining in China: overview

by Guohua (Annie) Wu and Yingnan (Jason) Li, Jincheng Tongda & Neal

Country Q&A | Law stated as at 01-May-2018 | China

This article highlights some of the key legal issues commonly associated with the exploration and extraction of mineral resources in China. These issues form part of any due diligence exercise conducted by an investor proposing to acquire mining assets or an interest in a mining project.

This article looks at mining investment, the legal system applicable to mining, various mining laws, mineral ownership in, different types of mining tenements available, rights of miners to access land against landowners' rights, imposition of royalties and other taxes by the various levels of government, and rules and restrictions concerning foreign investment in China.

To compare answers across multiple jurisdictions, visit the energy and natural resources Mining *Country Q&A tool*.

This article is part of the global guide to energy and natural resources. For a full list of content visit *www.practicallaw.com/energy-guide*.

Overview

1. What are the recent developments in the exploration and extraction of mineral resources in your jurisdiction?

Primary mineral resources

In total, there are more than 10,000 (mostly coal) mines in China, producing a large amount of the world's supply. China is the world's largest producer of coal, gold and most rare earth minerals. In addition to production, China is also the world's leading consumer of most mining products, particularly thermal coal and iron ore, consuming around 49% and 58% respectively of global supply.

With respect to oil and gas minerals, according to the Chinese Mineral Resources Report 2017 (which evaluates nationwide resources), at the end of 2016 the following were available:

- 125.7 billion tonnes of oil, of which 30.1 billion tonnes were recoverable.
- 90 trillion cubic metres of natural gas, with 50 trillion cubic metres recoverable.
- 122 trillion cubic metres of shale gas at a burial depth of 4,500 or fewer metres, with 22 trillion cubic metres recoverable.

- 30 trillion cubic metres of coal-bed methane at a burial depth of 2,000 or fewer metres, with 12.5 trillion cubic metres recoverable.

With respect to non-oil and gas minerals, the evaluation states that China boasts great prospecting potential for 24 major minerals, including coal, iron ore, manganese, chromite, copper, lead, zinc, bauxite, tungsten, tin, molybdenum, antimony, nickel, gold, silver, lithium, pyrites, sulphurite, phosphate rock, potash, magnesite, fluorite, boron and barite.

Current activity

The mining industry in China maintained a growth momentum for the first two months of 2018. According to the National Bureau of Statistics, the total profit of the mining industry during this period was CNY87.79 billion, a year-on-year increase of 42.1%.

- The industry has experienced total year-on-year profit growth at the following rates:
- Coal mining and washing industry, 19.6%
- Oil and natural gas mining industry, 138%
- Non-ferrous metal mining and processing industry, 22.4%
- Non-metallic mineral mining and processing industry 12.8%
- Ferrous metal mining and processing industry (total profit was down to CNY2.06 billion), a year-on-year decrease of 20.8%.

Government policy

The government has implemented the following to boost the mining industry:

- **Relaxation of restrictions on foreign investment.** On 28 June 2017, the Catalogue of Industries for Guiding Foreign Investment (2017 version) was issued. It eliminates certain restrictions on foreign investment in particular mining sector activities, including non-conventional oil and gas (fracking), precious metals and lithium ore.
- **Reform of examination and approval system.** On 14 March 2017, the Ministry of Land and Resources (MLR) issued a notice cancelling the requirement for approval to change the scale of mining production. Since 2013, the MLR has cancelled 25 requirements for examination or approval on geology and mineral resources and cleared up all relevant non-administrative examinations and approvals, including the requirement for the minimum registered capital needed for mining rights.
- **Strengthening supervision and management.** The MLR issued the Measures for the Publication of Information on Exploration and Exploitation by Mining Right Holders (Trial) on 29 September 2015. This set out that, starting from 1 July 2016, all mining right holders must promptly publicise on the MLR's website or in provincial level departments their exploration and exploitation information about land and resources and proactively co-operate with government supervision.
- **Reform of extraction right registration.** On 29 December 2017, the MLR issued the Circular on Improving Administration of the Approval and Registration of Mineral Resources Extraction (the circular). Highlights of this circular include the following:
  - applicants must no longer ask the competent authorities for approval on the mining area before extraction rights are granted, if these extraction rights are assigned by public bidding (however, the requirement is still valid for the grant of extraction rights which are converted from prospecting rights);

- the prospecting right holder can reserve the relevant mining area until its application for extraction rights is approved by competent authorities; and
- transfer of extraction rights will not be registered if the mine permit holder has not fulfilled their obligation to restore the geological environment. This is expected to incentivise the permit holder to perform its obligation to restore the environment even if it intends to transfer the mining rights to a third party.

Regulatory structure

Regulation

2. What is the regulatory framework for the exploration and extraction of mineral resources?

Regulatory framework
The main laws and regulations governing the mining sector include:

- Mineral Resources Law 2009.
- Rules for Implementation of the Mineral Resources Law 1994.
- Administrative Measures for the Block Registration of Mineral Resource Prospecting 2014.
- Circular of the Ministry of Land and Resources on Further Regulating the Administration of the Approval and Registration of Mineral Resources Exploration 2017.
- Administrative Measures for the Registration of Mineral Resources Exploitation 2014.
- Provisions on Administration of Mineral Resources Compensation Collection 1997.
- Measures for the Preparation and Implementation of Mineral Resource Plans 2012.
- Measures for the Administration of Transfer of Mineral Exploration Rights and Mining Rights 2014.

Other relevant laws and regulations include:

- Catalogue for the Guidance of Foreign Investment Industries 2017.
- Administrative Measures for Foreign-invested Mineral Exploration Enterprises
- Mine Safety Law 2009.
- Regulations for the Implementation of the Mine Safety Law 1996.
- Interim Regulations of Resources Tax 2011.
- Labour Law 2009.

- Law on the Prevention and Control of Occupational Diseases.
- Measures for Regulating Simultaneous Design, Construction and Operation of the Protective Devices for Occupational Diseases of Construction Projects.
- Environmental Protection Law.
- Circular of the Ministry of State Land and Resources on Further Regulating the Management of Transfer of Mining Rights.
- Notice of the Ministry of Land and Resources on Issues Regarding the Administration of Strict Control and Regulation of Transfer of Mineral Rights by Agreement.

Regulatory authorities
The most important regulatory authorities include:

- Ministry of Natural Resources.
- National Development and Reform Commission.
- Ministry of Ecology and Environment.
- Ministry of Commerce.
- State Administration of Taxation.
- Ministry of Emergency Management.
- National Health Commission.
- Customs Tariff Commission of the State Council.

See box, *Regulatory Authorities*.

Ownership

3. How are rights to the mineral resources held, and who holds those rights?

Under the Mineral Resources Law, all property rights and control over mineral resources in, under or on any land in China are vested in the State Council for and on behalf of the people of China.

The government grants permits to prospect or extract mineral resources. The rights to the mineral resources then pass to the person(s) who are granted the permits under the Mineral Resources Law. A mining permit can be granted to an individual, a company or a co-operative.

Authorisation

4. What are the key features of the leases, licences or concessions which are issued under the regulatory regime? Can these rights be leased by the right-holder?

Lease/licence/concession term

The right to prospect for and extract mineral resources under the current regulatory regime are obtained by:

- **Prospecting and extraction permits.** Prospecting and extraction permits confer on the holder rights to prospect and extract mineral resources in China (mining rights). Mining rights can be obtained by applying to the department in charge of geology and mining at different levels ("competent authorities") or participating in the public bidding process. One important right enjoyed by holders of a prospecting permit is that they have an exclusive right to secure an extraction permit within the area covered by the prospecting permit if mineral resources are discovered. Prospecting permits are usually granted for three years (seven years for oil and gas). Prospecting permit holders can extend the term of their permits by applying to the competent authorities 30 days before its expiration. Each extension is for two years at most. For a large mine, an extraction permit can last a maximum of 30 years. For medium and small mines, they can last 20 and ten years respectively. Extraction permits holders can extend the term of their permits by applying to the competent authorities 30 days before its expiration, otherwise, the permit will automatically expire.
- **Transfer of mining rights.** Mining rights (which include prospecting and extraction permits) can be transferred to eligible entities if certain requirements are met under the circular and the Measures for the Administration of Transfer of Mineral Exploration Rights and Mining Rights 2014.
- **Mining lease.** Mining rights can also be leased. The procedures and requirements for leasing mining rights are administered in the same way as the transfer of mining rights.

Fees

The registration fees for mining rights are as follows:

- CNY50 to CNY100 for prospecting permits.
- CNY200 to CNY500 for extraction permits.

Liability

The primary obligations of a prospecting permit holder include:

- Commencing and completing the prospecting within the set time frame.
- Preparing mineral prospecting reports and submitting them to the competent authorities for approval.
- Conducting prospecting in accordance with the construction designs and refraining from any unauthorised extraction.
- Complying with laws and regulations on labour safety, land recovery and environmental protection.
- Making immediate efforts to block the wells and holes caused by the prospecting and eliminating safety risks on completion of the project.

The primary obligations of an extraction permit holder include:

- Extracting minerals within the term of the permit.
- Protecting and using mineral resources in a reasonable way.
- Paying the resource tax and mineral resource compensation fees.
- Complying with laws and regulations on labour safety, land recovery and environmental protection.

Restrictions
An application for a mining permit will not be granted if:

- The applicant is not qualified under the Mineral Resources Law (for example, the applicant does not have sufficient capital, knowledge, experience or equipment suitable for the extraction plan).
- Application materials are not properly prepared and submitted.
- The mining area applied for is subject to existing mining permits.
- The mining area applied for is within a harbour, airport, military facility project, large industrial district, railway, important highway, river or natural reserves (unless approval is granted by competent bureaus authorised by the State Council).

Under the Mineral Resources Law, the consequences of failing to comply with any of the above obligations include:

- Suspension of prospecting and mining activities and compensation for losses.
- Confiscation of unlawful proceeds and products.
- Revocation of mining permits.
- Fines.
- Criminal punishment.

5. How are such leases, licences or concessions awarded?

Application, public bidding and written agreements
The Catalogue for Prospecting and Extraction of Mineral Resources groups mineral resources into three categories (Category I, Category II and Category III).

Under the Ministry of Land and Resources Notice on Further Regulating the Assignment of Mining Rights, there are different ways to obtain the relevant mining rights for different categories of mineral resources, as follows:

- For Category I resources, rights are granted to the first entity to apply for the prospecting rights (subject to relevant qualification requirements).

- For all Category II resources and Category I resources where the mines have already been prospected and there is evidence to show that further prospecting work is worthwhile, the prospecting rights must be granted through public bidding.
- For all Category III resources, extraction rights will be granted through public bidding. In this situation, no prospecting rights will be granted. This also applies to Category I and Category II resources where either:
  - the prospecting rights have been terminated (whether as a result of expiration of term or revocation) but the prospecting work has reached the level of "detailed exploration" and the mines can meet extraction design requirements; or
  - the extraction rights have been terminated or there were mining activities in the past and it has been proven that the reserves of mineral resources are worth being extracted.

Apart from by application and public bidding, mining rights can also be granted by written agreement between the applicants and the competent authorities. However, this happens only in very limited circumstances and subject to strict supervision and approval procedures. The public bidding is handled by local mining rights trading platform (which is also called public resources trading centre in many areas). Among other things, the platform is responsible for:

- Issuing notices on assignment of mining rights.
- Arranging auctions, tenders or public listings of mining rights.
- Determining the winning bidder.
- Refunding tender bonds.

If the mining rights are assigned by written agreements, the competent authorities are responsible for publicising relevant information. This includes the:

- Name of the assignee and the mine.
- Geological location of the mining rights.
- Type of mineral resources.
- Reasons why the assignment needs to be made through written agreements.

On 16 June 2017, General Office of the State Council and General Office of the Central Committee of the Communist Party jointly issued the Plan to Reform the Regime of Assignment of Mining Rights (the plan). One of the most significant changes made by the plan is to cancel the grant of mining rights through application to competent authorities. Apart from the written agreement approach, any grant of future mining rights must be made through a public bidding process. This plan is now in pilot implementation in Shanxi, Fujian, Jiangxi, Hubei, Guizhou Provinces and Xinjiang Autonomous Region and will be implemented nationwide from 2019.

Transfer

Subject to approval from the competent authorities, prospecting or extraction permit holders can transfer their prospecting or extraction rights to other qualified entities.

The following conditions apply to transferring a prospecting permit:

- Two years have passed since the permit was granted, or mineral resources are found that can be further prospected or extracted.
- A certain minimum prospecting investment has been made.
- There is no dispute over the ownership of prospecting rights.
- Consideration for the prospecting rights has been paid.
- Any other conditions required by the geology and mineral resources department of the State Council.

The following conditions apply to transferring an extraction permit:

- One year has passed since extraction was commenced.
- There is no dispute over the extraction right.
- Consideration for the extraction rights has been paid.
- Any other conditions required by the geology and mineral resources department of the State Council.

The transferor must meet the same qualification requirements as the applicant for the prospecting or extraction of the mineral resources. Typically, it takes 40 days for the competent authorities to decide whether to approve the transfer or not.

The procedures and requirements for leasing mining rights are administered in the same way as a transfer.

Environment

6. What are the main ongoing requirements for environmental protection?

China's Environmental Protection Law provides that construction projects with environmental impacts must be subject to environmental impact assessment (EIA). Without an EIA, project construction cannot commence. The Environmental Impact Assessment Law (EIA Law) provides different requirements for different types of construction projects. The Catalogue of Classification of Construction Projects Based on Their Environmental Impact groups construction projects into three types:

- Projects with a potentially major impact on the environment. The constructor must submit an environmental impact report and hold a public hearing to ask for the opinion of relevant authorities, experts and the public.
- Projects with a potentially moderate impact on the environment. The constructor must submit an environmental impact report form.
- Projects with a potentially minor impact on the environment. The constructor must complete an environmental impact registration form.

The environmental impact report and report form must be prepared by qualified environmental impact assessment institutions and are subject to approval from competent environmental protection authorities. The environmental impact registration form need only be recorded. The EIA Law provides a basic outline of what must be included in an environmental impact report, including:

- A brief introduction to the project.
- A summary of the existing environment in project areas.
- Analysis, prediction and assessment of impact that the construction project may have on the environment.
- Description of measures that will be taken to mitigate any adverse environmental impact.
- A comparison of the economic benefits and environmental impact.
- A proposal for monitoring the environmental impact of the project.
- A conclusion on the overall evaluation of the project's impact.

The project constructor must also:

- Implement mitigation measures set out in the environmental impact report.
- Rehabilitate adversely affected areas.
- Adopt pollution prevention and control measures and ensure that necessary pollution control equipment is constructed and in operation simultaneously with the construction and operation of the principal part of the project.

Health and safety

7. What are the main ongoing requirements for compliance with health and safety regulations?

No mining enterprise is allowed to engage in production activities without a valid production safety certificate. Safety requirements for mining are mainly set out in the Mine Safety Law and its implementing regulations, which provide detailed compliance requirements on the following matters:

- Facilities for ensuring safe production and preventing accidents.
- Preventive measures against potential dangers of accidents.
- Safe production responsibility system.
- Safe production education and training.

Health requirements for mining are mainly set out in the Law on the Prevention and Control of Occupational Diseases and implementing measures, which provide detailed compliance requirements in relation to the following matters:

- Pre-evaluation of occupational disease hazards.
- Protective facilities for occupational diseases.
- Occupational health training.
- Evaluation on the effect of occupational disease hazard control.

Foreign ownership

8. Are there any restrictions concerning the foreign investment in and ownership of companies engaged in the exploration and extraction of mineral resources in your jurisdiction?

Restrictions on prospecting and extracting mineral resources by foreign investors are set out in the Catalogue of Industries for Guiding Foreign Investment (2017 version). According to this, foreign investors are prohibited from prospecting and extracting tungsten, molybdenum, tin, stibonium, fluorite, rare earth and radioactive minerals. When prospecting and extracting oil and natural gas (including coalbed gas but excluding kerogen shale, oil sand and shale gas), foreign investors can only participate through equity or co-operative joint ventures with Chinese investors.

Processing and sale of mineral resources

9. Are there any restrictions or limitations on the processing of extracted mineral resources?

Restrictions on the extraction and processing of mineral resources are mainly set out in the 2011 Industrial Structure Adjustment Catalogue. This Catalogue categorises various construction projects into three parts:

- Encouraged projects.
- Restricted projects.
- Obsolete projects.

According to the Catalogue, no investment is allowed in new restricted projects. Relevant authorities cannot issue a permit or certificate for these new projects, and all financial institutions are prohibited from providing funds to them. Existing restricted projects can upgrade their productivity power and methods within a certain period and financial institutions can keep providing financial support. Restricted projects include but not limited to:

- Production of certain petrochemical products, such as certain pesticides and nitrogen fertiliser.
- Extracting and smelting tungsten, tin and antimony. To do this, companies must first obtain special access permits from the Ministry of Industry and Information Technology (MIIT). The first list of companies having access to the tungsten, tin and antimony industry was released by the MIIT in September 2013.
- Smelting of gold ores by pyrometallurgy with daily processing amount below 100 metric tonnes.

10. Are there any restrictions or limitations on the sale of extracted mineral resources?

Tungsten, tin, antimony and ionic rare earth are categorised as special ores subject to protective extraction measures. The sale of these minerals and related products is strictly controlled and administered by the provincial government and State Council. They must be sold only to entities designated by the provincial government and no other entities are allowed to purchase them or their related products.

Tax

11. What payments, such as taxes or royalties, are payable by interest holders to the government?

The main payments made by permit holders to the government include:

- **Mineral Royalties**. The applicant must pay mineral royalties for any assignment of mining rights by the government, which reflects the ownership of the government (*Mineral Royalties Reform Plan issued on 20 April 2017*). Before that, the applicant must pay the prospecting right price or the extraction right price for the assignment of mining rights if state investment is involved in the prospecting or extraction work. The mineral royalties are:
  - the price offered by the winning bidder if the mining rights are assigned by auction;
  - the price (not necessarily the highest) offered by the winning tenderer if the mining rights are assigned by tender; and

    - the valuation of the mining rights or the market benchmark price for mining rights of similar conditions (whichever is higher) if the mining rights are assigned by written agreements between the permit holder and the competent authorities.

  The mineral royalties must be paid with cash and payment by instalments is acceptable.

- **Prospecting right user fee.** For the first three years, the permit holder must pay CNY100 per square kilometre each year, increasing by an additional CNY100 per square kilometre each year from the fourth year onwards. The maximum fee is capped at CNY500 per square kilometre each year.
- **Extraction right user fee.** This fee is CNY1,000 per square kilometre per year. However, under the Plan to Reform the Regime of Assignment of Mining Rights, prospecting right user fee and extraction right user fee will be replaced with mining right occupancy fee which will be subject to dynamic adjustment based on the price of relevant mineral resources and economic development needs.
- **Resource tax.** Basic resource tax rates for some mineral resources are as follows:
    - crude oil: 6% of gross sales;
    - natural gas: 6% of gross sales;
    - coking coal and other coal: 2%-10% of gross sales;
    - iron (concentrate): 1%-6% of gross sales;
    - gold (bullion): 1%-4% of gross sales;
    - copper (concentrate): 2%-8% of gross sales;
    - nickel (concentrate): 2%-6% of gross sales;
    - graphite (concentrate): 3%-10%;
    - diatomite (concentrate): 1%-6%; and
    - kaolin (ore): 1%-6%.
- **Value added tax.** The tax rate is normally 11% or 17% depending on the types of mineral resources or mineral products. However, from 1 May 2018, the value added tax rate for mineral resources will change from 11% or 17% to 10% or 16% (*Notice on Adjustment of VAT Rate issued by the Ministry of Finance and State Administration of Taxation on 4 April 2018*).
- **City maintenance and construction tax.** For taxpayers located in cities, the rate is 7%. For taxpayers located in counties or towns, the rate is 5%. For taxpayers located in other places, the rate is 1%.
- **Land use tax.** For a mine, the mining yard, gangue storehouse, dynamite storehouse, waste disposal site and roads used to transport ore are exempt from land use tax. Everything else must pay at the following rates:
    - large cities: CNY1.5 to 30CNY;
    - medium cities: CNY1.2 to 24CNY;
    - small cities: CNY0.9 to 18CNY;
    - counties, towns and industrial and mining areas: CNY0.6 to 12CNY.
- **Business income tax.** The rate is normally 25% on taxable income and 20% for a non-resident entity whose income has no actual connection with its establishment in China.

- **Education surcharges.** Educational surcharges are collected at the rate of 3%, based on the sum of VAT, business tax and consumption tax paid by the companies.

12. Does the government derive any other economic benefits from the exploration and extraction of the mineral resources?

The government does not derive any other economic benefits from the exploration and extraction of the mineral resources.

13. What taxes and duties apply on the import and export of mineral resources?

Generally, customs duties and VAT apply to the import and export of mineral resources. The consignees of imported goods and the consignors of exported goods must pay customs duty. The VAT rate for importing mineral resources is currently 11% or 17% and will be 10% or 16% from 1 May 2018, but for exporting goods the rate is usually zero.

Reform

14. Are there any plans for changes to the legal and regulatory framework?

On 16 June 2017, the Ministry of Land and Resources released a plan to reform the regime for assigning mining rights. The plan is now in force in six provincial areas and will be implemented nationwide before 2019. In addition to the cancelling the ability to obtain mining rights through application (*see Question 5*), the plan also made some other changes, including:

- Further narrowing down the circumstances where mining rights can be granted by written agreements.
- Delegating the power to approve to lower level administrations.
- Implementing a comprehensive information disclosure system for mining permit holders.

The regulatory authorities

Ministry of Natural Resources of the People's Republic of China (MLR)
Address. 64 Fucheng Mennei Avenue, Xicheng District, Beijing China
T + 86 010 12336
W *www.mlr.gov.cn*
Main responsibilities. The MNR is the main regulator for the mining sector.

Ministry of Ecology and Environment of the People's Republic of China (MEE)
Address. 115 Xizhimen Nanxiao Street, Xicheng District, Beijing China
T +86 010 6655 6006
W *www.mep.gov.cn*
Main responsibilities. The MEE is the main supervisor for environmental protection.

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EXHIBIT 32

New York Law Journal

Comparing and Contrasting U.S. and Chinese Environmental Law

In their Domestic Environmental Law column, Christine A. Fazio and Ethan I. Strell of Carter Ledyard & Milburn report on a recent environmental law study tour of China, writing: China is experiencing unprecedented growth and pollution without the legal capacity to address it. It does not bode well that China's current growth dwarfs anything in history. On the positive side, though, China has made impressive strides in environmental protection, and many Chinese we met are encouraged by the incremental progress and are optimistic about the future.

by Christine A. Fazio and Ethan I. Strell | February 23, 2012

Case Digest Summary

In their Domestic Environmental Law column, Christine A. Fazio and Ethan I. Strell of Carter Ledyard & Milburn report on a recent environmental law study tour of China, writing: China is experiencing unprecedented growth and pollution without the legal capacity to address it. It does not bode well that China's current growth dwarfs anything in history. On the positive side, though, China has made impressive strides in environmental protection, and many Chinese we met are encouraged by the incremental progress and are optimistic about the future.

In November, eight American environmental lawyers had the opportunity to participate in an environmental law study tour of China and teach Chinese practitioners about U.S. law.[1] This column describes several Chinese legal tools, and compares them to their American counterparts.

China has a robust compilation of national, provincial, and local environmental laws, some dating back to the beginning of China's reform period in the late 1970s following the chaos and lawlessness of the Cultural Revolution. Many of those laws are modeled on U.S. environmental laws.

However, despite fairly comprehensive laws on the books, there are significant differences between implementation and enforcement of the Chinese and American laws: Chinese standards are generally lower than in the United States, enforcement is inconsistent, political incentives favor economic growth, public access to information is restricted, the NGO (non-governmental organization) and philanthropic communities are immature, the judiciary is not independent, and there is an enormous poor and rural population seeking to improve its standard of living.

Despite these structural obstacles and the enormous scale of the problem, China has made progress, and it was encouraging to learn of the many people inside and outside of the government working to improve the environment.

China's Environment

China has industrialized faster than any nation in history. In 1981, the per capita income was $195; in 2010, it soared to $4,428.[2] In the 1970s, 80 percent of Chinese were peasants; now, more than half live in cities.[3] While industrialization and urbanization have increased China's global power and have benefitted many of its impoverished citizens, legal institutions for environmental protection have not kept pace with economic output.

The World Bank estimates that 16 of the world's 20 most polluted cities are in China.[4] China's urban air is notoriously polluted, and 20 percent of water in China's major rivers is too contaminated for even industrial use. Although China's per capita greenhouse gas emissions are comparatively low, in 2006, China eclipsed the United States as the world's largest emitter.

Pollution also harms China's economy and international reputation. In December, for instance, 200 flights were cancelled at Beijing's airport due to lack of visibility from the dense smog, and a recent MIT study concluded that costs to the Chinese economy from air pollution increased from $22 billion in 1975 to $112 billion in 2005.[5]

U.S. Contribution to Air Data

Although it still is possible to experience beautiful, blue skies in Beijing, the modern city of 20 million people frequently suffers from a pall of brownish-gray smog, unlike anything experienced in the United States today, short of being downwind of a forest fire. Despite the obvious air pollution, the Beijing Environmental Protection Bureau reported that last year, approximately 75 percent of days were considered "blue sky," an improvement from prior years.

Because of the pollution, the United States installed an air quality monitor at its embassy, and publishes on its website and Twitter feed hourly fine particulate matter ("PM2.5") readings keyed to the health-based U.S. Air Quality Index.[6] (Although Twitter is blocked in China, the data are re-posted on Chinese micro-blog sites such as weibo.com and are widely available in China.) The air quality index ranges from "good" through "moderate," "unhealthy for sensitive groups," "unhealthy," and "very unhealthy," all the way to "hazardous."

On particularly bad days, observers may notice the readings exceeding the maximum and reporting "Beyond Index." In November 2010, however, at the start of the winter heating season, when tons of coal were shoveled into Beijing's residential boilers, the automatic monitor caused a minor diplomatic incident. Apparently whoever programmed it hadn't thought that the air would ever exceed "hazardous" levels. When particulate levels spiked, however, the normally sober Embassy data feed reported that Beijing's air was "Crazy Bad." This programming joke embarrassed both the Chinese and Americans simultaneously, no small feat.

The discrepancy between the American and Chinese air reports had to do principally with the locations of the monitoring stations (the Chinese discount the U.S. data because it comes from only one unit located close to a major road); the pollutants monitored (the Chinese only reported data for larger particles, PM10, not the smaller, more insidious PM2.5); and the differences in Chinese and American air standards (Chinese standards are more lax). Nevertheless, the opaque air and availability of alternative data have spurred Beijing to release its own real-time PM2.5 data last month.[7] It will be interesting to see how the Chinese and American data compare over time.

Environmental Laws

China not only has a full range of environmental laws, but its 1978 Constitution codified its responsibility to protect the environment. Its Environmental Protection Law also was one of seven basic codes enacted following the lawless years of the Cultural Revolution.[8] Since then, China has enacted a full range of statutes, including laws concerning the ocean, water pollution, forests, grasslands, air pollution, solid waste, radioactivity, environmental impact assessments, genetically modified crops, invasive species, toxics, urban planning, and noise. China also now reportedly is drafting a statute imposing a carbon tax, and has instituted pilot carbon trading programs.[9]

Despite these laws, nearly every Chinese practitioner we spoke with lamented that they either are not implemented well or do not have teeth: Many laws express goals rather than mandates; none have citizen suit provisions like most U.S. environmental statutes; discharge information is often treated as proprietary business information, so citizens and NGOs lack proof of violations; even when there is litigation, courts do not have the ability to interpret and develop environmental requirements; enforcement penalties are low enough that businesses consider them a business cost (local governments use them as a reliable revenue source); and enforcement agencies are understaffed and beholden to local politics. One provincial environmental enforcement official we spoke with, however, indicated that the agency now publishes names of egregious polluters in the local newspaper, a promising strategy to shame polluters into compliance.

Environmental Impact Review

A principal statute is China's environmental impact assessment (EIA) law, which is cosmetically similar to the U.S. National Environmental Policy Act (NEPA).

EIAs must be completed for the establishment, expansion, or renovation of business facilities such as factories, as well as for certain government plans. Similar to the difference between a smaller American environmental assessment and a full environmental impact statement, there is a three-tier system for the EIAs, ranging from registration with little or no anticipated impact, a less involved assessment, and a full EIA. Like in the United States, EIAs must include mitigation, which in China seem to consist mainly of industrial pollution control equipment. The local environmental protection bureau must approve each EIA and inspect the facility to ascertain whether it is in compliance with its mitigation before full operation is permitted. The extent to which there is further monitoring to ensure that costly pollution control measures remain operational is unclear, though it is likely that there is more enforcement against foreign companies, which are seen as having sufficient financial resources.

In NEPA, consideration of alternatives is of paramount importance. The Chinese law does not require alternatives. While public participation is required in Chinese EIAs, it does not resemble NEPA's public hearing and comment requirements. Rather than seeking comment from any member of the public, public participation in China may include only those directly affected by a project, or those with special expertise, such as professors. Moreover, although China also has laws governing public access to information, most portions of the EIAs are considered proprietary and confidential, and even government regulators do not have access to the entire document! Access to environmental information is improving, however.[10] Finally, in the United States, NEPA's procedural and substantive requirements have been clarified through judicial decisions and regulations. In China, court decisions are cursory and hold no precedential value, so the EIA requirements are not subject to judicial interpretation.

Environmental Courts

Public interest and environmental litigation in China is still in its infancy and suffers from many legal, institutional, and cultural hurdles. As a one-party, civil law nation with a longstanding tradition of mediation over litigation, Chinese in general are less likely to seek courts to resolve differences, particularly when environmental claims conflict with economic development and local government revenue. In fact, the legal profession has only had around 30 years to become established after the Cultural Revolution, and private law firms were not common before the 1990s.[11] Despite the prevalence of U.S. lawyer jokes, the legal profession is less respected in China, and there are far fewer lawyers. In the world's most populous nation, there are only approximately 200,000 lawyers, about the same number in New York State. Also, lawyers can face persecution for championing controversial cases.[12]

Rarely addressing industry- or society-wide problems, most environmental cases in China involve tort compensation, not unlike early U.S. environmental litigation before the enactment of the major environmental statutes. In addition, many or most Chinese cases are resolved through mediation, rather than by a definitive judicial decision.

A primary obstacle to environmental public interest litigation is standing for individuals and NGOs. NGOs are relatively new creatures in China, and must have official government sponsorship and be registered with the government to be legal entities. Some NGOs with particularly close government ties are commonly referred to as GONGOs, or "government-organized NGOs." Unregistered NGOs, while growing more common, are not officially recognized, have a more tenuous legal existence, and would clearly lack standing in court. NGOs are further hampered by not being allowed to have branch offices. In contrast to U.S. courts, many cases are frustrated when the court clerk either rejects a case or, even worse, simply fails to act. Without an official decision, there is nothing to appeal, and the case withers.

One interesting development in Chinese litigation is the rise of specialized environmental courts. Still largely experimental and not in every province, environmental courts experiment with expanded standing, the use of regulatory pollution limits as evidentiary standards rather than causation, long-arm jurisdiction to bring out-of-jurisdiction polluters to justice, and injunctive relief to stop pollution and restore habitats.

One of the most successful environmental courts is the Qingzhen Environmental Court in Guizhou Province, which the U.S. environmental law delegation visited. Established to protect the main drinking water sources for the provincial capital, the Qingzhen court has been at the forefront of innovative environmental litigation in China.[13]

Conclusion

China is experiencing unprecedented growth and pollution without the legal capacity to address it. It does not bode well that China's current growth dwarfs anything in history. On the positive side, though, China has made impressive strides in environmental protection, and many Chinese we met are encouraged by the incremental progress and are optimistic about the future.

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Endnotes:

1. The trip was sponsored by the National Committee on United States-China Relations, www.ncuscr.org. The American delegation consisted of lawyers from private practice, NGOs, and government, including co-author Ethan Strell. The group travelled to Beijing, Guiyang, and Wuhan and met with Chinese lawyers, judges, NGOs, scholars, officials, and journalists.

2. "World Development Indicators: GDP Per Capita," World Bank, available at http://data.worldbank.org/indicator/NY.GDP.PCAP.CD (http://data.worldbank.org/indicator/NY.GDP.PCAP.CD).

3. Manish Bapna, Green Tech: "China's Population Challenge: Designing Sustainable Cities for the Future," Forbes, Feb. 15, 2012.

4. "World Development Indicators 2008," World Bank Online, available at http://data.worldbank.org/sites/default/files/wdi08.pdf (http://data.worldbank.org/sites/default/files/wdi08.pdf).

5. Matus, et al., Health damages from air pollution in China, Global Environmental Change, 22(1): 55-66, 2012.

6. http://beijing.usembassy-china.org.cn/070109air.html (http://beijing.usembassy-china.org.cn/070109air.html); http://twitter.com/beijingair (http://twitter.com/beijingair).

7. Only available in Chinese, the air quality monitoring data is available from the Beijing Environmental Protection Bureau at http://zx.bjmemc.com.cn (http://zx.bjmemc.com.cn). See also "Comparing Pollution Data: Beijing vs. U.S. Embassy on PM2.5," China Real Time Report, Wall Street Journal, Jan. 23, 2012; "New Year Fireworks Leaves Beijing Air Smothering," China Daily, Feb. 16, 2012.

8. See Stefanie Beyer, "Environmental law and Policy in the People's Republic of China," Chinese Journal of International Law (2006), Vol. 5, No. 1, 185-211.

9. Wei Tan, "Officials Weighing Green Benefits of Carbon Taxation," China Daily, Jan. 6, 2012; Alvin Lin, "China's Carbon Tax Is Very Real," NRDC News, Jan. 28, 2012.

10. The Chinese Institute of Public and Environmental Affairs (http://en.ipe.org.cn:90 (http://en.ipe.org.cn:90)) and NRDC (http://www.nrdc.cn/english/E_index.php (http://www.nrdc.cn/english/E_index.php)) publish an annual survey on environmental disclosure in China. IPE also maintains an influential interactive map of water pollution discharges.

11. Dick Thornburgh, "China's Harassed Lawyers," op-ed, The New York Times, July 28, 2009.

12. See, e.g., Stanley Lubman, "Don't Overlook China's 'Ordinary' Lawyers," The Wall Street Journal, Aug. 31, 2011.

13. See, e.g., Alex Wang and Jie Gao, Environmental Courts and the Development of Environmental Public Interest Litigation in China, Journal of Court Innovation, 2010.

EXHIBIT 33

PRODUCTION CONTACTS COMPANY DETALS WE ARE HERE ABOUT US SAFETY

Print | E-mail |

ABOUT US

“Ferrolat” Ltd was founded in 2006, in Latvia, in the Liepaja city.

SIA Ferrolat has a full cycle of the process of obtaining ferroalloys as an external furnace method, and on an electric arc furnace with a capacity of 2500 kWa.

The company has licenses to buy, sell and transport spent catalysts. As well as a permit and license for the processing of spent catalysts of the petrochemical, chemical, automotive industry.

The location of the plant a few kilometers from the seaport at the intersection of railway and auto routes allows building logistic schemes for buying raw materials and selling finished products to the most beneficial customers.

EXHIBIT 34

U.S. IMPORTS OF FERROVANADIUM AS CLASSIFIED UNDER TARIFF CODE 7202.92.00

Imports For Consumption | Monthly data for 2018 and 2019

Country	Units	2018 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Austria	componentpounds	140,897	390,903	399,717	340,512	333,350	447,317	208,013	360,693	332,360	325,918	230,597	216,979	3,727,256
Canada	componentpounds	92,982	110,956	84,329	84,428	131,649	75,089	163,783	74,115	305,155	268,800	252,169	200,898	1,844,354
Czech Republic	componentpounds	-	-	-	-	-	-	-	-	-	-	-	-	-
Japan	componentpounds	21,535	-	38,828	-	58,387	21,484	21,581	21,557	-	21,427	21,984	42,798	269,581
Russia	componentpounds	-	-	-	106,437	67,479	35,607	140,608	105,315	-	-	-	-	455,446
Latvia	componentpounds	25,364	-	-	30,944	52,399	54,251	55,761	-	-	27,084	20,719	18,916	285,439
Ukraine	componentpounds	-	-	-	-	5,430	-	-	22,672	-	22,697	44,785	-	95,584
India	componentpounds	-	-	-	61,837	8,891	35,296	35,741	35,062	-	-	9,231	-	186,059
New Zealand	componentpounds	-	-	-	-	-	-	-	-	-	-	-	-	-
South Korea	componentpounds	-	-	-	-	-	-	-	-	-	19,407	-	-	19,407
Germany	componentpounds	-	-	-	891	-	-	-	-	-	-	-	-	891
South Africa	componentpounds	-	-	-	-	-	-	-	-	-	6,870	-	-	6,870
Total		280,778	501,860	522,874	625,049	657,585	669,045	625,488	619,414	637,514	692,202	579,484	479,591	6,890,886

Country	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Austria	Customs Value (US$)	2,510,565	8,179,304	10,462,081	9,596,277	10,506,352	13,844,690	6,053,116	12,106,994	12,025,986	12,313,871	10,813,582	10,821,036	119,233,854
Canada	Customs Value (US$)	1,726,625	1,922,423	1,865,563	2,316,928	2,328,387	1,989,726	3,376,972	1,209,623	1,908,004	10,026,833	6,423,694	6,417,528	41,512,306
Czech Republic	Customs Value (US$)	1,543,219	264,261	739,881	2,042,363	-	6,513,739	3,384,584	8,555,336	-	2,961,511	6,288,566	-	32,293,460
Japan	Customs Value (US$)	337,852	-	826,147	-	1,120,943	638,363	614,642	641,890	-	708,159	724,229	1,647,791	7,260,016
Russia	Customs Value (US$)	-	-	-	3,170,544	2,098,708	1,086,890	4,242,473	3,517,801	-	-	-	-	14,116,416
Latvia	Customs Value (US$)	415,260	-	-	829,558	838,029	970,874	1,574,181	-	-	793,484	389,265	695,343	6,505,994
Ukraine	Customs Value (US$)	-	-	-	-	153,925	-	-	761,016	-	736,114	2,231,455	-	3,882,510
India	Customs Value (US$)	-	-	-	1,191,869	280,259	1,128,705	1,090,200	1,105,328	-	-	302,267	-	5,098,628
New Zealand	Customs Value (US$)	-	-	-	-	-	-	-	-	-	-	-	-	-
South Korea	Customs Value (US$)	-	-	-	-	-	-	-	-	-	629,400	-	-	629,400
Germany	Customs Value (US$)	-	-	-	31,250	-	-	-	-	-	-	-	-	31,250
South Africa	Customs Value (US$)	-	-	-	-	-	-	-	-	-	312,761	-	-	312,761
Total		6,533,521	10,365,988	13,893,672	19,178,789	17,326,603	26,172,987	20,336,168	27,897,988	13,933,990	28,482,133	27,173,058	19,581,698	230,876,595

Country	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Austria	US$/component pound	17.82	20.92	26.17	28.18	31.52	30.95	29.10	33.57	36.18	37.78	46.89	49.87	31.99
Canada	US$/component pound	18.57	17.33	22.12	27.44	17.69	26.50	20.62	16.32	6.25	37.30	25.47	31.94	22.51
Czech Republic	US$/component pound	-	-	-	-	-	-	-	-	-	-	-	-	-
Japan	US$/component pound	15.69	-	21.28	-	19.20	29.71	28.48	29.78	-	33.05	32.94	38.50	26.93
Russia	US$/component pound	-	-	-	29.79	31.10	30.52	30.17	33.40	-	-	-	-	30.99
Latvia	US$/component pound	16.37	-	-	26.81	15.99	17.90	28.23	-	-	29.30	18.79	36.76	22.79
Ukraine	US$/component pound	-	-	-	-	28.35	-	-	33.57	-	32.43	49.83	-	40.62
India	US$/component pound	-	-	-	19.27	31.52	31.98	30.50	31.52	-	-	32.75	-	27.40
New Zealand	US$/component pound	-	-	-	-	-	-	-	-	-	-	-	-	-
South Korea	US$/component pound	-	-	-	-	-	-	-	-	-	32.43	-	-	32.43
Germany	US$/component pound	-	-	-	35.09	-	-	-	-	-	-	-	-	35.09
South Africa	US$/component pound	-	-	-	-	-	-	-	-	-	45.53	-	-	45.53
Total	US$/component pound	17.77	20.13	25.16	27.42	26.35	29.38	27.10	31.23	21.86	36.87	36.04	40.83	28.82
Total Excluding Latvia		17.91	20.13	25.16	27.45	27.25	30.40	26.99	31.23	21.86	37.18	36.68	41.00	29.08
												17.89		6.29
												48.8%		21.6%

Source: USITC Dataweb HTS Nos.7202.92.00

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U.S. IMPORTS OF FERROVANADIUM AS CLASSIFIE

Imports For Consumption | Monthly data for 2018 and 201

Country	Units	2019 Jan	Feb	Mar	Apr	May	June	July	YTD Total	Annualized	Change '18 to '19
Austria	componentpounds	50,069	85,769	107,235	110,304	139,017	175,631	41,024	709,048	1,215,510	-67.4%
Canada	componentpounds	354,834	240,057	288,955	230,096	199,811	194,959	76,646	1,585,358	2,717,756	47.4%
Czech Republic	componentpounds	-	-	-	-	-	-	-	-	-	-
Japan	componentpounds	22,531	45,151	67,373	45,151	45,426	34,282	55,490	315,404	540,693	100.6%
Russia	componentpounds	-	-	-	35,201	-	-	-	35,201	60,345	-86.8%
Latvia	componentpounds	-	39,531	-	38,894	21,136	-	45,503	145,064	248,681	-12.9%
Ukraine	componentpounds	66,077	45,327	75,852	44,622	-	61,156	88,141	381,174	653,442	583.6%
India	componentpounds	6,993	5,686	-	-	-	-	-	12,679	21,735	-88.3%
New Zealand	componentpounds	-	-	-	-	34,615	-	-	34,615	59,340	-
South Korea	componentpounds	-	-	-	-	-	-	-	-	-	-100.0%
Germany	componentpounds	-	18,334	-	-	-	-	-	18,334	31,429	3428.7%
South Africa	componentpounds	-	-	-	-	-	-	-	-	-	-100.0%
Total		500,504	479,853	539,415	504,267	440,005	466,028	306,804	3,236,876	5,548,930	-19.5%

Country	Units	Jan	Feb	Mar	Apr	May	June	July	YTD Total	Annualized	Change '18 to '19
Austria	Customs Value (US$)	2,498,382	3,960,006	4,247,620	4,293,731	3,173,187	3,379,158	792,461	22,344,545	38,304,934	-67.9%
Canada	Customs Value (US$)	8,920,066	8,688,010	7,855,217	7,984,672	3,227,991	4,500,185	1,379,619	42,555,760	72,952,731	75.7%
Czech Republic	Customs Value (US$)	8,049,733	2,008,341	8,099,533	2,838,370	1,891,129	3,393,608	4,690,208	30,970,922	53,093,009	64.4%
Japan	Customs Value (US$)	1,021,989	2,196,788	2,728,227	1,441,676	1,481,454	734,998	1,029,181	10,634,313	18,230,251	151.1%
Russia	Customs Value (US$)	-	-	-	978,271	-	-	-	978,271	1,677,036	-88.1%
Latvia	Customs Value (US$)	-	1,409,626	-	1,289,519	463,476	-	669,805	3,832,426	6,569,873	1.0%
Ukraine	Customs Value (US$)	2,749,459	1,507,611	2,463,015	1,348,690	-	1,213,745	1,256,035	10,538,555	18,066,094	365.3%
India	Customs Value (US$)	233,801	194,834	-	-	-	-	-	428,635	734,803	-85.6%
New Zealand	Customs Value (US$)	-	-	-	-	177,510	-	-	177,510	304,303	-
South Korea	Customs Value (US$)							-	-	-	-100.0%
Germany	Customs Value (US$)	-	424,885	-	-	-	-	-	424,885	728,374	2230.8%
South Africa	Customs Value (US$)							-	-	-	-100.0%
Total		23,473,430	20,390,101	25,393,612	20,174,929	10,414,747	13,221,694	9,817,309	122,885,822	210,661,409	-8.8%

Country	Units	Jan	Feb	Mar	Apr	May	June	July	YTD Total	YTD Ave.	Change '18 to '19
Austria	US$/component pound	49.90	46.17	39.61	38.93	22.83	19.24	19.32	31.51	31.51	-1.5%
Canada	US$/component pound	25.14	36.19	27.18	34.70	16.16	23.08	18.00	26.84	26.84	19.3%
Czech Republic	US$/component pound	-	-	-	-	-	-	-	-	-	-
Japan	US$/component pound	45.36	48.65	40.49	31.93	32.61	21.44	18.55	33.72	33.72	25.2%
Russia	US$/component pound	-	-	-	27.79	-	-	-	27.79	27.79	-10.3%
Latvia	US$/component pound	-	35.66	-	33.15	21.93	-	14.72	26.42	26.42	15.9%
Ukraine	US$/component pound	41.61	33.26	32.47	30.23	-	19.85	14.25	27.65	27.65	-31.9%
India	US$/component pound	33.43	34.27	-	-	-	-	-	33.81	33.81	23.4%
New Zealand	US$/component pound	-	-	-	-	5.13	-	-	5.13	5.13	-
South Korea	US$/component pound	-	-	-	-	-	-	-	-	-	-
Germany	US$/component pound	-	23.18	-	-	-	-	-	23.18	23.18	-33.9%
South Africa	US$/component pound	-	-	-	-	-	-	-	-	-	-
Total	US$/component pound	30.82	38.31	32.06	34.38	19.37	21.09	16.71	28.40	28.40	-1.5%
Total Excluding Latvia		30.82	38.54	32.06	34.48	19.24	21.09	17.06	28.49	28.49	-2.0%

Source: USITC Dataweb HTS Nos.7202.92.00

EXHIBIT 35

September 29, 2016

Scoring the Trump Economic Plan:

Trade, Regulatory, & Energy Policy Impacts

AUTHORS:

Peter Navarro is a business professor at the University of California-Irvine; he holds a Ph.D. in economics from Harvard University. Wilbur Ross is an international private equity investor. Both are senior policy advisors to the Trump campaign.

I. Introduction

Donald Trump's economic plan proposes tax cuts, reduced regulation, lower energy costs, and eliminating America's chronic trade deficit. Trump's goal is to significantly increase America's real GDP growth rate and thereby create millions of additional new jobs and trillions of dollars of additional income and tax revenues.

Hillary Clinton's economic plan will inhibit growth. It proposes higher taxes, more regulation, and further restrictions on fossil fuels that will significantly raise energy and electricity costs. Clinton will also perpetuate trade policies and trade deals she has helped put in place that have led to chronic trade deficits and reduced economic growth.

In considering how to score these competing plans fiscally, it is important to note that the Trump plan generates positive and substantial tax revenue offsets from its synergistic suite of trade, regulatory, and energy policy reforms. Any analysis that scores the Trump tax cuts in isolation is incomplete and highly misleading.

Separately from this report, the non-partisan Tax Foundation has released its analysis of the Trump tax plan. It dynamically scores a $2.6 trillion reduction[1] in revenues relative to the current tax policy baseline as of the end of a 10-year budgeting horizon. However, as is the typical practice within the modeling community, the Tax Foundation does *not* score other elements of the Trump economic plan that are growth-inducing and therefore revenue-generating.

This report fills this analytical gap. Specifically, we provide our own fully transparent scoring of the Trump economic plan in the areas of trade, regulatory, and energy policy reforms based on conservative assumptions. Along with tax reform, these areas represent the four main points of the Trump policy compass. Each works integratively and synergistically with the others and in conjunction with proposed spending cuts.

We believe it is essential that third parties view this analysis in conjunction with the Tax Foundation report. The tax cuts of the Trump plan have been criticized for significant reductions in Federal revenues. However, the Trump economic plan is much more than just about taxes.

As this report demonstrates, the overall plan is fiscally conservative and approaches revenue neutrality in the baseline Tax Foundation scenario.[2] The Trump plan also grows the economy much faster than Hillary Clinton's plan to raise taxes, increase regulation, stifle our energy sector, and continue the trade deficit status quo.

Table One provides a summary of the additional Federal tax revenues generated as a result of Trump's trade, regulatory, and energy policy reforms. These revenues represent a significant offset to the revenue reductions forecast by the Tax Foundation from the Trump tax cuts.[3]

Table One: Tax Revenue Offset Under Trump Trade, Regulatory and Energy Policy Reforms

	Cumulative Federal Tax Revenue Increases (2017-2026, Nominal Dollars, Trillions)
Trade Policy Reforms	$1.740
Regulatory Policy Reforms	$0.487
Energy Policy Reforms	$0.147
Total	$2.374

At $1.74 trillion, trade policy reforms provide the largest revenue gain. This is followed by regulatory reforms at $487 billion and energy policy reforms at $147 billion.

This total positive revenue offset of $2.374 trillion dollars approaches the $2.6 trillion of tax reductions calculated by the Tax Foundation.[4] With proposed spending cuts, the overall Trump economic plan is revenue neutral.

In the remainder of this report, we explain in detail each of these calculations. Our approach is fully transparent. To facilitate third party analysis, we provide the assumptions and calculations in appendices.

II. There Is Nothing Normal About The "New Normal"

From 1947 to 2001, the nominal US gross domestic product (GDP) grew at an annual, rate of 3.5% a year.[5] However, from 2002 to today, that average has fallen to 1.9%.[6] This loss of 1.6% real GDP growth points annually represents a 45% reduction of the US growth rate from its historic, pre-2002 norm.

Just why did the US growth rate fall so dramatically? Many left-of-center economists – and the Obama Administration – have described this era of slower growth as the "new normal." They blame this plunge at least in part on demographic shifts such as a declining labor force participation rate and the movement of "baby boomers" into retirement.

This view of America's economic malaise is incomplete – and unnecessarily defeatist. It ignores the significant roles higher taxes and increased regulation have played in inhibiting US economic growth since the turn of the 21st century as well as our ability to fix the problems.

This new normal argument also ignores the self-inflicted negative impacts from poorly negotiated trade deals and the failure to enforce them. One need look no further than the lengthy list of transgressions detailed in the National Trade Estimate for examples. These bad deals include most notably NAFTA, China's entry into the World Trade

Organization in 2001 – a critical catalyst for America's slow growth plunge – and most recently Hillary Clinton's debilitating 2012 South Korea trade deal.

China's 2001 entry into the WTO, negotiated by President Bill Clinton, opened America's markets to a flood of illegally subsidized Chinese imports, thereby creating massive and chronic trade deficits. China's accession to the WTO also rapidly accelerated the offshoring of America's factories and a concomitant decline in US domestic business investment as a percentage of our economy.

As David Dollar of Brookings notes, US direct investment flows to China were "fairly stable at about $1.6 billion per year in the period 1999-2003" but "jumped in the period 2004-2008 to an annual average of $6.4 billion."[7]

Justin Pierce of the Federal Reserve Board of Governors staff and Yale School of Management's Peter Schott attribute most of the decline in US manufacturing jobs from 2001 to 2007 to the China deal. David Autor of MIT, David Dorn of the University of Zurich, and Gordon Hanson of UC-San Diego have described a "China trade shock" that has raised the unemployment rate, depressed wages and the labor participation rate, and reduced the lifetime income of workers in American manufacturing most "exposed" to the shock.

Most recently, the 2012 South Korea trade deal was negotiated by Secretary of State Hillary Clinton – she called it "cutting edge." It was sold to the American public by President Obama with the promise it would create 70,000 jobs. Instead, it has led to the loss of 95,000 jobs and roughly doubled America's trade deficit with South Korea.

Corporate America does not oppose these deals. They both allow and encourage corporations to put their factories anywhere. However, Mr. and Ms. America are left back home without high-paying jobs.

There is nothing inevitable about poorly negotiated trade deals, over-regulation, and an excessive tax burden – this is a politician-made malaise. Therefore, nothing about the "new normal" is permanent.

Donald Trump's tax, trade, regulatory, and energy policy reforms deal with the root causes of this problem. Trump understands that our economic problems are long run and structural in nature and can only be addressed by fundamental structural reforms.

This is a key distinction between Donald Trump and an Obama-Clinton strategy that has relied so heavily – and futilely – on repeated fiscal and monetary stimuli. All we have gotten from tilting at Keynesian windmills is a doubling our of national debt from $10 trillion to $20 trillion under Obama-Clinton and the weakest economic recovery since World War II – combined with depleted infrastructure and a shrunken military.

The analytical questions, of course, are: (1) What is the specific nature of America's structural economic problems? and (2) How will the Trump economic plan in the areas of trade, regulation, and energy help solve these structural problems and thereby create more growth and job and generate more income and tax revenues? It is to answering this questions we next turn.

III. How Nations Grow and Prosper

The growth in any nation's gross domestic product (GDP) – and therefore its ability to create jobs and generate additional income and tax revenues – is driven[8] by four factors: consumption growth, the growth in government spending, investment growth, and net exports. When net exports are negative, that is, when a country runs a trade deficit by importing more than it exports, this subtracts from growth.

The structural problems driving the slow growth in the US economy over the last 15 years have primarily been the investment and net exports drivers in the GDP growth equation.

The national income accounts divide investment into three categories: residential fixed investment, the change in private inventories, and the category we are most concerned with in this report, *nonresidential fixed investment.* We focus on nonresidential fixed investment in this analysis because it specifically measures capital investment in new plant and equipment (and intellectual property).

To the extent unfavorable tax, trade, energy, and/or regulatory policies "push" capital investment offshore or discourage onshore investment, nonresidential fixed investment is reduced in the GDP equation, and this "offshoring drag" subtracts directly from GDP growth.

In 2015, the US trade deficit in goods was a little under $800 billion while the US ran a surplus of about $300 billion in services. This left an overall deficit of around $500 billion.[9] Reducing this "trade deficit drag" would increase GDP growth.

These trade-related structural problems of the US economy have translated into slower growth, fewer jobs, and a rising public debt. For example, each additional point of real GDP growth translates into roughly 1.2 million jobs.[10] When the US economy grows at a rate of only 1.9% annually instead of its historic norm of 3.5%, we create almost 2 million fewer jobs a year. To put this number in perspective, consider the problem of "missing workers."

Missing workers are defined as potential workers who are neither employed nor actively seeking a job." The Economic Policy Institute estimates that there are more than 2.2 million workers "missing" from the accounting by the Bureau of Labor Statistics in the calculation of the unemployment rate.[11] If these workers were actually counted, the US unemployment rate would be at 6.2%, significantly higher than the official rate of 4.9%. Increasing real GDP growth from 1.9% to 3.5% would put almost all of these missing workers back to work a year.

IV. Regulatory Effects on Growth

The Business Roundtable has frequently complained about the steady expansion of America's regulatory state. According to its survey:

> *Nearly three-quarters of Business Roundtable CEOs list regulations as one of the top three cost pressures facing their businesses. … Fifty-six percent believe pending regulations will negatively affect their hiring and capital spending over the next two years. And 68 percent indicate that if existing regulatory costs were reduced by 20 percent, the money saved would be invested in increased research and development.*

Excessive regulation drives ups costs, drives down both R&D and hiring, and contributes to the "push" offshore of domestic business investment. Notes the Business Roundtable survey in connecting these dots: "82 percent of Business Roundtable members said they find the U.S. regulatory system more burdensome than those of other developed countries."

In 2015, the Federal Register lists over 3,400 final rules issued. According to the Heritage Foundation:

> *The number and cost of federal regulations increased substantially in 2015, as regulators continued to tighten restrictions on American businesses and individuals. The addition of 43 new major rules last year increased annual regulatory costs by more than $22 billion, bringing the total annual costs of Obama Administration rules to an astonishing $100 billon-plus in just seven years.*

Excessive regulation is even more burdensome on the 28 million small businesses that have provided two-thirds of our post-recession job growth.

The Heritage Foundation and National Association of Manufacturers (NAM) have estimated[12] regulatory costs to be in the range of $2 *trillion* annually – about 10% of our GDP. NAM finds that "small manufacturers face more than three times the burden of the average US business." According to the Competitive Enterprise Institute, this "hidden tax" of regulation amounts to "nearly $15,000 per US household" annually.

Hillary Clinton has promised to continue Obama's regulatory agenda, particularly in the area of energy. Neither of these career politicians, each lacking any business experience, seem to understand the real costs this increasing regulatory burden imposes on the US economy and how this regulatory burden is restricting economic growth.

In theory, all major new rules undergo a thorough cost analysis. In practice, the White House's Office of Information and Regulatory Affairs is woefully understaffed. The results, as the Heritage Foundation has pointed out, are not just low quality analyses but also long delays. Many new rules never are adequately quantified – or quantified at all.

The Trump Regulatory Reform Plan

We assume the Trump plan seeks to reduce the current regulatory burden by a minimum of 10% or $200 billion annually. It proposes a temporary pause on new regulations not compelled by Congress or public safety and a review of previous regulations to see which need to be scrapped. Each Federal agency will prepare a list of all of the regulations they impose on American business, and the least critical regulations to health and safety will receive priority consideration for repeal.

To attack those regulations that "inhibit hiring," the Trump plan will target, among others: (1) The Environmental Protection Agency's Clean Power Plan, which forces investment in renewable energy at the expense of coal and natural gas, thereby raising electricity rates; and (2) The Department of Interior's moratorium on coal mining permits, which put tens of thousands of coal miners out of work.

Trump would also accelerate the approval process for the exportation of oil and natural gas, thereby helping to also reduce the trade deficit. Numerous other low-level rules that are individually insignificant but important in the aggregate will also be reviewed.

Note that the Trump regulatory reform plan will disproportionately – and quite intentionally – help the manufacturing sector. This is the economy's most powerful sector for driving both economic growth and income gains. These income gains will, in turn, disproportionately benefit the nation's blue collar workforce.

According to the National Association of Manufacturers (NAM), "for every one worker in manufacturing, there are another four employees hired elsewhere." In addition, "for every $1.00 spent in manufacturing, another $1.81 is added to the economy" and this is "the highest multiplier effect of any economic sector." (In the calculations below for trade effects, we will conservatively assume a discounted multiplier of 1.0 based on this 1.81 NAM multiplier.)

This high multiplier effect is precisely why the Trump Trade Doctrine and overall economic plan seek to strengthen the US manufacturing base – and regulatory reform is a key structural reform. Right now, as Mark and Nicole Crain calculate: "The cost of federal regulations fall disproportionately on manufacturers…. Manufacturers pay $19,564 per employee on average to comply with federal regulations, or nearly double the $9,991 per employee costs borne by all firms as a whole." According to the Manufacturing Institute:

> *More than any other sector, manufacturers bear the highest share of the cost of regulatory compliance. ... Manufacturers spend an estimated $192 billion annually to abide by economic, environmental and workplace safety regulations and ensure tax compliance—equivalent to an 11 percent "regulatory compliance tax."*

Scoring The Effects of Regulatory Reform

Hillary Clinton's economic plan proposes an increasing regulatory burden – and slower GDP growth from the Clinton regulatory agenda. Donald Trump's strategy will trim a minimum of $200 billion from America's annual regulatory burden. This is roughly one-tenth of the $2 trillion consensus estimate of that burden.

This reduction in regulatory drag would add $200 billion of pre-tax profit to businesses annually. Taxing that additional profit at Trump's 15% rate would yield $30 billion more in annual taxes. This would leave businesses with an additional $170 billion of post-tax earnings.

Businesses typically pay out one third of increased post-tax earnings so on this $170 billion of increased post-tax earnings, $56.67 billion more would be paid in dividends and taxed at an 18% percent effective rate. This would leave $113.33 billion of investible extra cash flow, and add $10.2 billion of personal income tax revenues to the Federal treasury each year.

This is an *intermediate* calculation because businesses would also earn a return on the $113 billion more in cash flow each year to invest. Assuming they only earn a very conservative 5% pretax per year on their investments and reinvest the profits, the cumulative pretax earnings on the reinvestment would be $256.86 billion over 10 years.

These pretax earnings would be taxed at 15% for another $37.51 billion of taxes. This brings the total taxes generated by regulatory relief to $439.51 billion in 2016 dollars over 10 years. Taxes are paid in nominal dollars so we have added a 1.1082 inflation factor for total taxes of $487.1 billion over the ten-year forecasting period.

V. Energy Policy Growth Effects

Some benefits of the Trump regulatory reform plan would accrue to the energy sector. In contrast, Hillary Clinton's restrictions on oil production and refining could significantly drive up energy and electricity prices. Columbia Business School Professor Geoffrey Heal found that the Obama-Clinton plan to cut US carbon emissions by 80% by 2050 would cost the US economy a staggering $5.3 trillion over 30 years.

As an example of the kind of effects that should be considered and scored by those modeling the Clinton vs. Trump plans, the Clinton plan could easily drive up the price of the 19.4 million barrels of oil we consume per day in the US by $10 per barrel. This would raise the US oil cost burden by $194 million a day or $70.8 billion per year – almost one half of a percent of the US economy.

The Obama-Clinton "clean power plan" will similarly drive up electricity prices. According to National Economic Research Associates, this plan will have "virtually no effect on climate change" but it will add as much as $39 billion to America's annual electricity bill. That's roughly a quarter of a percent of the US economy.

Trump proposes to lift restrictions on all sources of American energy. This will undoubtedly make more projects available to exploration, production, and distribution companies. It will also result in more opportunities to develop properties that are economical at today's prices. This expansion of the energy sector, in turn, will reduce our needs for imports.

For modeling purposes, it is difficult to forecast the effect that increased supply will have on prices. However, the Institute for Energy Research (IER) has estimated that America's GDP will increase by $127 billion annually for the first seven years and by $450 billion annually for the subsequent 30 years as a result of the expansion of our energy sector.[13]

In view of the prospect for continued price volatility (and to ensure that our scoring estimates are indeed conservative), we discount the IER $127 billion estimate by 25% to

$95.25 billion for the purposes of our calculations and ignore any step-up in years eight through ten. From this $95.25 billion estimate, we can use our income statement approach to score the Trump energy plan. We have modeled only the impacts of implicit profits and wages, not any other economic aspect of the increased activity.

Running The Energy Policy Numbers

We assume that wages are 44% of revenues,[14] or $41.9 billion per year. They are taxed at a 28% effective rate (including a withholding tax rate of 21% and a trust tax rate of 7%). Therefore, $11.73 billion will be paid in personal taxes.

We assume that the pre-tax profit margin on incremental sales will be 15%, or $14.29 billion. Applying the 15% business tax rate, this results in $2.15 billion in taxes paid, leaving $12.14 billion in post-tax earnings.

We also assume that energy companies will pay out only 20% of their incremental post-tax earnings in dividends or $2.43 billion. This yields additional tax revenues of $440 million at a tax rate of 18%.

At this point, the $12.14 billion in post-tax earnings minus the $2.43 billion in dividends paid leaves producers with $9.71 billion of post-tax, post-dividends earnings. We assume these producers will reinvest these $9.71 billion of earnings back into their businesses along with the additional earnings as they accrue after 15% taxes. To ensure our estimate is conservative, we again assume a subpar 5% pretax return on that reinvestment and on the resultant cash flows as they cumulate, adding $4.11 billion of taxes for a total of $147.3 billion in 2016 dollars. As further conservatism, we did not apply an inflation factor.

VI. The Role of Offshoring In The GDP Growth Process

Just as there are those who argue that a “new normal” means the US economy is now permanently stuck in a lower gear, there are those, including Hillary Clinton, who insist that US manufacturing is destined to move offshore. Their “solution” is to convert the US to a “service sector” economy – yet service sector jobs tend to be of lower pay.

This point of view shows a fundamental lack of understanding of: (1) the role of domestic manufacturing in the process of economic growth and income creation, (2) how corporate strategy guides locational and investment decisions, (3) why high taxation and over-regulation help “push” US corporate investment offshore, and (4) how the “pull” of poorly negotiated trade deals and the unfair trade practices of America’s trading partners help transform what would otherwise be growth-inducing domestic investment into growth-inhibiting outbound Foreign Direct Investment (FDI).

The Role of Manufacturing in Economic Growth

As previously noted, manufacturing jobs are a critical part of the American economy. They provide some of the highest wages for our labor force, especially for blue collar workers.

When auto companies like GM or Ford build new factories in China or Mexico rather than in Michigan or Ohio, additional jobs are also lost throughout the economy. As the National Association of Manufacturers notes, for every one manufacturing job in the US auto industry, many more jobs are created downstream in industries ranging from aluminum, plastics, rubber, and steel to glass, rubber, textiles, and computer chips."

Since the era of globalization, manufacturing as a percent of the labor force has steadily fallen from a peak of 22% in 1977 to about 8% today. To those who would blame automation for the decline of manufacturing, one need only look at two of the most technologically advanced economies in the world, those of Germany and Japan, each of which is a worldwide leader in robotics. Despite declines in recent years, Germany still maintains almost 20% of its workforce in manufacturing while Japan has almost 17%.

To be clear, when we are talking about manufacturing, we are not just talking about cheap tee shirts and plastic toys. We are talking about aerospace, biomedical equipment, chemicals, computer chips, electronics, engines, motor vehicles, pharmaceuticals, railroad rolling stock, robotics, 3-D printing, resins, ship building, and more.

The US will become more competitive in each of these sectors if our businesses are not being pushed offshore by high taxes and a heavy regulatory burden or pulled offshore by unfair trade practice like the lure of undervalued currencies and the availability of illegal export subsidies.

The Offshore "Push" of Unfavorable Tax and Regulatory Policies

Every day, American corporations face a binary choice in allocating capital investment to new plant and equipment: These corporations can either expand or locate new facilities on US soil or move to foreign locations around the world.

If such investment stays home, these dollars show up in the national income accounts as nonresidential fixed investment and provide a net contribution to growth. Offshore investment shows up as outbound foreign direct investment (FDI) that subtracts directly from our economy and contributes to the GDP growth of the recipient countries.

While these are complex investment decisions driven by factors such as market location, resource availability, and the configuration of the supply chain, this is also true: Corporate executives seeking to maximize profits will be far more inclined to produce not in the US but in countries where the tax burden is lower and the regulatory environment is less burdensome. Reducing the US tax will help close the current offshoring gap.

Lowering the Federal Corporate Income Tax

At 35%, the U.S has the highest federal tax rate of the 34 industrialized nations of the Organization for Economic Cooperation and Development and the third highest of the world's 196 nations. The only countries with higher rates are Chad and the United Arab Emirates.

America's high business tax rate helps to transform what would otherwise be *domestic* investment that would increase the GDP into *outbound* FDI that instead generates more growth, jobs and tax revenues in foreign countries.

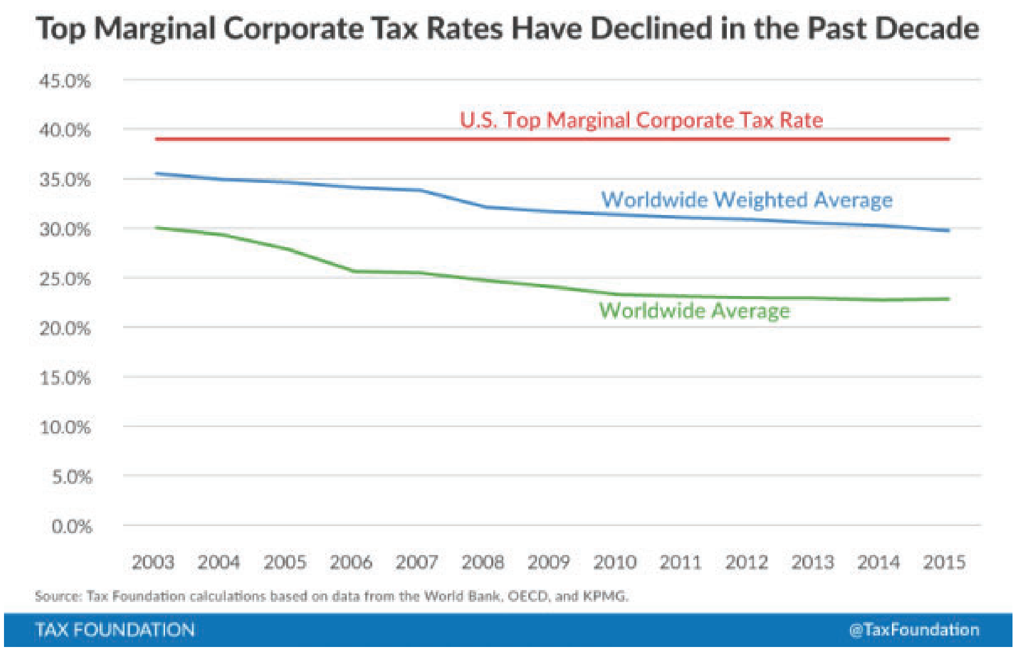
This high business tax rate means businesses currently carry down only 65% of pre-tax earnings to their post-tax net. In contrast, at Trump's proposed 15% rate, businesses would carry down 85% of pre-tax earnings, and this 30% increase in post-tax return on investing would greatly improve the attractiveness of domestic investment.

The express goal of the Trump tax reforms is to realign corporate incentives and thereby encourage more onshoring and reshoring of investment while discouraging offshoring. The *Wall Street Journal* has offered this Aesop's-style tax tale to further illustrate the need for such a realignment of incentives:

> *The US system of world-wide taxation means that a company the moves from Dublin, Ohio to Dublin, Ireland, will pay a rate that is less than a third of America's. A dollar of profit earned on the Emerald Isle by an Irish-based company becomes 87.5 cents after taxes, which you can then invest in Ireland or the US or somewhere else. But if the company stays in Ohio and makes the same buck in Ireland, the after-tax return drops to $.65 or less if the money is invested in America.*

It's not just that the US has the highest business tax rate in the world. It is also that top marginal business tax rates have significantly fallen around the globe since 2003 – as is apparent in Figure One.[15]

Figure One: Top Corporate Marginal Tax Rates Over Time



Over time, the average top marginal corporate tax rate in Asia has fallen from 31% in 2003 to 20.6 by 2015. In Europe, that rate has fallen from nearly 30% to under 20%. This fall in global tax rates relative to the US is no accident.

Indeed, America's trading partners long ago figured out that lowering corporate tax rates increases competitiveness. The US has yet to respond. This is a politician-made failure perpetuated by Obama-Clinton that a Trump presidency would immediately address.

Donald Trump will also firmly address the trillions of corporate dollars now parked overseas to legally avoid the high corporate tax. The plan provides for "a deemed repatriation held offshore at a one-time tax rate of 10 percent. This incentive will spur considerable additional investment on domestic soil."

Ending the Unequal Value-Added Tax Treatment Under WTO Rules

In addition to the obvious problem of relatively high corporate tax rates pushing American capital offshore, there is a more subtle tax problem pulling US corporations offshore. It relates to the unequal treatment of the US income tax system by the World Trade Organization (WTO).

The WTO consists of 164 members and officially began its oversight of the global trading order in 1995. America helped negotiate and agrees to its trading rules, but in a "one country, one vote" system, the US has effectively surrendered its sovereignty to a group of countries that do not always (or often) have America's interests at heart. While the US is the largest economy in the world, it has the same WTO voting rights as countries like Albania with economies a tiny fraction of that of the US.

Here is the key unequal tax treatment issue: While the US operates primarily on an income tax system, all of America's major trading partners depend heavily on a "value-added tax" or VAT system. Under current rules, the WTO allows America's trading partners to effectively create backdoor tariffs to block American exports and backdoor subsidies to penetrate US markets. Here's how this exploitation works:

VAT rates are typically between 15% and 25%. For example, the VAT rate is 25% in Denmark, 19% in Germany, 17% in China and 16% in Mexico.

Under WTO rules, any foreign company that manufactures domestically and exports goods to America (or elsewhere) receives a rebate on the VAT it has paid. This turns the VAT into an implicit export subsidy.

At the same time, the VAT is imposed on all goods that are imported and consumed domestically so that a product exported by the US to a VAT country is subject to the VAT. This turns the VAT into an implicit tariff on US exporters over and above the US corporate income taxes they must pay.

Thus, under the WTO system, American corporations suffer a "triple whammy": foreign exports into the US market get VAT relief, US exports into foreign markets must pay the VAT, and US exporters get no relief on any US income taxes paid.

The practical effect of the WTO's unequal treatment of America's income tax system is to give our major trading partners a 15% to 25% unfair tax advantage in international transactions. (While in principle, exchange rates should adjust over time to offset border adjustment, in the near term, exchange rate manipulation leads to major effects on trade flows.)

It is thus not surprising that US corporations want to move their factories offshore and then export their products back to the US and to the rest of the world. An American subsidiary located overseas gets the VAT benefits on its exports *back* to the US. Of course, such exports to America from the offshored production facility add to the US trade deficit. Such offshoring of capital investment also subtracts from GDP growth.

Like many countries, Mexico has shrewdly exploited the VAT backdoor tariff to further its competitive advantage. While Mexico's VAT existed prior to NAFTA, the Mexican government increased its VAT by 50%, from 10% to 15%, shortly after the NAFTA agreement was signed in 1993 and in the same year the WTO commenced. With the Mexican VAT now raised again to 16%, this discourages US exports to Mexico, encourages US manufacturers to offshore to Mexico, and has helped to increase our annual trade deficit in goods with Mexico from nearly zero in 1993 to about $60 billion. This is yet another case in which Corporate America wins, but Mr. and Ms. America lose.

Barack Obama and Hillary Clinton have failed to act on this problem. It's not even on Clinton's radar screen.

Donald Trump would deal swiftly and firmly with the unequal treatment of corporate income taxes that heavily penalizes American corporations under the rules of the World Trade Organization.

The WTO's VAT Rules Are A Poster Child of Poorly Negotiated US Trade Deals

The WTO's unequal tax treatment of US exports is a prime example of how US trade representatives often fail to recognize the consequences of the bad deals they negotiate on behalf of the American people. Our negotiators were naive at best in failing to protect the US against the adverse effects of the VAT – they very well should have seen such strategic "VAT gaming" coming.

At the bargaining table, US representatives should have demanded, in no uncertain terms, equal tax treatment for US exports. Since the WTO would be meaningless without the presence of the world's largest importer and third largest exporter, we had the leverage then – and have the leverage now – to fix this anomaly and loophole. In contrast, sophisticated foreign countries bargained hard to achieve what is effectively a border tax adjustment loophole. They have repeatedly refused to give that loophole up.

As a further nuance, no WTO rule effectively prevents state-controlled banks from propping up big exporters like steel companies that are losing money. Since VAT is paid to foreign governments and since those governments are typically the health care delivery systems, US exporters end up paying both for the health care of America's own workers and for a portion of the healthcare costs of these other countries through the VAT payments they make on the exports they sell – because of America's naïve trade negotiators. The US Congress has already passed three different pieces of legislation to try to eliminate this unequal tax treatment. However, each time the WTO – led by heavily exporting countries – has rejected the American proposal.

Donald Trump understands that the only way to correct this unfair tax treatment is for the US to use its status as the world's largest economy, the world's largest consumer, and the world's largest importer to put pressure on the WTO to change this unequal treatment. Without the US as a member, there would not be much purpose to the WTO, but prior occupants in the White House have been unwilling to lead on this issue despite its significant negative impacts.

Hillary Clinton did nothing as Secretary of State to address any of these issues and has no plan to end this unfair treatment.

Corporate Strategy and the "Push" and "Pull" of Tax, Regulatory, and Trade Policies

In the next section of this analysis, we will turn to the role of trade deficits in the growth process. For now, let us end this section with a brief observation on how bad trade deals and unfair trade practices have also contributed to the "pull" of domestic investment offshore.

Consider, for example, the rules of the WTO. They provide no specific dispute resolution mechanisms or relief against the use of either sweatshop labor or lax environmental regulations. Nor do the rules of the WTO prevent countries from undervaluing their currency to gain competitive advantage.

The dispute resolution mechanisms that do exist within the WTO make it a lengthy and uncertain process to obtain relief against even the most egregious behavior. Examples include the dumping of steel into global markets by countries ranging from China, India, and Italy to Korea and Taiwan and the use of non-tariff barriers to offset lower tariffs required under WTO rules.

As another problem, it takes a long time to adjudicate trade cases. In the interim, American companies go bankrupt, cheaters take over the market, and the court ruling becomes moot. This happened a few years ago to Bethlehem and 30 other steel companies that went bankrupt waiting for relief.

Finally, there is this very real "gaming of the system" problem: When the US files legitimate cases based on demonstrable violations, our trading partners often retaliate with bogus countervailing trade claims designed to clog up and slow down the dispute resolution process while obfuscating the underlying issues.

In these ways, bad trade deals have thereby helped pull capital investment offshore that would otherwise have remained in the United States. Statistically, this shows up as less nonresidential fixed investment than would otherwise be, slower real GDP growth, and more outbound FDI.

As we shall discuss more fully in the next section, Donald Trump has promised to renegotiate America's bad trade deals and crack down on trade cheating. While Trump's primary goal is to reduce the trade deficit and its drag on GDP growth, we have seen in this section that Trump's trade reforms will also reduce the pull of domestic investment offshore and thereby help to stimulate more real GDP growth.

VII. The Structural Underpinnings of Trade Deficit Drag

Critics have attacked Trump as an "isolationist" and a "protectionist" who will start a "trade war." These attacks reveal a more fundamental lack of understanding of the role trade deficits have played in constraining US economic growth.

The prevailing view within the White House and Clinton campaign is that America's economic woes are short run and cyclical and can be solved through Keynesian fiscal deficits and higher Keynesian monetary stimuli. This Keynesian misdiagnosis has led to a near doubling of America's national debt during the Obama presidency from $10 trillion to almost $20 trillion and the weakest economic recovery since World War II, all while America's infrastructure deficit has continued to increase and our military has grown smaller.

In contrast, Donald Trump views America's economic malaise as a long-term structural problem inexorably linked not just to high taxation and over-regulation but also to the drag of trade deficits on real GDP growth. Trade policy factors identified by the Trump campaign that have created this structural problem include: (1) currency manipulation, (2) the equally widespread use of mercantilist trade practices by key US trading partners, and (3) poorly negotiated trade deals that have insured the US has not shared equally in the "gains from trade" promised by textbook economic theory.

#1: Currency Manipulation

According to textbook theory, balanced trade among nations should be the long-term norm, and the chronic and massive trade deficits the US has sustained for over a decade simply should not exist. This textbook state of balanced trade would exist because freely floating currencies would effectively adjust differences in national domestic cost structures to bring about balanced trade.

The problem, however, is that not all currencies freely float. Many are actively managed, and some are pegged to another currency or currency basket. This hybrid international monetary system makes it impossible for market forces to bring about balanced trade and thereby fairly distribute what the textbooks promise us will be the "gains from trade."

A poster child for this problem is China and its narrowly pegged currency. In a world of freely floating currencies, the US dollar would weaken and the Chinese yuan would strengthen because the US runs a large trade deficit with China and the rest of the world. American exports to China would then rise, Chinese imports to America would fall, and trade should come back towards balance. The problem, however, is that China stymies major adjustments.

China's purchases of US treasury securities are one way the Chinese government holds down their currency relative to ours. Maintaining their manipulated currency peg perpetuates the trade imbalance. Effectively, we are borrowing from China to pay for our trade deficit. It is analogous to a money-losing business borrowing money every year to stay afloat.

A similar problem exists because of the European Monetary Union. While the euro freely floats in international currency markets, this system deflates the German currency from where it would be if the German Deutschmark were still in existence.

In effect, the weakness of the southern European economies in the European Monetary Union holds the euro at a lower exchange rate than the Deutschmark would have as a freestanding currency. This is a major reason why the US has a large trade in goods deficit with Germany – $75 billion in 2015 – even though German wages are relatively high.

The Germans, too, are buyers of US Treasuries as are the Japanese. The US runs trade deficits with both of these countries as well as with China.

The broader structural problem is an international monetary system plagued by widespread currency manipulation. Of course, a weaker currency stimulates the currency manipulator's exports, discourages imports, brings about a more favorable trade balance, and the currency manipulator grows at the expense of its trading partners.

Donald Trump has promised to use his Treasury Department to brand any country than manipulates its currency a "currency manipulator." This will allow the US to impose defensive and countervailing tariffs if the currency manipulation does not cease.

As Secretary of State, Hillary Clinton neither said nor did anything about this issue and supported China's earlier entry into the WTO. During her tenure as Secretary of State, she had a chance to engage in corrective diplomatic action, including addressing intellectual property theft, but she did nothing. Whatever she might vaguely promise now on the campaign trail rings hollow against the backdrop of her bad trade deals and past comments on the inevitability of outsourcing. This is an indefensible record documented by none other than President Barack Obama during his 2008 primary victory over Senator Clinton. Her one consistency has been ultimately favoring policies that in the end result in offshoring and expanded trade deficits.

#2: Mercantilism and Trade Cheating

The global trading order is riddled with trade cheaters. Not coincidentally, China is both the biggest trade cheater in the world and that country with which the US runs its largest trade deficit.

The elaborate web of unfair trade practices includes illegal export subsidies, the theft of intellectual property, the aforementioned currency manipulation, forced technology transfers and a widespread reliance upon both "sweat shop" labor and pollution havens. The People's Republic of China also engages in the massive dumping of select products such as aluminum and steel below cost. It is currently dumping over 100 million tons of steel alone into global markets. China is hardly the only cheater in the world; it's just the biggest.

It is fair for countries to benefit competitively from any inherently lower costs. It is unfair to game the system in addition.

When countries cheat to boost their exports, reduce their imports, and protect their own markets, trade becomes more of a zero sum game in which the cheating countries enjoy a disproportionate share of any gains from trade. Their economies grow faster and the US economy grows more slowly.

A Trump Administration will not tolerate cheating by any nation. If America's trading partners continue to cheat, a President Trump will use all available means to defend

American workers and American manufacturing facilities from such cheating, including tariffs.

Tariffs will be used not as an end game but rather as a negotiating tool to encourage our trading partners to cease cheating. If, however, the cheating does not stop, Trump will impose appropriate *defensive* tariffs to level the playing field.

While candidate Hillary Clinton has adopted the rhetoric of Donald Trump on trade, she has zero credibility on this issue, as the next portion of this analysis will illustrate.

#3: Renegotiating Bad Trade Deals

Dating back to at least 1993, the US has entered into a series of poorly negotiated trade deals that have not distributed the gains from trade fairly. Hillary Clinton supported virtually all of these deals – and she directly negotiated one of America's most recent and damaging deals.

For example, First Lady Hillary Clinton advocated for NAFTA and Bill Clinton signed it in 1993, promising it would create 200,000 new jobs within two years. To date, the US has lost over 850,000 jobs and its trade deficit with Mexico has soared from virtually zero to roughly $60 billion.

As noted earlier, in 2012, Secretary of State Hillary Clinton promised that the "cutting edge" South Korean deal would create 70,000 new jobs. Instead, the US has lost 95,000 jobs and America's trade deficit with South Korea nearly doubled within three years. Workers in the US auto industry, particularly in states like Michigan, Ohio, and Indiana, have been particularly hard hit.

Donald Trump has pledged to renegotiate every one of these bad trade deals according to the principles of the Trump Trade Doctrine, i.e., any deal must increase the GDP growth rate, decrease the trade deficit, and strengthen the US manufacturing base.

In contrast, Hillary Clinton wants to create yet another bureaucracy to enforce existing agreements. If she read these poorly negotiated agreements carefully, she would realize there is little enforcement to be had – in either the large or fine print.

A case in point is the 2012 South Korea deal she herself helped put in place. If the Koreans violate the automotive provisions, there is a required and lengthy consultative process at the end of which the maximum possible penalty appears to be a modest 2.5% tariff – hardly a behavior-changer.

While Donald Trump knows that in some cases enforcement might be enough, most of the deals America has entered into must be renegotiated. Clinton's campaign notably is funded by the very entities that would oppose such renegotiations.

There is a clear binary choice between Clinton and Trump. One leads to ever-larger trade deficits and the offshoring of American jobs. The other leads to balanced trade and the rebuilding of America's manufacturing base.

The analytical question is not whether trade deficits matter in the process of economic growth. We know that to be true from the simple arithmetic of the GDP equation.

Instead, the analytical questions are: How much growth might be gained from reducing America's trade deficit as Trump has proposed to do, and how might a policy of balanced trade contribute to a balanced budget through the creation of additional income and tax revenues? We address these questions in the next section.

VIII. Trade Policy Effects

As the GDP equation illustrates, trade deficits matter to economic growth. When the United States runs massive and chronic deficits as it has been doing since the turn of this century, trade deficits matter a great deal.

This point is often lost on those who look only and singularly at the growth in US *exports* since the advent of globalization. For example, exports in goods have rapidly risen from $59.7 billion in 1970 to $1.5 trillion by the end of 2015 in nominal dollars. Along the way, these exports have created new jobs and generated additional income and wealth.

However, imports in goods have risen at an even faster pace, from $40.9 billion in 1970 to $2.3 trillion in 2015. Although some of our imported goods contain American export content, they still represent a significant subtraction from GDP growth, even after accounting for the positive contribution of services to the trade balance.

Trump's goal is not to reduce overall trade flows but rather increase them. Through tough, smart negotiations, he will improve our trade deals, increase our exports, and displace some goods we now currently import with products made in America.

Scoring Trade Deficit Drag

In 2015, the US exported $2.3 trillion worth of goods and services and imported $2.8 trillion for a total net exports deficit of $500 billion. When we divide this $500 billion trade deficit by the change in the nominal GDP of $644 billion from 2014 to 2015, we see that the trade deficit represents 78% of the net gain in nominal GDP relative to the 2014 period. This comparison suggests that trade deficits matter a great deal when it comes to GDP growth.

To illustrate this, suppose the US had been able to completely eliminate its roughly $500 billion 2015 trade deficit through a combination of increased exports and decreased imports rather than simply closing its borders to trade. This would have resulted in a one-time gain of 3.38 real GDP points and a real GDP growth rate that year of 5.97%.

Income Statement Approach to Scoring Trade Effects

To score the benefits of eliminating trade deficit drag, we don't need any complex computer model. We simply add up most (if not all) of the tax revenues and capital expenditures that would be gained if the trade deficit were eliminated. We have modeled only the impacts of implicit profits and wages, not any other economic aspect of the increased activity.

Trump proposes eliminating America's $500 billion trade deficit through a combination of increased exports and reduced imports. Again assuming labor is 44 percent of GDP, eliminating the deficit would result in $220 billion of additional wages. This additional wage income would be taxed at an effective rate of 28 percent (including trust taxes), yielding additional tax revenues of $61.6 billion.

In addition, businesses would earn at least a 15% profit margin on the $500 billion of incremental revenues, and this translates into pretax profits of $75 billion. Applying Trump's 15% corporate tax rate, this results in an additional $11.25 billion of taxes.

This leaves businesses with $63.75 billion of additional net profit which must be distributed between dividends and retained earnings. If businesses pay out one third of this additional profit as dividends and these $21.25 billion worth of dividends are taxed at a rate of 18%, this yields another $3.8 billion of taxes, after which there remains $17.45 billion of net income.

Together, these tax revenues from wage, corporate, and dividend income total $76.68 billion per year and over the standard ten-year budget window, this recurring contribution to the economy cumulates to $766.8 billion dollars of additional tax revenue.

To this total, we must add at least two more increments of revenues. Under the dividend payout schedule, we have noted that businesses will retain $42.5 billion of cash flow after paying both taxes and dividends.

Reinvesting this $42.5 billion each year at even as subpar a return as 5 percent pretax per year on the cumulating balances invested and assuming reinvestment of the post tax proceeds each year at the same 5 percent pretax return generates another $120.21 billion of pretax profits and taxes of $18.04 billion over the standard 10-year budget window. Adding these increments to the previous calculation results in a ten-year direct incremental contribution to Federal tax revenues of $766.8 billion in 2016 dollars.

Since taxes are paid in nominal, not real, dollars, we have applied to them a 1.1082 inflation factor for a total of $869.76 billion of incremental tax revenues over the ten years from the elimination of the trade deficit.

This is an *intermediate* calculation. To account for multiplier effects, we must add our conservative multiplier of 1.0 (versus the National Association of Manufacturers' 1.81 multiplier). This produces a grand total from trade of $1.74 trillion of additional Federal tax revenues. If the National Association of Manufacturers multiplier of 1.81 were achieved instead of the 1:1 ratio we used, the tax revenue increment from trade alone would be $2.44 trillion nominal dollars.

IX. Inflation and Trade War Critiques of The Trump Plan

If past is prologue, some critics will argue that reducing the flow of cheap imports from locales such as China, Mexico, and Vietnam will be inflationary and act as a "regressive tax" by denying lower income households cheap imports. Other critics will insist that Trump's trade policies will start a "trade war" and trigger a recession.

In reality, four decades of one-sided globalization and chronic trade deficits have shifted wealth and capital from workers to the mobile owners of capital and reduced the purchasing power of Americans. Trump's proposals will reverse these trends, concentrate more wealth and purchasing power in the hands of domestic workers, and result in substantially higher employment. A visit to cities from Johnstown, Pennsylvania to Flint, Michigan reveals quickly the falsehoods and broken promises of those who preach the gains from trade deficits – entities often financed by those who turn a profit from offshoring production.

Income Benefits Vs. Inflation Concerns

To those who oppose reducing America's trade deficit on the grounds that this would increase prices for consumers and disadvantage the poor, we say that the numbers directly contradict these assertions. Suppose, for example, we eliminate our $500 billion trade deficit with 50% of the trade balance improvement from increased exports and 50% from reduced imports. This would mean fewer imports of $250 billion per year.

In plain terms, reducing the trade deficit means increasing the money workers will have in their paychecks and consumers will have in their pockets. This increased income and purchasing power will more than offset any price increases.

Moreover, as products develop a competitive advantage in America and increase their production and margins, prices per unit will go down. Those purchasing products made in America will not only purchase them duty-free but from a dramatically reduced business tax, with lower energy costs, and reduced regulatory costs. In these ways, all of Trump's policy reforms will work together to increase wealth and the concentration of wealth among the poor, working, and middle classes of this country.

Trump Will End, Not Start, A Trade War

Those who suggest that Trump trade policies will ignite a trade war ignore the fact that we are *already* engaged in a trade war. It is a war in which the American government has surrendered before engaging. Unfair trade practices and policies of our competitors are overlooked or ignored. As a well-documented result, America has already lost tens of thousands of factories, millions of jobs, and trillions in wages and tax revenues. Donald Trump will simply put our government on the field in defense of American interests.

As a very practical matter, as Trump pursues a policy of more balanced trade, our major trading partners are far more likely to cooperate with an America resolute about balancing its trade than they are likely to provoke a trade war. This is true for one very simple reason: America's major trading partners are far more dependent on American markets than America is on their markets.

Consider that roughly half of our trade deficit is with just six countries: Canada, China, Germany, Japan, Mexico and South Korea. If we look at the bilateral relationships of America with each of these countries, improvement in our trade balance is clearly achievable through some combination of increased exports and reduced imports, albeit after some tough, smart negotiations – an obvious Trump strength.

Consider South Korea, and recall here that Hillary Clinton's 2012 South Korea trade deal has resulted in the loss of 75,000 jobs – especially in America's auto industry. As has been noted, this poorly negotiated Clinton deal has also led to a near doubling of the US trade deficit with South Korea.

Donald Trump has promised to promptly renegotiate bad deals such as this. Given that it is abundantly clear that this deal did not perform as promised, South Korea will have no grounds to complain when Trump calls for a renegotiation. The two parties will simply seek a far more equitable deal.

As for South Korea, Germany, and Japan, all import a very high percentage of their hydrocarbons (as does South Korea). However, most of these imports do *not* come from the US. With Trump promising to increase oil and natural gas production in the US and remove any restrictions on US exports, there are reasonable deals to be made here with little or no cost to our petroleum-dependent trading partners, and there are many high-paying American jobs that would be created in our energy industries as a result.

China is likely to pose the biggest challenge. That said, the US is still China's biggest market, and the Chinese Communist Party runs a huge risk if it chooses to destabilize its own economy, and undermine Party control.

For example, China cannot cancel imports of American soybeans because there is not enough global excess supply of soybeans to replace the American output. If China paid a premium to divert supplies from other countries, the US would simply fill the market void created so there would be no net impact on US exports.

In terms of deals to be had, China likewise imports much of its petroleum needs so there is room to negotiate here. However, a Trump Administration will confront China's continued high tariffs on a wide range of American products, from motorcycles to raisins, as well as China's limits on imports such as cotton from the US.

Trump will also insist that China relax its numerous non-tariff barriers now blocking US exports across a wide range of products, including autos, agricultural commodities, fertilizers, and telecommunications equipment. Nor will a Trump Administration condone China's continued dumping of billions of dollars of illegally subsidized goods into US markets, e.g., the massive dumping of steel.

Our view is that China's leaders will quickly understand they are facing strength on the trade issue in Trump rather than the kind of weakness on trade that has characterized the Obama-Clinton years. Just as these Chinese leaders have been exploiting American weakness by cheating in the trade arena, they will acknowledge the strength and resoluteness of Trump and rein in their mercantilist impulses.

Ultimately, our view is that doing nothing about unfair trade practices is the most hazardous course of action – and the results of this hazard are lived out every day by millions of displaced American workers and deteriorating communities. There are many markets in the world and China is just one of them. We simply cannot trade on their one-sided terms as they are too destructive to the US growth process. The same is true of other trading partners.

X. Conclusions and Recommendations

The economic plans of Hillary Clinton and Donald Trump differ dramatically in the key areas of trade, regulation, and energy policies. These differences are not being fully accounted for in the various scorings of the fiscal impacts of the Clinton vs. Trump plans.

Our analysis indicates that the Trump trade, regulatory, and energy policy reforms would collectively increase Federal tax revenues by $2.4 trillion. In a separate analysis, the Tax Foundation has reported a dynamically scored $2.6 trillion revenue reduction from the Trump tax cuts assuming guardrails to prevent abuse of the business tax.

Taken together, these two analyses indicate the Trump economic plan is fiscally conservative. When properly scored, it approaches revenue neutrality and, with proposed budget savings outlined by the campaign are taken into account, it achieves revenue neutrality

While one can choose to debate the precision of our estimates, the positive impacts are undeniably significant and should be appropriately accounted for in the scoring models. Modelers are therefore urged to think more broadly about the overarching question they are seeking to answer: How will the competing economic plans of Clinton vs. Trump affect budget balance and more broadly growth, jobs, and income? Modelers can only answer that question by including the effects of trade, regulatory, and energy policies in their forecasts and by accounting for proposed spending cuts like Trump's one percent annual reduction in non-military, non-entitlement discretionary spending.

Journalists are likewise urged to consider the following checklist when they are reporting the latest results from the modeling community:

1. Does the model account for supply side tax policy effects?
2. Does the model account for energy and regulatory policy effects?
3. Does the model account for synergies between tax and trade policies? (For example, a cut in the corporate tax will boost business investment, and increase GDP growth and revenues – is that counted?)
4. Does the model account for trade deficit and offshoring effects, which represent significant drags on U.S. GDP growth?

We hope this analysis will spark an important debate that goes beyond the old and tired critiques that have little or no relevance for the challenges we face in this new century. The bigger, more exciting, and hopeful story here is about the underlying structural problems facing the US economy and how to fix them. That's why no journalist, analyst, or modeler should ever mistake the Trump tax plan for the whole Trump economic plan.

The Trump tax cuts are an essential piece of the growth puzzle. So, too are the combined effects of trade, regulation, and energy policies.

APPENDIX A: Trump Plan Scoring Assumptions

Savings Rate	8%
Dividend Tax Rate	18%
Withholding Tax Rate	21%
Trust Tax Rate	7%
Business Tax Rate	15%
Dividend Payout Ratio (Energy Sector)	20%
Dividend Payout Ratio (Non-Energy)	33%
Pretax Rate of Return on Investment	5%
Wages As Percent of Revenues	44%
Pre-tax Profit Margin on Incremental Sales	15%
Multiplier on Economic Activity (Energy, Trade)	1.00

Appendix B: Regulatory Reform Calculations

Eliminating $200 billion of costs equals $200 billion of pretax profits taxed at 15%, $30 billion. This leaves $170 billion post-tax of which one third or $56.67 billion is paid as dividends taxed at 18%, $10.2 billion. This leaves $46.47 billion post-tax minus an 8% savings rate or $3.72 billion leaves $42.75 billion for consumption. The remaining $113.33 is reinvested on the same basis. This creates an additional $37.51 billion of taxes for a total of $439.51 billion in 2016 dollars. This tax amount is converted to nominal dollars using the 1.1082 inflation factor for a final tax figure of $487 billion.

Reinvestment of Annual Returns on Prior Investments: Regulatory Reform

Year	Beginning Principal	Interest	Taxes	Earnings After Tax
1	56.66	2.83	.42	2.41
2	172.43	8.62	1.29	7.33
3	293.09	14.65	2.20	12.45
4	418.87	20.94	3.14	17.80
5	550.00	27.50	4.12	23.38
6	686.71	34.34	5.15	29.19
7	829.23	41.46	6.22	35.24
8	977.80	48.89	7.33	41.56
9	1,152.69	57.63	7.64	48.99
10		53		
		256.86	37.51	219.35

Note: First year principal is the average of zero beginning balance and $42.50 ending balance

Tax Revenue Additions: Regulatory Reform	
	Billions of Dollars
Corp. Dividend	30.00
Reinvestment	10.20
Annual Tax	40.20
X10 year Reinvestment	402.00
Tax on Reinvestment Return	+ 37.51
Total Tax	439.51
Inflation Factor	1.1082
Taxes in Nominal Dollars	487.1

Appendix C: Energy Calculations

The Institute for Energy Research estimated the annual GDP impact at $127 billion for the first seven years and $450 billion annually in the next 30 years. To be conservative we use the $127 billion figure for all ten years of our modeling horizon. As a further conservative step, we discounted the $127 by 25%, or $31.75 billion yielding $95.25 billion, of which 44% or $41.91 billion are wages taxed at 28% (21% + 7% for the trust fund). This yields $11.73 billion of taxes, for $30.18 billion post-tax minus an 8% savings rate, $2.41 billion, for $27.77 billion of annual consumption.

The pre-tax profit margin on the $95.25 billion of revenues is assumed to be 15%, or $14.29 billion taxed at 15%, $2.15 billion. This leaves $12.14 post tax, of which 20% is dividends, $2.43 billion. This leaves $9.71 billion for reinvestment. The dividends are taxed at 18%, yielding $437 million of taxes. The $9.71 is reinvested each year at 5% pre-tax, a conservative number, and the earnings after 15% taxes are also reinvested as they occur at the same 5% pre-tax rate. This results in $4.11 billion of additional taxes for a total in 2016 dollars of $147.3 billion.

Tax Revenue Additions: Energy	
	Billions of Dollars
Wage	11.73
Corp.	2.15
Div.	+ .44
Annual Tax	14.32
Years	X 10
	143.2
Reinvestment earnings	+ 4.1
Basic Taxes	147.3

Reinvested Principal: Energy Impacts				
Year	Beginning Principal	Interest	Taxes	Earnings After Tax
1	4.86	.24	.04	.20
2	14.77	.74	.11	.63
3	25.11	1.26	.19	1.07
4	35.89	1.79	.26	1.53
5	47.13	2.36	.35	2.01
6	58.85	2.94	.44	2.50
7	71.06	3.55	.53	3.02
8	83.79	4.19	.63	3.56
9	97.06	4.85	.73	4.12
10	110.89	5.54	.83	4.71
Total		27.46	4.11	23.35

Note: First year principal is the average of zero beginning balance and $42.50 ending balance

Appendix D: Trade Calculations

$500 billion revenues x 44% labor content = $220 billion of wages times taxed at 21 + 7 for 28% = $61.6 billion of taxes and $158.4 billion post tax income minus 8% savings rate of $12.7 billion = $145.7 billion of consumption per year. Corporate incremental pre-tax margin of 15% equals $75 billion pre-tax minus 15% taxes, $11.25 billion, equals $63.75 billion post tax of which one third or $21.25 billion is distributed as dividends taxed at 18%, $3.8 billion.

The $42.50 billion retained by the business is reinvested domestically at 5% pre-tax per annum as it comes in and so are the returns on the reinvestment. The returns are taxed at 15% for additional taxes of $18.04 billion for a total of $784.84 billion in 2016 dollars. Since taxes are paid in nominal rather than real dollars we applied to them a 1.1082 adjustment factor for inflation over the 10 years. We applied the $1 to $1 discounted NAM multiple to this amount.

Tax Revenue Additions: Trade	
	Billions of Dollars
Wages	$61.60
Business	11.25
Dividends	+ 3.83
Annual Tax	$76.68
	X 10 years
	$766.8
Tax on Reinvested Income	+ 18.04
Total Taxes in 2016 Dollars	$784.84
Inflation Factor	x 1.1082
	869.76
+ Discounted NAM Multiplier	+ 869.76
+ Taxes in nominal dollars	$1,739.52

Reinvestment Calculation: Trade				
	Reinvested Principal	Pre-tax Return	Taxes	Post-tax Reinvestment
1	21.25	1.06	.16	.90
2	64.65	3.23	.48	2.75
3	109.9	5.5	.82	4.68
4	157.08	7.85	1.18	6.67
5	206.25	10.31	1.55	8.76
6	257.51	12.88	1.94	10.94
7	310.95	15.55	2.33	13.22
8	366.68	18.33	2.75	15.58
9	424.76	21.23	3.19	18.04
10	485.30	24.27	3.64	20.63
Total		120.21	18.03	102.18

Note: First year principal is the average of zero beginning balance and $42.50 ending balance

ENDNOTES

[1] The Tax Foundation's $2.6 trillion estimate assumes guardrails are in place to insure the
[2] We take this baseline to be the $2.6 trillion estimate of tax reductions as the assumptions best reflecting the actual Trump plan's overall tax effects. We also reject any estimates expressed in under static, rather than dynamically, scored modeling assumptions.
[3] These gains are expressed in nominal dollars and cumulated over the course of the standard ten-year budget window that stretches from 2017 to 2026. They represent gains above the baseline scenario of a 1.96% annual increase in real GDP growth over the 10-year period as forecast by the Congressional Budget Office. We use the CBO baseline because this is common practice in the modeling community.
[4] To reiterate, the assumption about the tax treatment of pass-through income used to generate the higher $3.9 trillion Tax Foundation estimate is inconsistent with the intent of the Trump tax plan.
[5] "Nominal" refers to inflation-adjusted. We start in 1947 to avoid the skew of the steep falloff in GDP in 1946 (-11.6) as the economy transitioned from a war economy to a peacetime one. (From 1941 through 1943, at the height of wartime production, the annual real GDP growth rate was roughly 18%.)
[6] US Department of Commerce, Bureau of Economic Analysis, GDP & Personal Income Data. Table 1.1.1. Percent Change From Preceding Period in Real Gross Domestic Product.
[7] Like everything else, it declined in the 2009 crash.
[8] This is the standard formulation of aggregate demand in any economic principles textbook.
[9] The 2015 trade deficit in goods and services was $540 billion. We use a figure of $500 billion in our estimates to be conservative, as the trade deficit over the last 12 months has fallen to that level partly because of lower oil prices.

[10] As support for this conservative rule of thumb, consider the time period 2000 to 2015. If we simply divide the real GDP growth in each year during that time period (available from the Bureau of Economic Analysis) by the nonfarm employee net job gain in that same year (available from the Bureau of Labor Statistics) and compute an average, we arrive at a number of 1.3 million jobs a year – 100,000 higher than our rule of thumb.

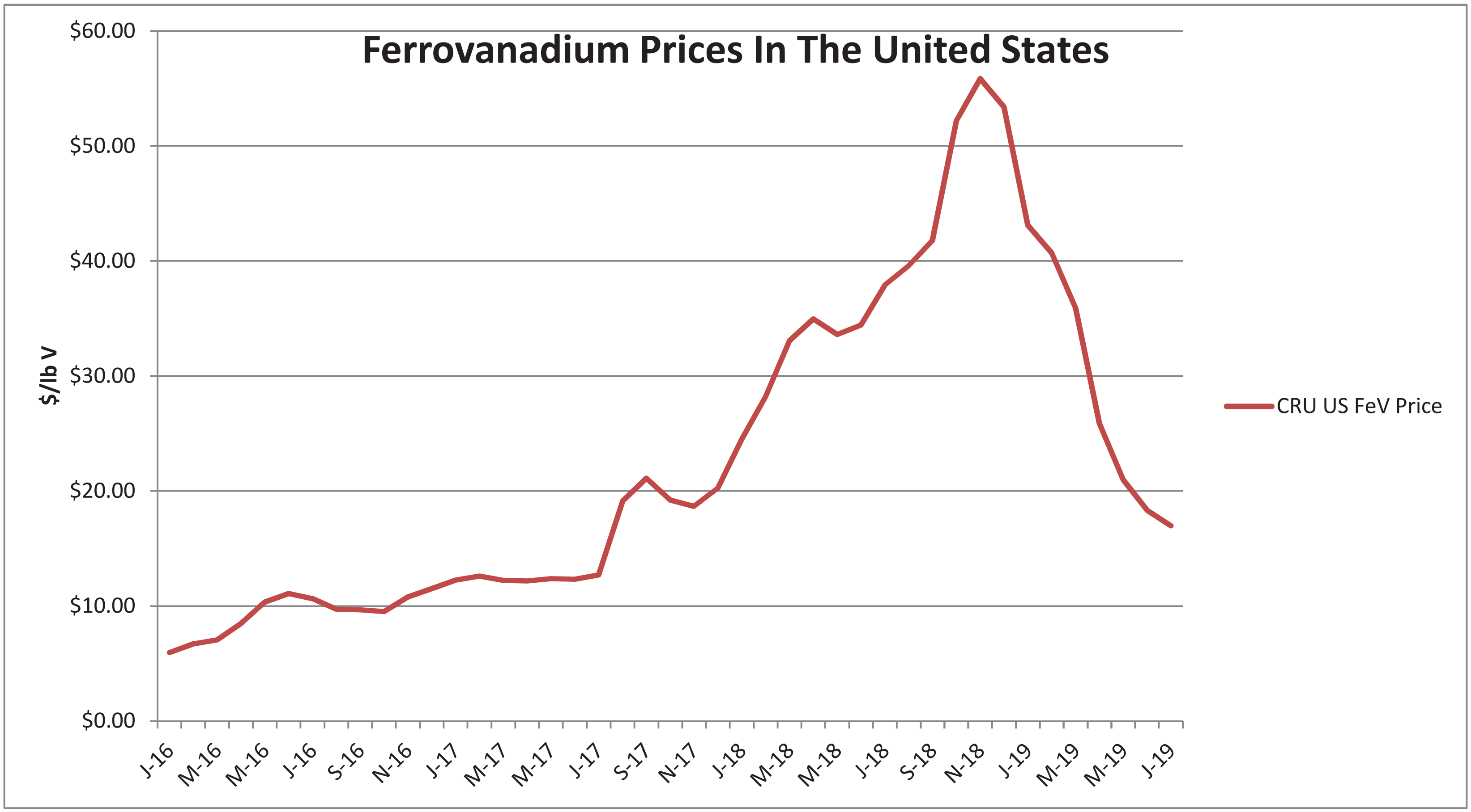
[11] This is as of August 2016.
[12] These estimates are in line with those of the Obama administration itself. Its Office of Information and Regulatory Affairs within the Office of Management and Budget estimates the cost burden at $1.7 trillion.
[13] This study focuses narrowly on opening Federal lands that are "statutorily or as a matter of administration policy prohibited from leasing" and projects savings over a seven-year period rather than the 10-year period used in this study. We use this study's figures as a proxy for broader effects and note that its narrow scope contributes to our use of only conservatively estimated impacts. In years 8 through 10, the annual costs

estimated in the Institute for Energy Research study rise to $450 billion annual, so our use of the discounted seven-year figure is conservative.

[14] The Congressional Budget Office model calculates wages as a percent of GDP at 44%, which is our proxy. See detailed revenue projections, income, wages and salaries.

[15] Note that this figure adds state and local taxes to the 35% Federal rate.

EXHIBIT 36



Source: CRU Ryan's Notes (US FeV 80% V EXW)

34547170

EXHIBIT 37

CHWMEG, Inc.

Globally Promoting Responsible Waste Stewardship

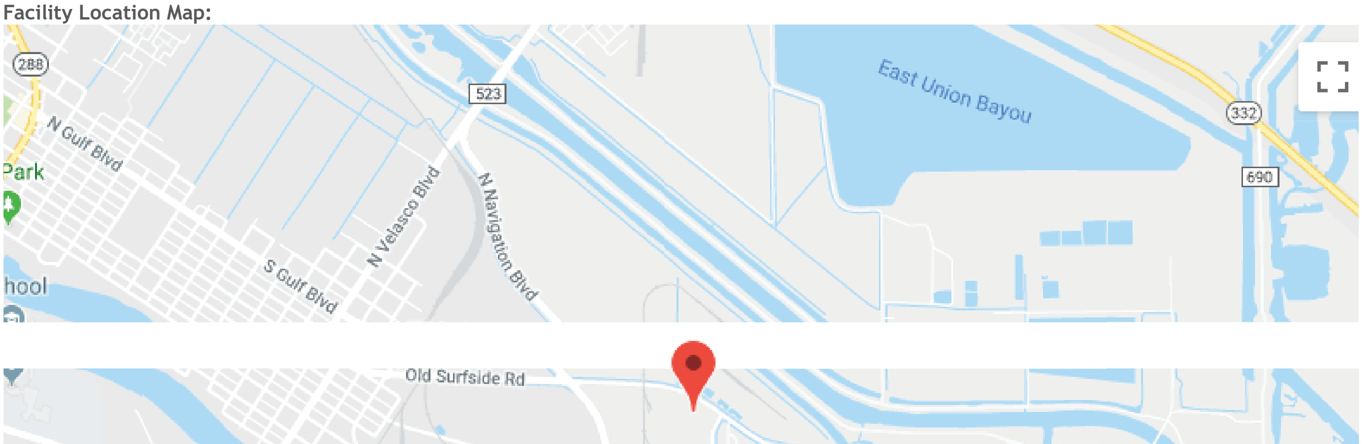
NOTE: CHWMEG Inc. is not affiliated with this facility in any way.
CHWMEG Inc. does **not** approve any facilities.

FACILITY DETAIL

Gladieux Metals Recycling
(a.k.a./f.k.a.: *Gulf Chemical & Metallurgical*)
CHWMEG Report Number: H118.9

City, State/Prov, Country:	Freeport, Texas, USA
Member Interest:	This facility is currently being tracked by 18 **members** (Member interest is not related to how many members use this facility.)
***Location Map:**	Google Maps
Review Program (Visit Date):	2015 (6/23/2015) 2014 (4/3/2014) There are 7 more reviews conducted prior to 2014 not shown.
Description of Services:	Review canceled for 2019. Review canceled for 2018. Review canceled for 2017. **Gulf Chemical filed for bankruptcy in 2016, and closed the facility in April, 2017. As of May 10, 2017, the facility is being purchased by Gladieux and will reportedly reopen by the 4th quarter 2017. 2018 Update: Operations should reopen by late 1st quarter 2019. 2019 Update: Operations should reopen by late 1st quarter 2020** The facility is a RCRA Part B facility that receives waste petroleum catalyst (hazardous and non-hazardous) ar sends it through a roasting and secondary smelting process to recover metals such as vanadium, molybdenum, nickel/cobalt alloy and fused alumina.
Description Date:	2015 Facility Review Program

Facility Location Map:



*CHWMEG, Inc. cannot guarantee the accuracy of the maps. Maps are for informational purposes only. **The latitude and longitude for this map are from the most recent CHWMEG facility review.**

EXHIBIT 38

Energy Fuels Provides Update on Vanadium Production

Lakewood, Colorado – April 1, 2019

Energy Fuels Inc. (NYSE American: UUUU; TSX: EFR) ("Energy Fuels" or the "Company"), a leading producer of uranium and vanadium in the United States, is pleased to provide the following update on the Company's ongoing vanadium production programs.

The Highest Quality Vanadium Production in the History of the White Mesa Mill:

Energy Fuels is currently producing a high-purity vanadium product at commercial rates from the pond solutions at its 100%-owned White Mesa Mill (the "Mill"), the only conventional vanadium processing facility located in the United States. The Mill has produced about 45 million pounds of vanadium pentoxide ("V_2O_5") during its nearly 40-year operating history. As a result of facility upgrades and improved procedures put in place in 2018, the Mill is currently producing the highest-purity V_2O_5 in its history, averaging approximately 99.6% V_2O_5, using innovative approaches never utilized in the past to recover vanadium from its existing pond solutions. The Company is currently selling this vanadium (as ferrovanadium) into the steel industry, and it continues to pursue opportunities to sell portions of this high-purity material into specialty chemical and aerospace markets, potentially at a premium to reported spot prices. The Company has successfully implemented this efficient, low-cost method of producing vanadium at the Mill with little capital exposure.

As previously reported, the Company estimates that a total of up to four million pounds of recoverable V_2O_5 could reside in the Mill's pond solutions. This vanadium is currently being recovered at commercial rates of approximately 150,000-160,000 pounds of V_2O_5 per month, and as a result of expected seasonal influences, could increase to approximately 200,000-225,000 pounds per month in the warmer, dryer months of the year, settling back to current production rates in the winter months. Average production rates, taking into account these expected seasonal influences, are expected to be approximately 160,000-200,000 pounds per month on an annualized basis, which would exceed the average annualized production rates during the last five full conventional vanadium ore runs at the Mill since 2008, *without having to mine a single ton of ore*. Conservatively allowing for the uncertainties associated with a new project of this nature and the impacts of seasonal influences as they unfold over the first full year of production, this is expected to result in a total recovery over the life of the project of approximately 2.5 million – 4.0 million pounds of V_2O_5, subject to continued successful recovery and supportive market conditions.

The Company is also pleased that it is able to achieve these results at a production cost per pound of recovered V_2O_5 at current production rates that is less than originally budgeted, which is resulting in margins that exceed original expectations, even at today's V_2O_5 prices of approximately $13.88 per pound. If production rates increase as expected, the production costs per pound would be expected to decrease, resulting in even more attractive margins. In addition, of course, if vanadium prices increase to recent levels, the margins would also improve.

This new source of vanadium recovery is also extremely flexible. The Company is able to turn production on and off within a matter of days, at little to no cost, in response to any changes in vanadium market conditions. If the Company decides to defer or slow down production, either due to a significant decline in the price of V_2O_5, or if it decides to retain its vanadium pond inventory for recovery and sale in potentially improved market conditions, it has the flexibility to make those decisions. If vanadium prices increase, production can then be resumed very quickly in response. The Company considers this type of production readiness/flexibility to be a great attribute of this program, and to be very attractive in the typically volatile vanadium market, with limited capital exposure.

Further Impressive Results from Test Mining Campaign at the La Sal Complex:

Energy Fuels is also pleased to provide the following update on activities at the Company's 100%-owned La Sal Complex of uranium/vanadium mines (the "La Sal Complex"). Over the past several months, the Company has been engaged in a limited conventional vanadium test-mining program at the La Sal and Pandora mines, two connected mines within the La Sal Complex, located in southeast Utah. In October 2018, the Company announced the initial results of the test-mining program, including vanadium grades averaging 1.67% V_2O_5 and uranium grades averaging 0.10% U_3O_8 over about 420 tons of mineralized material.

The Company is pleased to announce that, to date, it has mined approximately 5,200 tons of mineralized material under this test-mining program, and the grades observed early in the campaign have held since that time, averaging approximately 1.60% V_2O_5 and 0.19% U_3O_8. While these numbers are not intended to represent the basis of a new resource or reserve estimate of any kind, the Company believes that the new mining methods being tested are likely to result in reduced costs, higher grades, and higher value for mined material due to significantly improved grade control at the mine site. Furthermore, vanadium recoveries at the Mill increase as feed grade increases. Therefore, the Company believes there is a good chance that the Mill can increase average vanadium recoveries from mined ores as compared to historic performance, as a result of this improved grade control. The Company expects to deploy these new mining techniques at full production rates once the Company makes the decision to go back into full production at the La Sal Complex, and other Company-owned, fully permitted and developed uranium/vanadium mines on the Colorado Plateau, as market conditions warrant.

Through the test-mining campaign, the Company refurbished the Pandora and La Sal mines, so they are now ready to enter full production shortly following a positive commercial production decision. Due to the inherent volatility of vanadium prices, the economics of these mines are expected to be supported primarily by uranium sales contracts at prices higher than today's spot price, which may result from generally improved global uranium market conditions, or the ongoing government investigation into uranium imports into the U.S. Once uranium prices improve sufficiently, the Company expects to be able to produce significant quantities of vanadium from these mines at costs competitive to some of the lowest-cost primary vanadium mines in the World, and in a more sustainable way than has been achievable for our mines in the past, due to the new grade control techniques developed during this campaign.

Vanadium Market Update:

Historically, over many decades, prices for vanadium have been highly volatile, and they continue to be so today. The mid-point spot price of V_2O_5 in Europe began 2018 at $9.75 per pound, reached a high of $28.83 per pound in November 2018, and ended 2018 at $15.50 per pound. In 2019, spot prices rose through January, reaching a high of $17.38 per pound in February and early-March. At the current time, the spot price of V_2O_5 in Europe has dropped to $13.88 per pound. The global market for vanadium is currently primarily guided by market fundamentals and government policies in China. China is continuing to enforce strict new environmental standards, which are having the effect of restricting supply of vanadium. In addition, China is continuing to enforce new rebar standards, which require the use of more vanadium and have the effect of increasing demand. There is also a chance that China will pursue new infrastructure spending to spur economic growth, which would likely have the effect of increasing demand for steel and rebar containing vanadium.

For these reasons, the Company believes there is a good chance vanadium prices will strengthen in the coming months, reaching or surpassing the higher levels seen earlier this year.

The Company intends to continue to produce V_2O_5 from its Mill pond solutions at today's prices, which support attractive margins for the Company. We will also closely monitor vanadium market conditions and sales opportunities, including sales opportunities at a premium, and adjust the Company's production and sales if necessary.

Mark S. Chalmers, President and CEO of Energy Fuels stated: "We are extremely pleased with the excellent results obtained thus far on our significant vanadium assets, creating substantial value for the Company. Our campaign to recover vanadium from pond solutions at the White Mesa Mill is going very well. Product purities are higher than expected, production costs are lower than expected, and vanadium prices remain at high levels. We also have the ability to adjust our vanadium production very easily in response to changing market conditions. This production readiness and flexibility is a key attribute when dealing with minor metals like vanadium. It allows us to be able to produce or conserve our vanadium, as we see fit, in response to market volatility.

"We also believe we have shifted the paradigm for both mining and processing of uranium/vanadium deposits on the Colorado Plateau, including our fully permitted and developed mines at the La Sal Complex as well as two of our other fully permitted mines nearby. This will become even more important to Energy Fuels if the Trump Administration decides to help support domestic uranium mining through the ongoing Section 232 investigation into uranium imports. This could result in uranium sales contracts at prices that would support commencing full-scale production from these mines at current or lower vanadium prices. And, if vanadium prices rise further – which they could at any time – we will be in the enviable position of being able to fully capitalize on those higher prices almost immediately.

"We are first and foremost a uranium producer. But in addition, our successful re-establishing of the Company as the only primary producer of vanadium in North America through our innovative Mill pond-return program, and our ability to capitalize on high vanadium prices through our uranium/vanadium mines when producing, highlights the unique optionality of Energy Fuels, in addition to our unsurpassed uranium mining readiness and capacity and our uranium recycling and clean-up businesses. These key attributes significantly differentiate our Company from a typical 100% uranium-only play. We are extremely proud of these other aspects of our business model, which provide value to our shareholders in unique and creative ways during periods of low uranium prices and which also complement our uranium production activities during periods of higher uranium prices."

About Energy Fuels: *Energy Fuels is a leading US-based uranium mining company, supplying U_3O_8 to major nuclear utilities. The Company also produces vanadium from certain of its projects, as market conditions warrant. Its corporate offices are in Denver, Colorado, and all of its assets and employees are in the United States. Energy Fuels holds three of America's key uranium production centers, the White Mesa Mill in Utah, the Nichols Ranch in-situ recovery ("ISR") Project in Wyoming, and the Alta Mesa ISR Project in Texas. The White Mesa Mill is the only conventional uranium mill operating in the U.S. today, has a licensed capacity of over 8 million pounds of U_3O_8 per year, and has the ability to produce vanadium when market conditions warrant. The Nichols Ranch ISR Project is in operation and has a licensed capacity of 2 million pounds of U_3O_8 per year. The Alta Mesa ISR Project is currently on standby. In addition to the above production facilities, Energy Fuels also has one of the largest NI 43-101 compliant uranium resource portfolios in the U.S., and several uranium and uranium/vanadium mining projects on standby and in various stages of permitting and development. The primary trading market for Energy Fuels' common shares is the NYSE American under the trading symbol "UUUU", and the Company's common shares are also listed on the Toronto Stock Exchange under the trading symbol "EFR". Energy Fuels' website is www.energyfuels.com.*

Cautionary Note Regarding Forward-Looking Statements: *Certain information contained in this news release, including any information relating to: the Company being a leading producer of uranium and vanadium in the U.S.; any expectations about pounds of vanadium that may be recovered at the White Mesa Mill, including current and expected rates of* *production and the total amount of vanadium expected to be recovered from the Mill's pond solutions; any expectations relating to the product quality or purity of the recovered vanadium; any expectations regarding the Company's expected costs of production, margins, sales strategy, and/or ability to maximize profits on vanadium, including conversion to ferrovanadium for sale into the metallurgical market and/or sales into the aerospace, chemical or energy storage industries, at a premium to spot prices or otherwise; the Company's ability to turn production on and off within a matter of days, at little to not cost, in response to any changes in vanadium market conditions; any expectation that the new mining methods being tested are likely to result in reduced costs, higher grades, and higher value for mined material due to significantly improved grade control at the mine site; any expectation that the Mill may be able to increase average vanadium recoveries from mined ores as compared to historic performance, as a result of improved grade control resulting from the test-mining program; any expectation that the Company may be able to deploy these new mining techniques at full production rates; any expectation that the Company may be able to produce significant quantities of vanadium from any of its mines at costs competitive to some of the lowest cost primary vanadium mines in the World; any expectations regarding current and/or future vanadium markets, including whether current vanadium prices may continue to support production and increase in the future; any expectations about the ongoing Section 232 Investigation, including any remedies that may be granted thereunder, and any expectation that any such remedies may result in uranium sales contracts at sufficient prices to justify production at any of the Company's mines; and any other statements regarding Energy Fuels' future expectations, beliefs, goals or prospects; constitute forward-looking information within the meaning of applicable securities legislation (collectively, "forward-looking statements"). All statements in this news release that are not statements of historical fact (including statements containing the words "expects", "does not expect", "plans", "anticipates", "does not anticipate", "believes", "intends", "estimates", "projects", "potential", "scheduled", "forecast", "budget" and similar expressions) should be considered forward-looking statements. All such forward-looking statements are subject to important risk factors and uncertainties, many of which are beyond Energy Fuels' ability to control or predict. A number of important factors could cause actual results or events to differ materially from those indicated or implied by such forward-looking statements, including without limitation factors relating to: the Company being a leading producer of uranium and vanadium in the U.S.; any expectations about pounds of vanadium that may be recovered at the White Mesa Mill, including current and expected rates of production and the total amount of vanadium expected to be recovered from the Mill's pond solutions; any expectations relating to the product quality or purity of the recovered vanadium; any expectations regarding the Company's expected costs of production, margins, sales strategy, and/or ability to maximize profits on vanadium, including conversion to ferrovanadium for sale into the metallurgical market and/or sales into the aerospace, chemical or energy storage industries, at a premium to spot prices or otherwise; the Company's ability to turn production on and off within a matter of days, at little to not cost, in response to any changes in vanadium market conditions; any expectation that the new mining methods being tested are likely to result in reduced costs, higher grades, and higher value for mined material due to significantly improved grade control at the mine site; any expectation that the Mill may be able to increase average vanadium recoveries from mined ores as compared to historic performance, as a result of improved grade control resulting from the test-mining program; any expectation that the Company may be able to deploy these new mining techniques at full production rates; any expectation that the Company may be able to produce significant quantities of vanadium from any of its mines at costs competitive to some of the lowest cost primary vanadium mines in the World; any expectations regarding current and/or future vanadium markets, including whether current vanadium prices may continue to support production and increase in the future; any expectations about the ongoing Section 232 Investigation, including any remedies that may be granted thereunder, and any expectation that any such remedies may result in uranium sales contracts at sufficient prices to justify production at any of the Company's mines; and other risk factors as described in Energy Fuels' most recent annual report on Form 10-K and quarterly financial reports. Energy Fuels assumes no obligation to update the information in this communication, except as otherwise required by law. Additional information identifying risks and uncertainties is contained in Energy Fuels' filings with the various securities commissions which are available online at www.sec.gov and www.sedar.com. Forward-looking statements are provided for the purpose of providing information about the current expectations, beliefs and plans of the management of Energy Fuels relating to the future. Readers are cautioned that such* *statements may not be appropriate for other purposes. Readers are also cautioned not to place undue reliance on these forward-looking statements, that speak only as of the date hereof.*

Energy Fuels Inc.
Curtis Moore – VP – Marketing & Corporate Development
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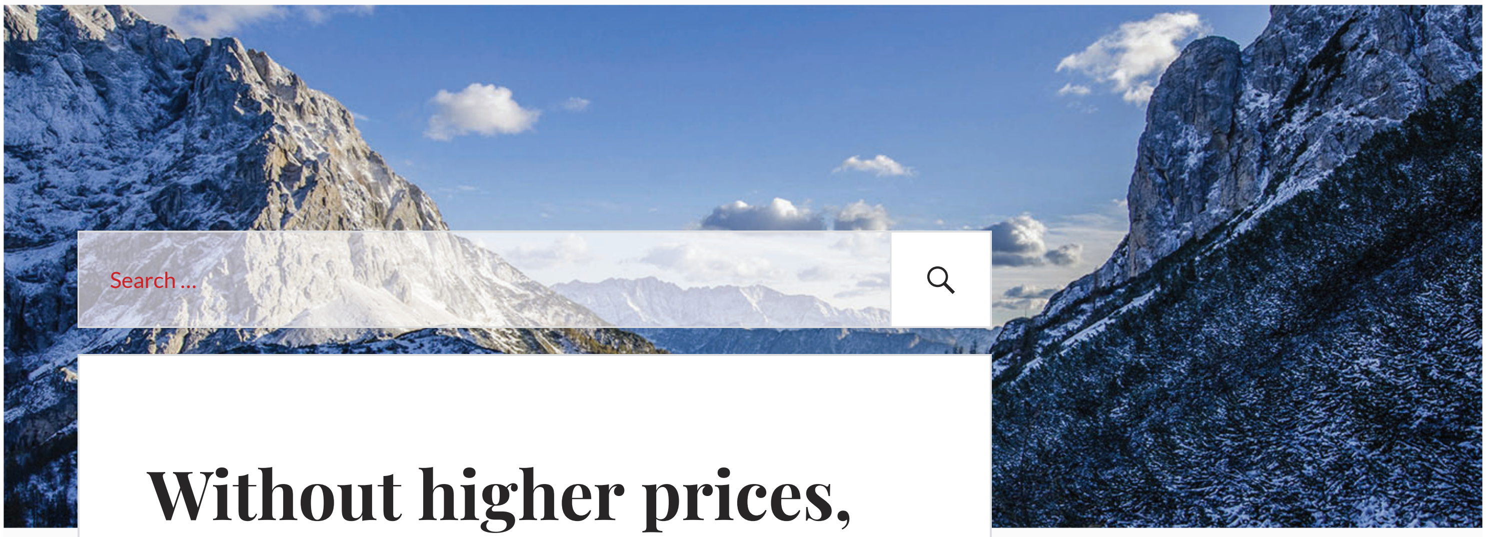
investorinfo@energyfuels.com
www.energyfuels.com

225 Union Blvd., Suite 600 Lakewood, Colorado, 80228
1.888.864.2125

EXHIBIT 39

IN THE RIGHT VEIN

patrick ryan's



Without higher prices, Energy Fuels will shut V205 recovery

ON **AUGUST 4, 2019** / BY **ALICE AGOOS** / IN **UNCATEGORIZED**

Energy Fuels, which only began recovering vanadium from tailings pond solutions at the White Mesa mill in Utah at commercial rates in February 2019 is not likely to continue producing beyond September 2019 unless prices improve significantly from current levels. In fact, Energy Fuels hinted that it might halt recovery operations before the end of September if vanadium prices fall below current levels.

The escalation of V_2O_5 prices a year ago from $9 per lb to over $28 in November 2018 prompted Energy Fuels to look to its tailings pond for vanadium. By January 2019, V_2O_5 prices had dropped to $15.50 per lb and today prices are around $8.

RECENT COMMENTS

Correction to a correction
August 21, 2019
by CCMA Sales
Thumbs up! Loading...

Chinese FeV CORRECTION
August 20, 2019
by LSALLOYS
isn't it a pity to only be able to report ...

Another record low for Ferroglobe's stock
August 15, 2019
by Rainer Metro
What is the minimum Market

Energy Fuels produced 437,000 lb of V_2O_5 in the second quarter and expects to continue to produce 160,000 to 200,000 ppm of V_2O_5 through Q3 2019 "subject to continued successful recovery and suitable sales prices." (The company estimates that the tailings pond contains 4-million lb of V_2O_5. It originally hoped to be producing at a rate of 200,000-225,000 ppm in the second quarter of 2019.)

Energy Fuels reported 98,000 lb of vanadium sales into the steel industry during the quarter at an average price of $7.87 per lb of V_2O_5, following conversion of the V_2O_5 product into ferrovanadium.

Currently, Energy Fuels is selling only small quantities of vanadium, while mainly focusing on building V_2O_5 inventory for sale in the future as the company expects prices to increase.

At the end of Q2 2019, Energy Fuels had 610,000 lb of finished vanadium goods in inventory.

Energy Fuels reported an operating loss of $11.5-million during the quarter, due primarily to an impairment to inventories of $4.9-million as a result of low uranium prices and a decrease in vanadium prices during the quarter; the decision not to sell any uranium product during the quarter; and the decision to retain most of the company's vanadium inventory for future sale.

"We are also very happy with our vanadium production campaign; except prices failed to cooperate during the quarter," said Mark Chalmers, Energy Fuels CEO. "At the current time, we expect to continue producing vanadium through Q3 2019, due in large part to seasonal considerations, while only making selective sales," he added.

Energy Fuels is moving forward with discussions to potentially sell the vanadium at premium prices to customers who require higher purities.

"If vanadium prices do not make a dramatic recovery in the next few months," Chalmers said, "we expect to build inventory to capture future price spikes and then shut down production to save this valuable asset for later recovery."

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ENERGY FUELS

PREVIOUS

Chinese yuan softens to critical CNY7:$1 ratio

NEXT

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June 3, 2019 by LSALLOYS
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EXHIBIT 40

UNITED STATES
SECURITIES AND EXCHANGE COMMISSION

Washington, D.C. 20549

FORM 10-K/A

(Amendment No. 2)

[X] ANNUAL REPORT PURSUANT TO SECTION 13 OR 15(d) OF THE SECURITIES EXCHANGE ACT OF 1934

For the fiscal year ended December 31, 2018

OR

[ ] TRANSITION REPORT PURSUANT TO SECTION 13 OR 15(d) OF THE SECURITIES EXCHANGE ACT OF 1934

For the transition period from __________________ to __________________

Commission file number: 001-36204

ENERGY FUELS INC.

(Exact Name of Registrant as Specified in its Charter)

Ontario, Canada	**98-1067994**
(State of other jurisdiction of incorporation or organization)	(I.R.S. Employer Identification No.)
225 Union Blvd., Suite 600	
Lakewood, Colorado	**80228**
(Address of Principal Executive Offices)	(Zip Code)

(303) 389-4130

(Registrant's Telephone Number, including Area Code)

SECURITIES REGISTERED PURSUANT TO SECTION 12(b) OF THE ACT:

Title of Each Class	Name of Each Exchange on Which Registered
Common Shares, no par value	**NYSE American, Toronto Stock Exchange**

SECURITIES REGISTERED PURSUANT TO SECTION 12(g) OF THE ACT: **None**

Indicate by check mark if the registrant is a well-known seasoned issuer, as defined in Rule 405 of the Securities Act.

Yes [ ] No [X]

Indicate by check mark if the registrant is not required to file reports pursuant to Section 13 or Section 15(d) of the Act.

Yes [ ] No [X]

Indicate by check mark whether the registrant (1) has filed all reports required to be filed by Section 13 or 15(d) of the Securities Exchange Act of 1934 during the preceding 12 months (or for such shorter period that the registrant was required to file such reports), and (2) has been subject to such filing requirements for the past 90 days.

Yes [X]   No [ ]

Indicate by check mark whether the Registrant has submitted electronically every Interactive Data File required to be submitted pursuant to Rule 405 of Regulation S-T (§ 229.405 of this chapter) during the preceding 12 months (or for such shorter period that the registrant was required to submit such files).

Yes [X]   No [ ]

Indicate by check mark if disclosure of delinquent filers pursuant to Item 405 of Regulation S-K (§229.405 of this Chapter) is not contained herein, and will not be contained, to the best of the registrant's knowledge, in definitive proxy or information statements incorporated by reference in Part III of this Form 10-K or any amendment to the Form 10-K. [ ]

Indicate by check mark whether the registrant is a large accelerated filer, an accelerated filer, a non-accelerated filer, a smaller reporting company, or an emerging growth company. See the definitions of "large accelerated filer", "accelerated filer", "smaller reporting company", and "emerging growth company" in Rule 12b-2 of the Exchange Act (Check one):

Large Accelerated Filer [ ]   Accelerated Filer [X]   Non-Accelerated Filer [ ]   Smaller Reporting Company [ ]

Emerging Growth Company [X]

If an emerging growth company, indicate by check mark if the registrant has elected not to use the extended transition period for complying with any new or revised financial accounting standards provided pursuant to Section 13(a) of the Exchange Act. [ ]

Indicate by check mark whether the registrant is a shell company (as defined in Rule 12b-2 of the Act).

Yes [ ]   No [X]

State the aggregate market value of the voting and non-voting common equity held by non-affiliates computed by reference to the price at which the common equity was last sold, or the average bid and asked price of such common equity, as of the last business day of the registrant's most recently completed second fiscal quarter: $196.67 million.

The number of common shares of the Registrant outstanding as of March 8, 2019 was 91,505,255.

DOCUMENTS INCORPORATED BY REFERENCE

Certain information required for Items 10, 11, 12, 13 and 14 of Part III of this Annual Report on Form 10-K is incorporated by reference to the registrant's definitive proxy statement for the 2019 Annual Meeting of Shareholders.

Explanatory Note

This Amendment No. 2 on Form 10-K/A (the “Amendment”) amends Energy Fuels Inc.’s Annual Report on Form 10-K for the fiscal year ended December 31, 2018 (the “Form 10-K”), as filed with the Securities and Exchange Commission on March 12, 2019, and is being filed solely to correct an administrative error of a missing conformed signature in The Report of Independent Registered Public Accounting Firm under Item 8 of the Form 10-K.

Pursuant to Rule 12b-15 promulgated under the Securities Exchange Act of 1934, as amended, we have repeated the entire text of Item 8 from the Form 10-K in this Amendment. However, there have been no changes to the text of such item other than the change stated in the immediately preceding paragraph.

This Amendment includes new certifications by our Principal Executive Officer and Principal Financial Officer pursuant to Sections 302 and 906 of the Sarbanes-Oxley Act of 2002 as exhibits 31.1, 31.2, 32.1 and 32.2 hereto.

Except as expressly set forth above, this Amendment does not, and does not purport to, amend, update or restate the information in any other item of the Form 10-K or reflect any events that have occurred after the filing of the original Form 10-K.

PART II

ITEM 8. FINANCIAL STATEMENTS AND SUPPLEMENTARY DATA

ENERGY FUELS INC.
CONSOLIDATED FINANCIAL STATEMENTS
December 31, 2018
Contents

Report of Independent Registered Public Accounting Firm

To the Shareholders and Board of Directors

Energy Fuels Inc.:

Opinion on the Consolidated Financial Statements

We have audited the accompanying consolidated balance sheets of Energy Fuels Inc. and subsidiaries (the Company) as of December 31, 2018 and 2017, the related consolidated statements of operations and comprehensive loss, changes in equity, and cash flows for each of the years in the two-year period ended December 31, 2018, and the related notes (collectively, the consolidated financial statements). In our opinion, the consolidated financial statements present fairly, in all material respects, the financial position of the Company as of December 31, 2018 and 2017, and the results of its operations and its cash flows for each of the years in the two-year period ended December 31, 2018, in conformity with U.S. generally accepted accounting principles.

Change in Accounting Principles

As discussed in Note 3 to the consolidated financial statements, the Company has changed its method of accounting for revenue with the adoption of ASC Topic 606 - Revenue from Contracts with Customers in 2018.

Basis for Opinion

These consolidated financial statements are the responsibility of the Company's management. Our responsibility is to express an opinion on these consolidated financial statements based on our audits. We are a public accounting firm registered with the Public Company Accounting Oversight Board (United States) (PCAOB) and are required to be independent with respect to the Company in accordance with the U.S. federal securities laws and the applicable rules and regulations of the Securities and Exchange Commission and the PCAOB.

We conducted our audits in accordance with the standards of the PCAOB. Those standards require that we plan and perform the audit to obtain reasonable assurance about whether the consolidated financial statements are free of material misstatement, whether due to error or fraud. The Company is not required to have, nor were we engaged to perform, an audit of its internal control over financial reporting. As part of our audits, we are required to obtain an understanding of internal control over financial reporting but not for the purpose of expressing an opinion on the effectiveness of the Company's internal control over financial reporting. Accordingly, we express no such opinion.

Our audits included performing procedures to assess the risks of material misstatement of the consolidated financial statements, whether due to error or fraud, and performing procedures that respond to those risks. Such procedures included examining, on a test basis, evidence regarding the amounts and disclosures in the consolidated financial statements. Our audits also included evaluating the accounting principles used and significant estimates made by management, as well as evaluating the overall presentation of the consolidated financial statements. We believe that our audits provide a reasonable basis for our opinion.

/s/ KPMG LLP

We have served as the Company's auditor since 2017.

Denver, Colorado

March 11, 2019

Report of Independent Registered Public Accounting Firm

To the Board of Directors and Shareholders

Energy Fuels Inc.:

We have audited the accompanying consolidated statements of operations and comprehensive loss, changes in equity, and cash flows of Energy Fuels Inc. for the year ended December 31, 2016. These consolidated financial statements are the responsibility of Energy Fuels Inc.'s management. Our responsibility is to express an opinion on these consolidated financial statements based on our audit.

We conducted our audit in accordance with the standards of the Public Company Accounting Oversight Board (United States). Those standards require that we plan and perform the audit to obtain reasonable assurance about whether the financial statements are free of material misstatement. An audit includes examining, on a test basis, evidence supporting the amounts and disclosures in the financial statements. An audit also includes assessing the accounting principles used and significant estimates made by management, as well as evaluating the overall financial statement presentation. We believe that our audit provides a reasonable basis for our opinion.

In our opinion, the consolidated financial statements referred to above present fairly, in all material respects, the results of its operations of Energy Fuels Inc. and its cash flows for the year ended December 31, 2016, in conformity with U.S. generally accepted accounting principles.

/s/ KPMG LLP

Chartered Professional Accountants, Licensed Public Accountants
Toronto, Canada
March 8, 2017

ENERGY FUELS INC.
Consolidated Statements of Operations and Comprehensive Loss
(Expressed in thousands of US dollars, except per share amounts)

	For the years ended December 31,		
	2018	2017	2016
Revenues			
Uranium concentrates	$ **30,789**	$ **24,467**	$ **54,432**
Alternate feed materials processing and other	932	6,579	120
Total revenues	**31,721**	**31,046**	**54,552**
Costs and expenses applicable to revenue			
Costs and expenses applicable to uranium concentrates	14,752	14,676	35,315
Costs and expenses applicable to alternate feed materials and other	—	4,729	138
Total costs and expenses applicable to revenue	**14,752**	**19,405**	**35,453**
Impairment of inventories	4,579	3,305	5,362
Development, permitting and land holding	9,912	8,821	21,118
Standby costs	5,112	3,659	10,234
Abandonment of mineral properties	—	287	1,036
Impairment of assets held for sale	—	3,799	—
Accretion of asset retirement obligation	1,835	1,733	906
Selling costs	183	275	379
Intangible asset amortization	2,502	3,297	3,319
General and administration	14,158	14,923	15,519
Total operating loss	**(21,312)**	**(28,458)**	**(38,774)**
Interest expense	(1,722)	(2,101)	(2,289)
Other income (expense)	(2,328)	2,569	1,199
Net loss	**(25,362)**	**(27,990)**	**(39,864)**
Items that may be reclassified in the future to profit and loss			
Foreign currency translation adjustment	1,554	(1,049)	(729)
Unrealized gain on available-for-sale assets	—	30	532
Other comprehensive income (loss)	**1,554**	**(1,019)**	**(197)**
Comprehensive loss	$ **(23,808)**	$ **(29,009)**	$ **(40,061)**
Net loss attributable to:			
Owners of the Company	$ **(25,245)**	$ **(27,766)**	$ **(39,413)**
Non-controlling interests	(117)	(224)	(451)
	$ **(25,362)**	$ **(27,990)**	$ **(39,864)**
Comprehensive loss attributable to:			
Owners of the Company	$ **(23,691)**	$ **(28,785)**	$ **(39,610)**
Non-controlling interests	(117)	(224)	(451)
	$ **(23,808)**	$ **(29,009)**	$ **(40,061)**
Basic and diluted loss per share	$ **(0.30)**	$ **(0.39)**	$ **(0.70)**

See accompanying notes to the consolidated financial statements.

ENERGY FUELS INC.
Consolidated Balance Sheets
(Expressed in thousands of US dollars, except share amounts)

		December 31, 2018		December 31, 2017
ASSETS				
Current assets				
Cash and cash equivalents	**$**	**14,640**	$	18,574
Marketable securities		**27,061**		1,034
Trade and other receivables, net		**1,191**		1,253
Inventories, net		**16,550**		16,550
Prepaid expenses and other assets		**1,411**		780
Mineral properties held for sale		**—**		5,000
Total current assets		**60,853**		43,191
Investments accounted for at fair value		**1,107**		903
Inventories, net		**1,772**		—
Plant and equipment, net		**29,843**		33,076
Mineral properties, net		**83,539**		83,539
Intangible assets, net		**—**		2,502
Restricted cash		**19,652**		22,127
Total assets	**$**	**196,766**	$	185,338
LIABILITIES & EQUITY				
Current liabilities				
Accounts payable and accrued liabilities	**$**	**7,921**	$	6,449
Current portion of Warrant liabilities		**662**		—
Current portion of asset retirement obligation		**270**		32
Current portion of loans and borrowings		**—**		3,414
Total current liabilities		**8,853**		9,895
Warrant liabilities		**5,621**		3,376
Deferred revenue		**2,724**		2,474
Asset retirement obligation		**18,834**		18,248
Loans and borrowings		**15,880**		24,077
Total liabilities		**51,912**		58,070
Equity				
Share capital Common shares, without par value, unlimited shares authorized; shares issued and outstanding 91,445,066 at December 31, 2018 and 74,366,824 at December 31, 2017		**469,303**		430,383
Accumulated deficit		**(332,058)**		(309,287)
Accumulated other comprehensive income		**3,843**		2,289
Total shareholders' equity		**141,088**		123,385
Non-controlling interests		**3,766**		3,883
Total equity		**144,854**		127,268
Total liabilities and equity	**$**	**196,766**	$	185,338
Commitments and contingencies (Note 19)				

See accompanying notes to the consolidated financial statements.

ENERGY FUELS INC.
Consolidated Statements of Changes in Equity
(Expressed in thousands of US dollars, except share amounts)

	Common Stock						
	Shares	Amount	Deficit	Accumulated other comprehensive income	Total shareholders' equity	Non-controlling interests	Total equity
Balance at December 31, 2015	**46,519,132**	**$ 373,934**	**$ (242,108)**	**$ 3,505**	**$ 135,331**	**$ 4,156**	**$ 139,487**
Net loss	—	—	(39,413)	—	(39,413)	(451)	(39,864)
Other comprehensive income	—	—	—	(197)	(197)	—	(197)
Shares issued for cash by at-the-market offering	200,225	539	—	—	539	—	539
Shares issued for public offerings	13,368,750	22,980	—	—	22,980	—	22,980
Share issuance cost	—	(2,330)	—	—	(2,330)	—	(2,330)
Share-based compensation	—	2,657	—	—	2,657	—	2,657
Shares issued for exercise of stock options	8,369	18	—	—	18	—	18
Shares issued for the vesting of restricted stock units	138,608	—	—	—	—	—	—
Shares issued for acquisition of Alta Mesa	4,551,284	11,378	—	—	11,378	—	11,378
Shares issued for acquisition of 40% interest in Roca Honda	1,212,173	2,679	—	—	2,679	—	2,679
Shares issued for consulting services	206,612	479	—	—	479	—	479
Contributions attributable to non-controlling interest	—	—	—	—	—	37	37
Balance at December 31, 2016	**66,205,153**	**$ 412,334**	**$ (281,521)**	**$ 3,308**	**$ 134,121**	**$ 3,742**	**$ 137,863**
Net loss	—	—	(27,766)	—	(27,766)	(224)	(27,990)
Other comprehensive income	—	—	—	(1,019)	(1,019)	—	(1,019)
Shares issued for cash by at-the-market offering	7,202,479	14,548	—	—	14,548	—	14,548
Shares issued for the vesting of restricted stock units	752,580	—	—	—	—	—	—
Share issuance cost	—	(394)	—	—	(394)	—	(394)
Share-based compensation	—	3,525	—	—	3,525	—	3,525
Shares issued for consulting services	206,612	370	—	—	370	—	370
Contributions attributable to non-controlling interest	—	—	—	—	—	365	365
Balance at December 31, 2017	**74,366,824**	**$ 430,383**	**$ (309,287)**	**$ 2,289**	**$ 123,385**	**$ 3,883**	**$ 127,268**
Balance at January 1, 2018 as previously reported	74,366,824	$ 430,383	$ (309,287)	$ 2,289	$ 123,385	$ 3,883	$ 127,268
Impact of change in accounting policy			$ 2,474		$ 2,474		$ 2,474
Adjusted balance at January 1, 2018	**74,366,824**	**$ 430,383**	**$ (306,813)**	**$ 2,289**	**$ 125,859**	**$ 3,883**	**$ 129,742**
Net loss	—	$ —	$ (25,245)	$ —	$ (25,245)	$ (117)	$ (25,362)
Other comprehensive income	—	$ —	$ —	$ 1,554	$ 1,554	$ —	$ 1,554
Shares issued for cash by at-the-market offering	14,283,254	$ 32,192	$ —	$ —	$ 32,192	$ —	$ 32,192
Share-based compensation	—	$ 2,762	$ —	$ —	$ 2,762	$ —	$ 2,762
Shares issued for acquisition of royalties	1,102,840	$ 3,739	$ —	$ —	$ 3,739	$ —	$ 3,739
Shares issued for the vesting of restricted stock units	899,192	$ —	$ —	$ —	$ —	$ —	$ —
Share issuance cost	—	$ (922)	$ —	$ —	$ (922)	$ —	$ (922)
Shares issued for consulting services	247,485	$ 569	$ —	$ —	$ 569	$ —	$ 569

Cash paid to fund employee income tax withholding due upon vesting of restricted stock units	—	$	(914)	$	—	$	—	$	(914)	$	—	$	(914)
Shares issued for exercise of warrants	187,970	$	722	$	—	$	—	$	722	$	—	$	722
Shares issued for exercise of options	355,092	$	764	$	—	$	—	$	764	$	—	$	764
Shares issued for conversion of Debentures	2,409	$	8	$	—	$	—	$	8	$	—	$	8
Balance at December 31, 2018	**91,445,066**	**$**	**469,303**	**$**	**(332,058)**	**$**	**3,843**	**$**	**141,088**	**$**	**3,766**	**$**	**144,854**

See accompanying notes to the consolidated financial statements.

ENERGY FUELS INC.
Consolidated Statements of Cash Flows
(Expressed in thousands of US dollars)

	December 31, 2018	December 31, 2017	December 31, 2016
OPERATING ACTIVITIES			
Net loss for the period	**$ (25,362)**	$ (27,990)	$ (39,864)
Items not involving cash:			
Depletion, depreciation and amortization	**3,790**	4,636	4,258
Stock-based compensation	**2,762**	3,525	2,657
Change in value of convertible Debentures	**612**	940	407
Accretion of asset retirement obligation	**1,835**	1,733	906
Change in value of warrant liabilities	**3,470**	(784)	—
Unrealized foreign exchange (gain) loss	**(218)**	(263)	173
Non-cash standby cost accrued	**(662)**	249	4,186
Impairment of inventories	**4,579**	3,305	5,362
Abandonment of mineral properties	**—**	287	1,036
Acquisition of royalty interests	**3,622**	—	—
Impairment of mineral properties held for sale	**—**	3,799	—
Other non- cash (income) expense	**1,303**	1,909	(437)
Changes in assets and liabilities			
(Increase) decrease in inventories	**(4,299)**	73	13,158
(Increase) decrease in trade and other receivables	**(346)**	(39)	2,403
(Increase) decrease in prepaid expenses and other assets	**(631)**	290	(365)
Decrease in accounts payable and accrued liabilities	**(613)**	(1,410)	(4,007)
Changes in deferred revenue	**2,724**	135	174
Cash paid for reclamation and remediation activities	**(350)**	(735)	(2,086)
	(7,784)	(10,340)	(12,039)
INVESTING ACTIVITIES			
Purchase of mineral properties and property, plant and equipment	**(107)**	—	(260)
Purchase of marketable securities	**(25,554)**	—	—
Acquisition of Alta Mesa, net of cash acquired	**—**	—	3,242
Acquisition of Roca Honda, net of cash acquired	**—**	—	101
Proceeds from sale of mineral properties	**—**	—	845
Cash received from sale of Reno Creek	**2,940**	**—**	—
Proceeds from sale of marketable securities	**2,554**	**—**	—
	(20,167)	—	3,928

FINANCING ACTIVITIES			
Issuance of common shares for cash, net of issuance costs	**31,517**	14,154	25,291
Cash paid to fund employee income tax withholding due upon vesting of restricted stock units	**(914)**	—	—
Cash received for notes receivable	**500**	—	—
Cash received from exercise of stock option	**764**	—	—
Cash received from exercise of warrants	**601**	—	18
Repayment of loans and borrowings	**(10,855)**	(4,095)	(3,168)
Cash received from non-controlling interest	**—**	365	37
	21,613	10,424	22,178
CHANGE IN CASH, AND CASH EQUIVALENTS AND RESTRICTED CASH DURING THE PERIOD	**(6,338)**	84	14,067
Effect of exchange rate fluctuations on cash held in foreign currencies	**(71)**	541	64
Cash, cash equivalents and restricted cash - beginning of period	**40,701**	40,076	25,945
CASH, CASH EQUIVALENTS and RESTRICTED CASH- END OF PERIOD	**$ 34,292**	$ 40,701	$ 40,076
Non-cash investing and financing transactions:			
Issuance of common shares for acquisition of Alta Mesa	**—**	—	11,378
Issuance of common shares for acquisition of 40% interest in Roca Honda	**—**	—	2,679
Issuance of common shares for consulting services	**569**	370	479
Supplemental disclosure of cash flow information:			
Net cash paid during the period for:			
Interest	**1,722**	2,097	2,029
Warrant liability transferred to equity upon exercise	**115**	—	—

See accompanying notes to the consolidated financial statements.

1. THE COMPANY AND DESCRIPTION OF BUSINESS

Energy Fuels Inc. was incorporated under the laws of the Province of Alberta and was continued under the Business Corporations Act (Ontario).

Energy Fuels Inc. and its subsidiary companies (collectively "**the Company**" or "**EFI**") are engaged in uranium extraction, recovery and sales of uranium from mineral properties and the recycling of uranium bearing materials generated by third parties. As a part of these activities the Company also acquires, explores, evaluates and, if warranted, permits uranium properties. The Company's final uranium product, uranium oxide concentrates ("U_3O_8" or "**uranium concentrates**"), is sold to customers for further processing into fuel for nuclear reactors. The Company also produces vanadium along with uranium at certain of its Colorado Plateau properties, as market conditions warrant.

The Company is an exploration stage mining company as defined by the United States ("**U.S.**") Securities and Exchange Commission ("**SEC**") Industry Guide 7 ("**SEC Industry Guide 7**") as it has not established the existence of proven or probable reserves on any of our properties.

Energy Fuels is engaged in conventional and In-situ ("**ISR**") uranium extraction and recovery, along with the exploration, permitting and evaluation of uranium properties in the United States.

Mining activities

Mining activities consist of a standalone uranium recovery facility (the "**White Mesa Mill**"), an ISR recovery facility, conventional mining projects and ISR mining projects. The conventional projects are located in the Colorado Plateau, Henry Mountains, Arizona Strip, and the Roca Honda project in New Mexico which are in the vicinity of the White Mesa Mill, and the Sheep Mountain Project in Wyoming. ISR projects include the Nichols Ranch Project, the Jane Dough property and the Hank Project located in Wyoming and the Alta Mesa ISR Project (the "**Alta Mesa Project**") located in Texas.

At December 31, 2018, other than shaft-sinking and evaluation work at the Company's Canyon Project, and a small-scale test-mining project at the Company's La Sal complex, the conventional mining projects in the vicinity of the White Mesa Mill and Sheep Mountain are on standby, being evaluated for continued mining activities and/or in process of being permitted. The White Mesa Mill also processes third party uranium bearing mineralized materials from mining and recycling activities.

2. BASIS OF PRESENTATION

The consolidated financial statements have been prepared in accordance with accounting principles generally accepted in the United States ("**US GAAP**") and are presented in thousands of US dollars ("**USD**") except per share amounts. Certain footnote disclosures have share prices which are presented in Canadian dollars ("**Cdn$**").

3. SUMMARY OF SIGNIFICANT ACCOUNTING POLICIES

Use of estimates

The Company's consolidated financial statements have been prepared in accordance with U.S. GAAP. The preparation of the Company's consolidated financial statements requires the Company to make estimates and assumptions that affect the reported amounts of assets and liabilities and the related disclosure of contingent assets and liabilities at the date of the consolidated financial statements and the reported amounts of expenses during the reporting period. The more significant areas requiring the use of management estimates and assumptions relate to expectations of the future price of uranium and estimates of recoverable mineral resources that are the basis for future cash flow estimates utilized in assessing fair value for business combinations and impairment calculations; the determination of whether an acquisition represents a business combination or an asset acquisition; the use of management estimates and assumptions related to environmental, reclamation and closure obligations; marketable securities and derivative instruments; and stock-based compensation expense. Actual results may differ significantly from these estimates.

Basis of consolidation

These consolidated financial statements include the accounts of the Company together with subsidiaries controlled by the Company. Inter-company transactions, balances and unrealized gains on transactions between the Company and its subsidiaries are eliminated. The functional currency of the Company's operations is the USD.

Extracting and recovery activities while in the exploration stage

The Company extracts or recovers mineralized uranium from mining activities, mill tailings pond solutions, and alternate feed materials, resulting in saleable uranium concentrates from its White Mesa Mill and its Nichols Ranch Project. While the Company has established the existence of mineral resources and extracts and processes saleable uranium from these operations, the Company has not established proven or probable reserves, as defined under SEC Industry Guide 7, for these operations or any of its uranium projects. Furthermore, the Company has no current plans to establish proven or probable reserves for any of its uranium projects.

While in the exploration stage, the Company expenses most amounts that would normally be capitalized and subsequently depreciated or depleted over the life of the mining operation on properties that have proven or probable reserves. Items such as the construction of wellfields and related header houses, additions to recovery facilities and advancement of properties are expensed in the period incurred. As a result, the Company's consolidated financial statements may not be directly comparable to the financial statements of mining companies in the development or production stages.

The White Mesa Mill, and certain conventional mining projects in the vicinity of the White Mesa Mill, and the Nichols Ranch Project (collectively the "**Extracting and Recovery Operations**") were acquired in two unrelated business combinations. These Extracting and Recovery Operations were recorded at fair value on the date of the respective acquisition and included estimated values which included valuing these assets utilizing the Company's estimate of future market prices of uranium and expected recoveries of uranium. The values determined included estimated cash flows associated with value beyond proven and probable reserves to develop, extract and recover the estimated saleable uranium concentrates from these operations.

The fair value of the Extracting and Recovery Operations recorded on the acquisition date is depreciated on a straight-line basis over the estimated useful life of the components of the operation since the Extracting and Recovery Operations do not have proven or probable reserves. Accordingly, all expenditures incurred subsequent to the acquisition dates relating to the preparation of properties for mineral extraction, expansion of or additions to the Extracting and Recovery Operations are expensed as incurred. This includes expenditures relating to activities such as preparing properties for mineral extraction, construction of mine wellfields, header houses and disposal wells and additions to the recovery facilities are expensed as incurred as no proven or probable reserves have been established for these uranium projects.

Business combinations

Business combinations are accounted for using the acquisition method whereby acquired assets and liabilities are recorded at fair value as of the date of acquisition with any excess of the purchase consideration over such fair value being recorded as goodwill. If the fair value of the net assets acquired exceeds the purchase consideration, the difference is recognized immediately as a gain in the consolidated statement of operations.

Mining assets, which include mineral properties and rights, operating mines and recovery facilities, are recorded at fair value and includes estimated values of the mining assets beyond proven and probable reserves as well as the Company's estimate of future market prices of uranium. The estimated cash flow used to value the mining assets for operating properties and recovery facilities include the estimated cash outflows required to develop, extract and recover the value beyond proven and probable reserves.

Non-controlling interest in an acquisition may be measured at either fair value or at the non-controlling interest's proportionate share of the fair value of the acquiree's net identifiable assets. The acquisition date is the date the Company acquires control over the acquiree. The Company considers all relevant facts and circumstances in determining the acquisition date.

Acquisition related costs, other than costs to issue debt or equity securities of the acquirer, including investment banking fees, legal fees, accounting fees, change in control payments, valuation fees and other professional or consulting fees are expensed as incurred.

Impairment of assets

The Company reviews and evaluates its long-lived assets for impairment when events or changes in circumstances indicate that the related carrying amounts may not be recoverable. Mineral properties are monitored for impairment based on factors such as mineral prices, government regulation and taxation, the Company's continued right to explore the area, exploration reports, assays, technical reports, drill results and its continued plans to fund exploration programs on the property.

At each reporting date, the Company reviews its assets to determine whether there is any indication of impairment. If any such indication exists, the asset is tested for impairment. Impairment losses are recognized in profit or loss.

Recoverability is measured by comparing the undiscounted future net cash flows to the net book value. When the net book value exceeds future net undiscounted cash flows, the fair value is compared to the net book value and an impairment loss may be measured and recorded based on the excess of the net book value over fair value. Fair value for operating mines is determined using a combined approach, which uses a discounted cash flow model for the existing operations and non-operating properties with available cash flow models and a market approach for the fair value assessment of non-operating and exploration properties where no cash flow model is available. Future cash flows are estimated based on quantities of recoverable mineralized material, expected uranium prices (considering current and historical prices, trends and estimates), production levels, operating costs, capital requirements and reclamation costs, all based on life-of-mine plans. In estimating future cash flows, assets are grouped at the lowest level, for which there are identifiable cash flows that are largely independent of future cash flows from other asset groups. The Company's estimates of future cash flows are based on numerous assumptions and it is possible that actual future cash flows will be significantly different than the estimates, as actual future quantities of recoverable minerals, uranium prices, production levels, costs and capital are each subject to significant risks and uncertainties.

Cash and cash equivalents

Cash and cash equivalents consist of all cash balances and highly liquid investments with an original maturity of three months or less. Because of the short maturity of these investments, the carrying amounts approximate their fair value. Restricted cash is excluded from cash and cash equivalents and is included in other current or long-term assets, depending on the nature of the restriction.

Marketable securities

Marketable debt securities consist of excess cash invested in U.S. government notes, U.S. government agencies and tradeable certificates of deposits. We have classified and accounted for our marketable debt securities as available-for-sale. After consideration of our risk versus reward objectives, as well as our liquidity requirements, we may sell these debt securities prior to their stated maturities. As we view these securities as available to support current operations, we classify highly liquid securities with maturities beyond 12 months as current assets under the caption marketable securities on the Consolidated Balance Sheet. Subsequent to initial recognition, they are measured at fair value and changes therein, are recognized as a component of other (loss) income in the Consolidated Statements of Operations.

Marketable equity securities consist of investments in publicly traded equity securities. We have classified and accounted for our marketable equity securities as available for sale. Subsequent to initial recognition, they are measured at fair value and changes therein are recognized as a component of other (loss) income in the Consolidated Statements of Operations.

Investments at fair value

The Company accounts for investments over which the Company exerts significant influence, but not control, over the financial and operating policies through the fair value option of ASC Topic *825 – Financial Instruments*. The cost of such investments is measured at the fair value of the assets given up, shares issued or liabilities assumed at the date of acquisition plus costs directly attributable to the acquisition. Subsequent to initial recognition, they are measured at fair value and changes therein, are recognized in earnings.

Unrealized gains and losses on transactions between the Company and its associates are eliminated to the extent of the Company's interest in its associates.

Inventories

Expenditures related to the extraction and recovery of uranium concentrates and depreciation of the acquisition cost of the Extracting and Recovery Operations are inventoried as stockpiles and in-process and concentrate inventories.

Stockpiles are comprised of uranium or uranium/vanadium bearing materials that have been extracted from properties and are available for further processing. Extraction costs are added to the stockpile as incurred and removed from the stockpile based upon the average cost per ton of material extracted. The current portion of material in stockpiles represents the amount expected to be processed in the next twelve months.

In-process and concentrate inventories include the cost of the material processed from the stockpile, as well as production costs incurred to extract uranium bearing fluids from the wellfields, and all costs to recover the uranium into concentrates or process through the White Mesa Mill. Finished uranium concentrate inventories also include costs of any finished product purchased from the market. Recovery costs typically include labor, chemical reagents and directly attributable mill and plant overhead expenditures.

Materials and other supplies held for use in the recovery of uranium concentrates are added to the costs of inventories when consumed in the uranium extraction process.

Inventories are valued at the lower of average cost or net realizable value.

Plant and equipment

a. Recognition and measurement

Plant and equipment are measured at cost less accumulated depreciation, and any accumulated impairment losses. Cost includes expenditures that are directly attributable to the acquisition of the asset. Subsequent costs are included in the asset's carrying amount or recognized as a separate asset, when it is replaced, and the cost of the replacement asset is expensed.

b. *Depreciation and amortization*

Depreciation and amortization are calculated on a straight-line basis to their estimated residual value over an estimated useful life which ranges from 3 to 15 years depending upon the asset type. When assets are retired or sold, the resulting gains or losses are reflected in current earnings as a component of other income or expense. Residual values, method of depreciation and useful lives of the assets are reviewed at least annually and adjusted if appropriate.

Where straight-line depreciation is utilized, the range of useful lives for various asset classes is generally as follows:

•	Buildings	15 years
•	Shop tools and equipment	3-5 years
•	Mining equipment	5 years
•	Office equipment	4-5 years
•	Furniture and fixtures	5-7 years
•	Light trucks & utility vehicles	5 years

The amortization method, residual values, and useful lives of plant and equipment are reviewed annually, and any change in estimate is applied prospectively.

Intangible assets

Sales contracts acquired in a business combination are recognized initially at fair value at the acquisition date. The Company's intangible assets are recorded at cost less accumulated amortization.

Amortization is recorded as the Company sells inventory under its long-term sales contracts based on units sold and is recognized in the statement of operations.

Non-operating assets

Non-operating assets consist of mineral properties and rights, along with data and analyses related to the properties, which are in various stages of evaluation and permitting. Costs to acquire the non-operating assets are capitalized at cost or fair value if such assets were a part of a business combination.

Mining activities for non-operating assets involve the search for minerals, the determination of technical feasibility and the assessment of commercial viability of an identified resource. Expenditures incurred in relation to such mining activities include costs which are directly attributable to researching and analyzing existing exploration data; conducting geological studies, exploratory drilling and sampling; examining and testing extraction and treatment methods; and completing pre-feasibility and feasibility studies. Such expenditures are expensed as incurred.

Mineral properties, that are not held for production, and any related surface access to the minerals generally require periodic payments and/or certain expenditures related to the property in order for the Company to retain its interest in the mineral property (collectively, "**Holding Costs**"). The Company expenses all Holding Costs in the period they are incurred.

Stand-by properties

Stand-by properties are mineral properties that have extracted mineral resources in the past but are currently non-operating or properties which could extract mineral resources in the future. Expenditures related to these properties are primarily related to maintaining the assets and permits in a condition that will allow re-start of the operations or development given appropriate commodity prices. All costs related to stand-by assets are expensed as incurred.

The White Mesa Mill operates on a campaign basis. When the White Mesa Mill is not recovering material, all related costs are expensed as incurred.

Asset retirement obligations

The Company's ARO relates to expected mine, wellfield, plant and mill reclamation and closure activities, as well as costs associated with reclamation of exploration drilling. The Company's activities are subject to numerous governmental laws and regulations. Estimates of future reclamation liabilities for ARO are recognized in the period when such liabilities are incurred. These estimates are updated on a periodic basis and are subject to changing laws, regulatory requirements, changing technology and other factors which will be recognized when appropriate. Liabilities related to site restoration include long-term treatment and monitoring costs and incorporate total expected costs net of recoveries. Expenditures incurred to dismantle facilities, restore and monitor closed resource properties are charged against the related AROs.

As the Company has no proven or probable reserves, such costs, discounted to their present value, are expensed as soon as the obligation to incur such costs arises. The present value of AROs is measured by discounting the expected cash flows using a discount factor that reflects the credit-adjusted risk-free rate of interest, while taking into account an inflation rate. The decommissioning liability is accreted to full value over time through periodic accretion charges recorded to operations as accretion expense. The Company adjusts the estimate of the ARO for changes in the amount or timing of underlying future cash outflows. The impact of these adjustments to the ARO amounts are expensed as incurred.

Loans and borrowings

The Company's convertible Debentures are recognized at fair value through the fair value option based on the closing price on the TSX and changes are recognized in earnings as a component of other income (expense) . The Company's interest-bearing loans and borrowings are measured at amortized cost using the effective interest method.

Warrant liabilities

The Company issued several tranches of warrants for various equity transactions in 2016. The Company accounts for its warrants issued in accordance with the U.S. GAAP accounting guidance under FASB ASC Topic 815 *Derivative and Hedging* ("ASC 815") which requires instruments within its scope to be recorded on the balance sheet as either an asset or liability measured at its fair value, with changes in fair value recognized in earnings. In accordance with ASC 815, the Company has classified the warrants as liabilities. The warrants are subject to re-measurement at each balance sheet date, with any change in fair value recognized as a component of other income (expense), net in the statements of operations. The Company estimates the fair value of these warrants using market prices, if available, or the Black-Scholes option pricing model. The Black-Scholes option pricing model is based on the estimated market value of the underlying common stock at the measurement date, the remaining contractual term of the warrant, risk-free interest rates and expected dividends on, and expected volatility of the price of the underlying common stock.

Revenue

a. Sale of goods

Revenue from the sale of mineral concentrates is recognized when it is probable that the economic benefits will flow to the Company and delivery has occurred, title has transferred, the sales price and costs incurred with respect to the transaction can be measured reliably, and collectability is reasonably assured. For uranium concentrates, revenue is typically recognized when delivery is evidenced by book transfer at the applicable uranium storage facility.

b. Rendering of services

Revenue from toll milling services is recognized as material is processed in accordance with the specifics of the applicable toll milling agreement. Revenue and unbilled accounts receivable are recorded as related costs are incurred using billing formulas included in the applicable toll milling agreement. Deferred revenues represent proceeds received from processing of toll materials where the company has not delivered the material to the customer.

Taxes assessed by a governmental authority that are both imposed on and concurrent with a specific revenue-producing transaction, that are collected by the Company from a customer, are excluded from revenue.

Share-based compensation

The Company records share based compensation awards exchanged for employee services at fair value on the date of the grant and expenses the awards in the consolidated statement of operations over the requisite employee service period in capital stock. The fair value of stock options is determined using the Black-Scholes valuation model. The fair value of restricted stock units ("**RSUs**") is based on the Energy Fuels' stock price on the date of grant. The fair value of stock appreciation rights ("**SARs**") with performance conditions is based on a Monte Carlo simulation performed by a third-party valuation firm. Stock based compensation expense related to awards with only service conditions has a graded vesting schedule which are recorded on a straight-line basis over the requisite service period for each separately vesting portion of the award as if the award was, in substance, multiple awards, while all other awards are recognized on a straight-line basis. The Company's estimates may be impacted by certain variables including, but not limited to, stock price volatility, employee stock option exercise behaviors, additional stock option grants, estimates of forfeitures, the Company's performance, and related tax impacts.

Foreign currency

Transactions in foreign currencies are translated to the respective functional currency of the Company's subsidiaries and joint ventures at exchange rates at the dates of the transactions. Monetary assets and liabilities denominated in foreign currencies are translated to the functional currency at the exchange rate as of the reporting date. Non-monetary assets and liabilities that are measured at fair value in a foreign currency are translated to the functional currency at the exchange rate when the fair value was determined. Foreign currency differences are generally recognized in profit or loss. Non-monetary items that are measured based on historical cost in a foreign currency are not translated.

The assets and liabilities of entities whose functional currency is not the U.S. dollar are translated into the U.S. dollar at the exchange rate as of the reporting date. The income and expenses of such entities are translated into the U.S. dollar using average exchange rates for the reporting period. Exchange differences on foreign currency translations are recorded in other comprehensive income (loss). The Company's functional currency is the U.S. dollar.

Income taxes

The Company uses the asset and liability method of accounting for income taxes. Under this method, deferred income tax assets and liabilities are recorded based on differences between the financial statement carrying values of existing assets and liabilities and their respective income tax bases (temporary differences), and losses carried forward. Deferred income tax assets and liabilities are measured using the enacted tax rates which will be in effect when the temporary differences are likely to reverse. The effect on deferred income tax assets and liabilities of a change in tax rates is included in operations in the period in which the change is enacted.

The Company records a valuation allowance to reduce deferred income tax assets to the amount that is believed more likely than not to be realized. When the Company concludes that all or part of the deferred income tax assets are not realizable in the future, the Company makes an adjustment to the valuation allowance that is charged to income tax expense in the period such determination is made.

Net loss per share

The Company presents basic and diluted loss per share data for its common shares, calculated by dividing the loss attributable to common shareholders of the Company by the weighted average number of common shares outstanding during the period. Diluted loss per share is determined by adjusting the loss attributable to common shareholders and the weighted average number of common shares outstanding for the effects of all potential dilutive instruments.

Recently Adopted Accounting Pronouncements

Investments

In January 2016, ASU No. 2016-01 was issued related to financial instruments. The new guidance requires entities to measure equity investments that do not result in consolidation and are not accounted for under the equity method at fair value and recognize any changes in fair value in net income. This new guidance also updates certain disclosure requirements for these investments. This update is effective in fiscal years, including interim periods, beginning after December 15, 2017, and early adoption is not permitted. Adoption of this standard has no impact on the Company's financial statements as the Company had previously elected to account for these investments using the fair value option.

Revenue recognition

In May 2014, the FASB issued ASU No. 2014-09, as amended by ASU No. 2016-12, "Revenue from Contracts with Customers (Topic 606)," which requires revenue to be recognized based on the amount an entity is expected to be entitled to for promised goods or services provided to customers. The standard also requires expanded disclosures regarding contracts with customers. The guidance in this standard supersedes the revenue recognition requirements in Topic 605, "Revenue Recognition," and most industry-specific guidance. Adoption of the standard may be applied retrospectively to each prior period presented (full retrospective method) or retrospectively with the cumulative effect recognized as of the date of initial application (modified retrospective method). The Company adopted this guidance effective January 1, 2018 and applied the modified retrospective method with the as if revenue were recognized under Topic 605 See Note 22 for further discussion.

Statement of cash flows

In November 2016, the FASB issued ASU 2016-18, "Statement of Cash Flows (Topic 230): Restricted Cash" which became effective beginning January 1, 2018. This standard requires us to show the changes in the total of cash, cash equivalents, restricted cash and restricted cash equivalents in the statement of cash flows and will no longer require transfers between cash and cash equivalents and restricted cash and restricted cash equivalents in the statement of cash flows. As a result of including restricted cash with cash and cash equivalents when reconciling the beginning-of-period and end-of period total amounts presented on the condensed consolidated state of cash flows, net cash flows for the year ended December 31, 2017, decreased by $1.04 million, net cash flows for the year ended December 31, 2016, increased by $10.20 million.

Recently Issued Accounting Pronouncements not yet adopted

The FASB has issued the following standards which are not yet effective:

Leases

In February 2016, the FASB issued ASU 2016-02, “Leases” (“**ASU 2016-02**”) to increase transparency and comparability among organizations by requiring the recognition of right-of-use (“**ROU**”) assets and lease liabilities on the balance sheet. Most prominent among the changes in the standard is the recognition of ROU assets and lease liabilities by lessees for those leases classified as operating leases under current U.S. GAAP. The accounting for leases where we are lessor remain largely unchanged.

ASU 2016-02 is effective for annual and interim periods beginning January 1, 2019, with early adoption permitted. We will adopt the standard effective January 1, 2019 using the modified retrospective approach with a cumulative effect approach on the effective date of adoption at January 1, 2019. Therefore periods prior to the effective date of adoption will continue to be reported using current GAAP (ASC 840).

We will elect the package of practical expedients permitted under the transition guidance within the new standard on adoption, which among other things, allows us to carry-forward the historical lease classification. We will not separate non-lease components from lease components.

While we are still finalizing our adoption procedures, we estimate the primary impact to our consolidated balance sheet upon adoption will be the recognition of a right of use asset and lease liability of approximately $1.0 million to $1.5 million. We do not anticipate that adoption of the new standard will have a significant impact on our net earnings or cash flows.

Non-Employee Share-Based Payment

In June 2018, the FASB issued ASU 2018-07, which more closely aligns the accounting for employee and non-employee share-based payments. This standard more closely aligns the accounting for non-employee share-based payment transactions to the guidance for awards to employees except for specific guidance on certain inputs to an option-pricing model and the attribution of cost. This standard is effective for public business entities for annual and interim periods in fiscal years beginning after December 15, 2018. Early adoption is permitted, but no earlier than an entity’s adoption date of Topic 606. We do not anticipate that adoption of the new standard will have a significant impact on our net earnings.

Fair Value Measurement

In August 2018, the FASB issued ASU 2018-13, which amended the fair value measurement guidance by removing and modifying certain disclosure requirements, while also adding new disclosure requirements. The amendments on changes in unrealized gains and losses, the range and weighted average of significant unobservable inputs used to develop Level 3 fair value measurements, and the narrative description of measurement uncertainty should be applied prospectively for only the most recent interim or annual period presented in the initial fiscal year of adoption. All other amendments should be applied retrospectively to all periods presented upon their effective date. The amendments are effective for all companies for fiscal years, and interim periods within those years, beginning after December 15, 2019. Early adoption is permitted for all amendments. Further, a company may elect to early adopt the removal or modification of disclosures immediately and delay adoption of the new disclosure requirements until the effective date. The Company plans to adopt all disclosure requirements effective January 1, 2020.

4. ACQUISITION OF THE ALTA MESA ISR PROJECT

On June 16, 2016, the Company acquired 100% of the membership interests of EFR Alta Mesa LLC (“**Alta Mesa**”) (formerly named “**Mesteña Uranium, LLC**”) and its related companies, together referred to as “Alta Mesa”. Under the terms of the acquisition agreement, the sellers of Alta Mesa received 4,551,284 common shares of the Company.

Alta Mesa's primary asset is the Alta Mesa ISR Project (the "**Alta Mesa Project**") located in Texas. The Alta Mesa Project is a fully-permitted and licensed production facility that is not currently operating. The acquisition was accounted for as a purchase of assets as Alta Mesa did not meet the definition of a business under ASC Topic 805, Business Combinations because the assets in Alta Mesa do not have developed wellfields which are a key process for extraction of uranium. The development can only commence once uranium prices improve and economic feasibility of the Alta Mesa Project is established. The measurement of the purchase consideration was based on the market price of the Company's common stock on June 16, 2016 of $2.50 per share. The total transaction costs incurred through June 30, 2016 by the Company were $1.29 million which were capitalized as part of the purchase consideration.

The aggregate fair values of assets acquired and liabilities assumed were as follows on the acquisition date:

Issuance of 4,551,824 common shares	$	11,378
Transaction costs		1,290
Purchase consideration	$	12,668
The purchase price was allocated as follows:		
Plant and equipment (a)	$	13,626
Inventories		177
Restricted cash		4,532
Accounts payable and accrued liabilities		(213)
Asset retirement obligation		(5,454)
Net identifiable assets	$	12,668

(a) The plant and equipment include the value ascribed to the processing plant and equipment. The mineral properties, which were acquired as part of the acquisition of Alta Mesa in 2016, do not have proven and probable reserves under SEC Industry Guide 7. Accordingly, all subsequent expenditures at the Alta Mesa Project and equipment, which do not have any alternative use, and expenditures on mineral properties will be expensed as incurred.

5. MARKETABLE SECURITIES

The following tables summarize our marketable securities by significant investment categories as of December 31, 2018:

	Cost Basis	Gross Unrealized losses	Gross Unrealized gains	Fair Value
Marketable debt securities[1]	25,523	(5)	83	25,601
Marketable equity securities	1,062	(549)	947	1,460
Marketable securities	**$ 26,585**	**$ (554)**	**$ 1,030**	**$ 27,061**

(1) Marketable debt securities are comprised primarily of U.S. government notes, and also includes U.S. government agencies, and tradeable certificates of deposits.

The following tables summarize our marketable securities by significant investment categories as of December 31, 2017:

	Cost Basis	Gross Unrealized losses	Gross Unrealized gains	Fair Value
Marketable equity securities	$ 1,062	—	$ 378	$ 1,034
Marketable securities	**$ 1,062**	**—**	**$ 378**	**$ 1,034**

During the years ended December 31, 2018 and 2017, we did not recognize any other-than-temporary impairment losses. Losses on impairment are included as a component of other (loss) income in the Consolidated Statements of Operations.

The following table summarizes the estimated fair value of our investments in marketable debt securities with stated contractual maturity dates, accounted for as available-for-sale securities and classified by the contractual maturity date of the securities:

Due in less than 12 months	**$**	**17,434**
Due in 12 months to two years		**8,167**
	$	**25,601**

6. RECEIVABLES

		December 31, 2018		December 31, 2017
Trade receivables - other		**848**		403
Notes receivable, net	**$**	**343**	$	850
	$	**1,191**	$	1,253

During the year ended December 31, 2014 the Company received two notes with a combined principal totaling $1.05 million due in 2018 in connection with the sale of certain assets previously recorded as held for sale. The note with principal totaling $0.50 million was collected during the year ended December 31, 2018. Alternatively, the note with a principal payment of $0.55 million due November 7, 2018 was not paid and the Company notified the issuing party ("**Default Party**") of its default on November 9, 2018. This note, which remains outstanding as of the date of this Form 10-K carries a 3% annual interest payment plus default interest of 18% per annum, which continues to accrue. The Company has a reserve of $0.22 million as of December 31, 2018 (2017 - $0.22 million) against the collectability of this note. The promissory note is secured by all issued and outstanding stock and all of the assets sold to the default party.

7. INVESTMENTS ACCOUNTED FOR AT FAIR VALUE

		December 31, 2018		December 31, 2017
Investments accounted for at fair value		**1,107**		903
	$	**1,107**	$	903

Investments accounted for at fair value includes the Company's 16.5% investment in Virginia Uranium, Inc.

8. INVENTORIES

		December 31, 2018		December 31, 2017
Concentrates and work-in-progress (a)	**$**	**14,746**	$	14,118
Inventory of ore in stockpiles		**883**		—
Raw materials and consumables		**2,693**		2,432
	$	**18,322**	$	16,550
Inventories - by duration				
Current	**$**	**16,550**	$	16,550
Long term - raw materials and consumables	**$**	**1,772**	$	—
	$	**18,322**	$	16,550

(a) For the year ended December 31, 2018, the Company recorded an impairment loss of $4.58 million in the statement of operations related to concentrates and work in progress inventories (December 31, 2017 - $3.31 million).

9. INTANGIBLE ASSETS

The following is a summary of changes in intangible assets related to favorable sales contracts acquired in business combinations for the years ended December 31, 2018 and December 31, 2017:

Sales Contracts	**December 31, 2018**	December 31, 2017
Cost		
Balance at beginning of period	**$ 10,599**	$ 15,034
Sales contracts fulfilled	**(10,599)**	(4,435)
Balance, end of period	**—**	10,599
Accumulated amortization, beginning of period	**8,097**	9,235
Amortization of sales contracts	**2,502**	3,297
Sales contracts fulfilled	**(10,599)**	(4,435)
Accumulated amortization, end of period	**—**	8,097
Net book value	**$ —**	$ 2,502

The sales contracts when acquired were recorded at their acquisition date fair value, which are the incremental cash flows available to the Company arising from above-market pricing of the contracts.

10. PLANT AND EQUIPMENT AND MINERAL PROPERTIES

The following is a summary of plant and equipment:

	December 31, 2018			December 31, 2017		
	Cost	**Accumulated Depreciation**	**Net Book Value**	Cost	Accumulated Depreciation	Net Book Value
Plant and equipment						
Nichols Ranch	**$ 29,210**	**$ (12,021)**	**$ 17,189**	$ 29,210	$ (9,971)	$ 19,239
Alta Mesa	**13,656**	**(2,319)**	**11,337**	13,626	(1,388)	12,238
Equipment and other	**13,444**	**(12,127)**	**1,317**	13,367	(11,768)	1,599
Plant and equipment total	**$ 56,310**	**$ (26,467)**	**$ 29,843**	$ 56,203	$ (23,127)	$ 33,076

The net book value for Nichols Ranch Project includes the value beyond proven and probable reserves ascribed to the processing plant, the Nichols Ranch wellfields and the Jane Dough project upon acquisition.

For the year ended December 31, 2018, the Company recorded $2.05 million (2017 - $3.17 million) of depreciation expense related to Nichols Ranch, which is included in the costs and expenses applicable to revenue in the Statement of the operations and comprehensive income for the year ended December 31, 2018.

Acquisition of Royalties

On August 14, 2018, the Company issued 1.10 million shares for consideration of $3.74 million to acquire a 6% – 8% sliding-scale gross proceeds production royalty on its Nichols Ranch, Hank and Doughstick properties (Doughstick is a part of the Company's Jane Dough Project expansion area) and extinguished the royalty. This royalty also applied to the nearby Niles Ranch, Willow Creek, and Verna Ann properties, which are important pipeline uranium properties also owned by the Company. Acquisition of this royalty is expected to significantly decrease the Company's cost of production at Nichols Ranch. As the Company does not have any reserves as defined by SEC Industry Guide 7, the Company has expensed this as development, permitting and land holding costs in the statement of operations and comprehensive loss.

The following is a summary of mineral properties:

	December 31, 2018	December 31, 2017
Mineral properties		
Uranerz ISR properties (a)	**$ 25,974**	$ 25,974
Sheep Mountain	**34,183**	34,183
Roca Honda	**22,095**	22,095
Other (a)	**1,287**	1,287
Mineral properties total	**$ 83,539**	$ 83,539

a) In the year ended December 31, 2018 the Company renewed all mineral leases and therefore did not record abandonment expense in the statement of operations. In the year ended December 31, 2017 the Company did not renew certain mineral leases and recorded abandonment expense of $0.29 million (December 31, 2016 – $1.04 million) in the statement of operations.

11. IMPAIRMENTS

Impairment of plant and equipment, mineral properties and mineral properties held for sale

The Company conducts a review of potential triggering events for all its mineral properties on a quarterly basis. When events or changes in circumstances indicate that the related carrying amounts may not be recoverable, the Company carries out a review and evaluation of its long-lived assets in accordance with its accounting policy. No impairment of plant and equipment, mineral properties and mineral properties held for sale recorded in the year ended December 31, 2018.

In the year ended December 31, 2017 the Company entered into an agreement to sell certain non-core uranium properties. The Company re-classified these properties as held for sale and recorded an impairment of $3.80 million. The impaired properties are in the Reno Creek area. The impairment was based on the estimate of its fair value determined using the market approach less estimated selling costs.

12. ASSET RETIREMENT OBLIGATIONS AND RESTRICTED CASH

The following table summarizes the Company's asset retirement obligations:

	December 31, 2018	December 31, 2017
Asset retirement obligation, beginning of period	**$ 18,280**	$ 17,033
Revision of estimate	**(662)**	249
Accretion of liabilities	**1,835**	1,733
Settlements	**(349)**	(735)
Asset retirement obligation, end of period	**$ 19,104**	$ 18,280
Asset retirement obligation:		
Current	**$ 270**	$ 32
Non-current	**18,834**	18,248
Asset retirement obligation, end of period	**$ 19,104**	$ 18,280

The asset retirement obligations of the Company are subject to legal and regulatory requirements. Estimates of the costs of reclamation are reviewed periodically by the Company and the applicable regulatory authorities. The above provision represents the Company's best estimate of the present value of future reclamation costs, discounted using credit adjusted risk-free interest rates ranging from 9.5% to 11.5% and an inflation rate of 2.0%. The total undiscounted decommissioning liability at December 31, 2018 is $41.32 million.

The following table summarizes the Company's restricted cash:

	December 31, 2018	December 31, 2017
Restricted cash, beginning of period	**$ 22,127**	$ 23,175
Refunds of collateral	**(2,592)**	(14,657)
Additional collateral posted	**117**	13,609
Restricted cash, end of period	**$ 19,652**	$ 22,127

The Company has cash, cash equivalents and fixed income securities as collateral for various bonds posted in favor of the applicable state regulatory agencies in Arizona, Colorado, New Mexico, Texas, Utah and Wyoming, and the U.S. Bureau of Land Management and U.S. Forest Service for estimated reclamation costs associated with the White Mesa Mill, Nichols Ranch, Alta Mesa and other mining properties. Cash equivalents are short-term highly liquid investments with original maturities of three months or less. The restricted cash will be released when the Company has reclaimed a mineral property or restructured the surety and collateral arrangements. See Note 19 for a discussion of the Company's surety bond commitments.

13. LOANS AND BORROWINGS

The contractual terms of the Company's interest-bearing loans and borrowings, which are recorded at amortized cost, and the Company's convertible Debentures which are recorded at fair value, are as follows.

	December 31, 2018	December 31, 2017
Current portion of loans and borrowings:		
Wyoming Industrial Development Revenue Bond loan (b)	—	3,414
Total current loans and borrowings	**$ —**	$ 3,414
Long-term loans and borrowings:		
Convertible Debentures (a)	**$ 15,880**	$ 16,636
Wyoming Industrial Development Revenue Bond loan (b)	—	7,441
Total long-term loans and borrowings	**$ 15,880**	$ 24,077

Terms and debt repayment schedule

Terms and conditions of outstanding loans were as follows:

				December 31, 2018		December 31, 2017	
	Currency	Nominal interest rate	Year of maturity	Face value	Carrying amount	Face value	Carrying amount
Convertible debentures (a)	CDN$	8.5%	2020	**$15,298**	**$15,880**	$16,636	$16,636
Wyoming Industrial Development Revenue Bond loan (b)	USD	5.8%	2020	—	—	10,855	10,855
				$15,298	**$15,880**	$27,491	$27,491

(a) On July 24, 2012, the Company completed a bought deal public offering of 22,000 floating-rate convertible unsecured subordinated Debentures originally maturing June 30, 2017 (the "**Debentures**") at a price of Cdn$1,000 per Debenture for gross proceeds of Cdn$21.55 million (the "**Offering**"). The Debentures are convertible into common shares at the option of the holder. Interest is paid in cash and in addition, unless an event of default has occurred and is continuing, the Company may elect, from time to time, subject to applicable regulatory approval, to satisfy its obligation to pay interest on the Debentures, on the date it is payable under the indenture: (i) in cash; (ii) by delivering sufficient common shares to the debenture trustee, for sale, to satisfy the interest obligations in accordance with the indenture in which event holders of the Debentures will be entitled to receive a cash payment equal to the proceeds of the sale of such common shares; or (iii) any combination of (i) and (ii).

On August 4, 2016, the Company, by a vote of the Debentureholders, extended the maturity date of the Debentures from June 30, 2017 to December 31, 2020, and reduced the conversion price of the Debentures from Cdn$15.00 to Cdn$4.15

per common share of the Company. In addition, a redemption provision was added that enables the Company, upon giving not less than 30 days' notice to Debentureholders, to redeem the Debentures, for cash, in whole or in part at any time after June 30, 2019, but prior to maturity, at a price of 101% of the aggregate principal amount redeemed, plus accrued and unpaid interest (less any tax required by law to be deducted) on such Debentures up to but excluding the redemption date. A right (in favor of each Debentureholder) was also added to give the Debentureholders the option to require the Company to purchase, for cash, on the previous maturity date of June 30, 2017, up to 20% of the Debentures held by the Debentureholders at a price equal to 100% of the principal amount purchased plus accrued and unpaid interest (less any tax required by law to be deducted).

The Debentures accrue interest, payable semi-annually in arrears on June 30 and December 31 of each year at a fluctuating rate of not less than 8.5% and not more than 13.5%, indexed to the simple average spot price of uranium as reported on the UxC Weekly Indicator Price. The Debentures may be redeemed in whole or part, at par plus accrued interest and unpaid interest by the Company between June 30, 2019 and December 31, 2020 subject to certain terms and conditions, provided the volume weighted average trading price of the common shares of the Company on the TSX during the 20 consecutive trading days ending five days preceding the date on which the notice of redemption is given is not less than 125% of the conversion price.

Upon redemption or at maturity, the Company will repay the indebtedness represented by the Debentures by paying to the debenture trustee in Canadian dollars an amount equal to the aggregate principal amount of the outstanding Debentures which are to be redeemed or which have matured, as applicable, together with accrued and unpaid interest thereon.

Subject to any required regulatory approval and provided no event of default has occurred and is continuing, the Company has the option to satisfy its obligation to repay the Cdn$1,000 principal amount of the Debentures, in whole or in part, due at redemption or maturity, upon at least 40 days' and not more than 60 days' prior notice, by delivering that number of common shares obtained by dividing the Cdn$1,000 principal amount of the Debentures maturing or to be redeemed as applicable, by 95% of the volume-weighted average trading price of the common shares on the TSX during the 20 consecutive trading days ending five trading days preceding the date fixed for redemption or the maturity date, as the case may be.

The Debentures are classified as fair value through profit or loss where the Debentures are measured at fair value based on the closing price on the TSX (a Level 1 measurement) and changes are recognized in earnings. For the year ended December 31, 2018 the Company recorded a loss on revaluation of convertible Debentures of $0.61 million (December 31, 2017 – $0.94 million).

(b) The Company, upon its acquisition of Uranerz in 2015, assumed a loan through the Wyoming Industrial Development Revenue Bond program (the "Loan"). The Loan had an annual interest rate of 5.75% and was repayable over seven years, maturing on October 15, 2020. The Loan originated on December 3, 2013 and required the payment of interest only for the first year, with the amortization of principal plus interest over the remaining six years. The Loan was secured by most of the assets of the Company's wholly owned subsidiary, Uranerz, including mineral properties, the processing facility, and equipment as well as an assignment of all of Uranerz' rights, title and interest in and to its product sales contracts and other agreements. Uranerz was also subject to dividend restrictions. Principal and interest were paid on a quarterly basis on the first day of January, April, July and October. In September 2018, the Company repaid and retired the entire outstanding balance of $8.30 million of the loan and the mortgage on the Company's assets was released.

14. CAPITAL STOCK

Authorized capital stock

The Company is authorized to issue an unlimited number of Common Shares without par value, unlimited Preferred Shares issuable in series, and unlimited Series A Preferred Shares. The Series A Preferred Shares are non-redeemable, non-callable, non-voting and with no right to dividends. The Preferred Shares issuable in series will have the rights, privileges, restrictions and conditions assigned to the particular series upon the Board of Directors approving their issuance.

Issued capital stock

The significant transactions relating to capital stock issued during 2018, 2017, and 2016 are:

a) In the year ended December 31, 2018, the Company issued 14,283,254 common shares under the Company's "at-the-market" offering (the "ATM") for proceeds of $32.19 million. In the year ended December 31, 2017, the Company issued 7,202,479 common shares under the Company's "at-the-market" offering (the "ATM") for proceeds of $14.55 million. In the year ended December 31, 2016, the Company issued 200,225 common shares under the Company's ATM for proceeds of $0.54 million.

b) On August 14, 2018 the Company issued 1.10 million shares with a value of $3.74 million to acquire a production royalty on its Nichols Ranch, Hank and Doughstick properties.

c) On March 14, 2016, the Company completed a public offering of 5,031,250 units at a price of $2.40 per unit for gross proceeds of $12.08 million. Each Unit consisted of one common share and one half of one common share purchase warrant, or a total of 5,031,250 common shares and 2,515,625 warrants. Each warrant is exercisable until March 14, 2019 and entitles the holder thereof to acquire one common share upon exercise at an exercise price of US$3.20 per common share. These warrants are accounted for as a derivative liability, as the functional currency of the entity issuing the warrant is Cdn$.

The following weighted average assumptions were used for the Black-Scholes option pricing model to calculate the $2.09 million of fair value for the 2,515,625 warrants issued in connection with the public offering in March 2016.

Risk-free rate	1.15%
Expected life	3.0 years
Expected volatility	106.0%*
Expected dividend yield	0%

* Expected volatility is measured based on the Company's historical share price volatility over the expected life of the warrants.

d) On May 27, 2016, the Company issued 1,212,173 shares to acquire the remaining 40% interest of the Roca Honda Joint Venture for share consideration of $2.68 million.

e) On June 16, 2016 the Company issued 4,551,284 shares to acquire Alta Mesa with a value of $11.38 million.

f) On September 20, 2016, the Company completed a public offering of 8,337,500 units at a price of $1.80 per unit for gross proceeds of $15.01 million. Each Unit consisted of one common share and one half of one common share purchase warrant, or a total of 8,337,500 Shares and 4,168,750 Warrants. Each warrant is exercisable until September 20, 2021 and entitles the holder thereof to acquire one common share upon exercise at an exercise price of US$2.45 per common share. These warrants are accounted for as a derivative liability, as the functional currency of the entity issuing the warrant is Cdn$.

The following weighted average assumptions were used for the Black-Scholes option pricing model to calculate the $3.17 million of fair value for the 4,168,750 warrants issued in connection with the public offering in September 2016.

Risk-free rate	1.2%
Expected life	5.0 years
Expected volatility	145.2%*
Expected dividend yield	0%

* Expected volatility is measured based on the Company's historical share price volatility over the expected life of the warrants.

Share Purchase Warrants

The following table summarizes the Company's share purchase warrants denominated in US dollars. These warrants are accounted for as derivative liabilities as the functional currency of the entity issuing the warrants, Energy Fuels Inc., is Canadian dollars.

Month Issued	Expiry Date	Exercise Price USD$	Warrants Outstanding	Fair value at December 31, 2018
March 2016 (1)	March 14, 2019	3.20	2,328,925	$ 662
September 2016 (2)	September 20, 2021	2.45	4,167,480	5,621
				$ 6,283

(1) These US dollar-based warrants are classified as Level 3 under the fair value hierarchy (Note 21).

(2) These US dollar-based warrants are classified as Level 1 under the fair value hierarchy as they are traded on an active market.

The following weighted average assumptions were used for the Black-Scholes option pricing model to calculate the $0.66 million of fair value for the 2,328,925 warrants at December 31, 2018.

Risk-free rate	2.63%
Expected life	0.2 years
Expected volatility	80.5%*
Expected dividend yield	0%

* Expected volatility is measured based on the Company's historical share price volatility over the expected life of the warrants.

15. BASIC AND DILUTED LOSS PER COMMON SHARE

The following is a reconciliation of weighted average shares outstanding for the years ended December 31, 2018, 2017, 2016, respectively:

	Years Ended December 31,		
	2018	2017	2016
Issued common shares at beginning of period	74,366,824	66,205,153	46,519,132
Effect of share options exercised	115,330	—	3,471
Effect of shares issued for settlement of vesting of restricted share units	829,610	831,393	196,242
Effect of shares issued for exercise of share purchase warrants	44,185	—	—
Shares issued for consulting services	122,854	—	—
Effect of shares issued in asset acquisitions	419,986	—	3,184,175
Effect of shares issued for conversion of debentures	323	—	—
Effect of shares issued in public offerings	7,576,288	3,822,561	6,538,038
Weighted average shares outstanding	83,475,400	70,859,107	56,441,058

Basic and diluted loss per share

The calculation of diluted earnings per share after adjustment for the effects of all potential dilutive common shares, calculated as follows:

	Years Ended December 31,		
	2018	2017	2016
Net loss to owners of the Company	**$ (25,245)**	$ (27,766)	$ (39,413)
Basic and diluted weighted average number			
of common shares outstanding	**83,475,400**	70,859,107	56,441,058
Loss per common share	**$ (0.30)**	$ (0.39)	$ (0.70)

For the three years ended December 31, 2018, 2017 and 2016, 8.23 million, 8.71 million and 10.19 million options and warrants, respectively, and the potential conversion of the Debentures have been excluded from the calculation as their effect would have been anti-dilutive.

16. SHARE-BASED PAYMENTS

The Company, under the 2018 Omnibus Equity Incentive Compensation Plan (the "**Compensation Plan**"), maintains a stock incentive plan for directors, executives, eligible employees and consultants. Stock incentive awards include employee stock options, restricted stock units ("**RSUs**"), and share appreciation rights ("**SARs**"). The Company issues new shares of common stock to satisfy exercises and vesting under all of its stock incentive awards. At December 31, 2018, a total of 9,144,507 common shares were authorized for stock incentive plan awards.

Employee Stock Options

The Company, under the Compensation Plan may grant options to directors, executives, employees and consultants to purchase common shares of the Company. The exercise price of the options is set as the higher of the Company's closing share price on the day before the grant date or the five-day volume weighted average price. Stock options granted under the Compensation Plan generally vest over a period of two years or more and are generally exercisable over a period of five years from the grant date not to exceed 10 years. The value of each option award is estimated at the grant date using the Black-Scholes Option Valuation Model. There were 0.42 million options granted in the year ended December 31, 2018 (December 31, 2017 – 0.74 million, December 31, 2016 - 0.45 million). At December 31, 2018, there were 1.71 million options outstanding with 1.44 million options exercisable, at a weighted average exercise price of $3.85 and $4.21 respectively, with a weighted average remaining contractual life of 3.59 years. The aggregate intrinsic value of the fully vested shares was $0.41 million.

The summary of the Company's stock options at December 31, 2018, 2017 and 2016, respectively, and the changes for the fiscal periods ending on those dates are presented below:

	Range of Exercise Prices $	Weighted Average Exercise Price $	Number of Options
Balance, December 31, 2015	**2.55 - 32.10**	**6.54**	**2,122,897**
Granted	**2.12 - 2.22**	2.13	449,537
Exercised	**2.12**	2.12	(8,369)
Forfeited	2.12 - 18.99	5.52	(317,960)
Expired	2.95 - 32.03	8.03	(200,962)
Balance, December 31, 2016	**2.12 - 15.61**	**5.69**	**2,045,143**
Granted	1.77 - 2.35	2.34	738,893
Exercised	—	—	—
Forfeited	2.12 - 11.94	2.93	(316,289)
Expired	4.48 - 12.55	8.42	(438,900)
Balance, December 31, 2017	**1.77 - 15.61**	**4.48**	**2,028,847**
Granted	**1.70 - 2.88**	**1.75**	**442,956**
Exercised	**1.70 - 2.55**	**2.15**	**(355,092)**
Forfeited	**1.70 - 6.63**	**3.96**	**(213,393)**
Expired	**5.86 - 10.36**	**8.18**	**(170,564)**
Balance, December 31, 2018	**1.70 - 15.61**	**3.84**	**1,732,754**

As of December 31, 2018, the outstanding stock options denominated in Cdn$ were as follows:

	Options outstanding				Options exercisable			
Exercise price	Quantity	Weighted average price	Weighted average remaining contractual life	Intrinsic Value	Quantity	Weighted average price	Weighted average remaining contractual life	Intrinsic Value
$5.00 to $9.99	210,550	8.01	0.39	—	210,550	8.10	0.39	—
	210,550			$ —	210,550			$ —

As of December 31, 2018, the outstanding stock options denominated in USD$ were as follows:

	Options outstanding				Options exercisable			
Exercise price	**Quantity**	**Weighted average price**	**Weighted average remaining contractual life**	**Intrinsic Value**	**Quantity**	**Weighted average price**	**Weighted average remaining contractual life**	**Intrinsic Value**
$0.00 to $4.99	1,240,177	$ 2.83	3.90	$ 415	943,133	$ 3.08	3.98	$ 415
$5.00 to $9.99	255,762	6.00	3.10	—	255,762	6.00	3.10	—
$10.00 to $14.99	13,515	12.59	2.27	—	13,515	12.59	2.27	—
$15.00 to $19.99	12,750	$ 15.61	2.03	—	12,750	$ 15.61	2.03	—
	1,522,204			$ 415	1,225,160			$ 415

In the year ended December 31, 2018, the Company issued 355,092 shares upon exercise of stock options at an average exercise price of $2.15 for proceeds of $0.76 million. These options had an intrinsic value of $0.41 million.

In the year ended December 31, 2017,no shares were issued due to the exercise of stock options.

In the year ended December 31, 2016 the Company issued 8,369 shares upon exercise of stock options at an average exercise price of $2.12 for proceeds of $0.02 million. These options had an intrinsic value of $0.01 million.

The share-based compensation recorded during the years ended December 31, 2018, 2017 and 2016 are as follows:

	Years ended December 31,		
	2018	2017	2016
Share-based compensation (1)(2)	**$ 2,762**	$ 3,525	$ 2,657
Value of stock options and RSUs granted	**$ 2,762**	**$ 3,525**	**$ 2,657**

(1) The fair value of the options granted under the Compensation Plan for the years ended December 31, 2018, 2017 and 2016 was estimated at the date of grant, using the Black-Scholes Option Valuation Model, with the following weighted-average assumptions:

	2018	**2017**	**2016**
Risk-free interest rate	**2.84%**	1.93%	1.03% - 1.43%
Expected life	**5.0 years**	5.0 years	5.0 years
Expected volatility	**59.00%***	63.0%*	64.7% -74.8%*
Expected dividend yield	0%	0%	0%
Weighted-average expected life of option	**5.00**	5.00	5.00
Weighted-average grant date fair value	**$0.96**	$1.20	$1.22 - $1.23

* Expected volatility is measured based on the Company's historical share price volatility over a period equivalent to the expected life of the options.

(2) The fair value of the RSUs granted under the Compensation Plan for the years ended December 31, 2018, 2017 and 2016, was estimated at the date of grant, using the stated market price.

A summary of the status and activity of non-vested stock options at December 31, 2018 is as follows:

	Number of shares	Weighted Average Grant- Date Fair Value
Non-vested December 31, 2015	177,698	3.44
Granted	449,537	1.29
Vested	(331,482)	2.26
Forfeited	(68,575)	1.56
Non-vested December 31, 2016	227,178	1.48
Granted	738,893	1.18
Vested	(486,386)	1.30
Forfeited	(114,505)	1.22
Non-vested December 31, 2017	365,180	1.20
Granted	442,956	0.96
Vested	(448,662)	1.10
Forfeited	(62,430)	0.96
Non-vested December 31, 2018	297,044	1.06

Restricted Stock Units

The Company grants RSUs to executives and eligible employees. Awards are determined as a target percentage of base salary and vest over periods of three years. Prior to vesting, holders of restricted stock units do not have the right to vote the underlying shares. The restricted stock units are subject to forfeiture risk and other restrictions. Upon vesting, the employee is entitled to receive one share of the Company's common stock for each restricted stock unit for no additional payment. During the year ended December 31, 2018, the Company's Board of Directors approved the issuance of 1.19 million RSUs under the Compensation Plan (2017 – 1.39 million, 2016 - 1.21 million).

A summary of the status and activity of non-vested RSUs at December 31, 2018 is as follows:

	Number of shares	Weighted Average Grant- Date Fair Value
Non-vested December 31, 2015	272,866	4.03
Granted	1,205,336	2.14
Vested	(138,608)	4.65
Forfeited	(9,125)	5.39
Non-vested December 31, 2016	1,330,469	2.37
Granted	1,390,705	2.09
Vested	(752,580)	2.35
Forfeited	(59,118)	2.29
Non-vested December 31, 2017	1,909,477	2.17
Granted	1,191,132	1.70
Vested	(1,486,126)	2.24
Forfeited	(34,296)	2.00
Non-vested December 31, 2018	1,580,187	$ 1.99

The total fair value of RSUs that vested and were settled for equity in the year ended December 31, 2018 was $1.49 million (2017 – $1.69 million, 2016 - $0.30 million). At December 31, 2018, there was $0.05 million and $0.88 million of unrecognized compensation costs related to the unvested stock options and RSU awards, respectively. This cost is expected to be recognized over a period of approximately three years.

Share Appreciation Rights

No SARs were issued during the year ended December 31, 2018, or in any prior years.

17. INCOME TAXES

A reconciliation of income tax expense and the product of accounting income before income tax, multiplied by the combined Canadian federal and provincial income tax rate (the rate applicable to the Canadian parent company) is as follows:

	Year ended December 31,		
	2018	2017	2016
Loss before income taxes	**$ (25,364)**	$ (27,990)	$ (39,864)
Combined federal and provincial rate	**26.50%**	26.50%	26.50%
Expected income tax recovery	**(6,721)**	(7,400)	(10,600)
Stock based compensation	**623**	934	704
Other non-deductible/non-taxable items	**597**	(1,303)	—
Foreign tax rate differences	**—**	—	(2,962)
Unrecognized deferred tax assets	**5,501**	7,769	12,858
Income tax expense	**$ —**	$ —	$ —

The components of the net deferred tax assets and liabilities as of December 31, 2018, 2017 and 2016 are as follows:

	Year ended December 31,	
	2018	2017
Current deferred tax assets		
Inventories	**1,812**	2,148
Short-term investments	**209**	1,216
Total current deferred tax assets	**2,021**	3,364
Non-current deferred tax assets		
Operating loss carry forwards	**80,290**	74,644
Capital loss carry forwards	**14,903**	15,286
Deferred revenue and other	**3,622**	3,695
Mineral properties and deferred costs	**28,317**	28,080
Asset retirement obligations	**5,062**	4,844
Intangibles and other	**—**	(663)
Property, plant and equipment	**1,549**	845
Total non-current deferred tax assets	**133,743**	126,731
Subtotal deferred tax asset	**135,764**	130,095
Less: valuation allowance	**(135,764)**	(130,095)
Net deferred tax asset	**$ —**	$ —

At December 31, 2018, and 2017, the Company recorded a valuation allowance against the net deferred tax assets for the above related items in the financial statements as management did not consider it more likely than not that the Company will be able to realize the deferred tax assets in the future.

The following table summarizes the changes to the valuation allowance:

For the Year Ended December 31,	Balance at Beginning of Period	Additions (a)	Deductions (b)	Balance at End of Period
2018	130,095	7,469	(1,800)	135,764
2017	163,666	4,259	(37,830)	130,095

a) The additions to the valuation allowance result from additional losses incurred and increases to other tax assets such as mineral proprety and property, plant and equipment. Management does not feel these additions meet the more-likely-than-no ciriterion for recognition.

b) The reductions to the valuation allowance result primarily from the decreases to other tax assets such as inventories, short-term investments and deferred revenue.

The following table summarizes the Company's capital losses and net operating losses as of December 31, 2018 that can be applied against future taxable profit.

Country	Type	Amount		Expiry Date
Canada	Non-capital losses	$	37,018	2027 - 2036
Canada	Allowable Capital losses		3,293	None
Canada	Investment Tax Credits		1,213	2023-2027
United States	Pre-2018 Net Operating losses		250,370	2026-2036
United States	Post-2017 Net Operating losses		15,949	None
United States	Capital losses		52,591	2019
	Section 163j Disallowed Interest		353	None

Utilization of the United States loss carry forwards will be limited in any year as a result of previous changes in ownership. For the Energy Fuels Holding Corporation and Subsidiaries consolidated group, management estimates that approximately $75 million in net operating losses will expire unutilized as a result of these limitations.

In addition, as a result of the Tax Cuts and Jobs Act, United States net operating loss carryforwards generated after December 31, 2017 will be limited to usage at 80% of taxable income and will be permitted to be carried forward indefinitely.

Utilization of the Canadian loss carry forwards will be subject to the Acquisition of Control Rules in any year as a result of previous changes in ownership.

18. SUPPLEMENTAL FINANCIAL INFORMATION

The components of revenues are as follows:

The Company had three major customers to which its sales for the year were as follows: 2018 - $24.52 million; $5.03 million; $1.24 million; (2017 (three major customers) - $13.08 million; $6.99 million; $4.40 million); (2016 (three major customers) - $33.36 million; $8.69 million; $7.00 million).

The Company’s revenues by country of customer for the current year were as follows: 2018 - $25.76 million - U.S.; Other - $5.03 million; (2017 - $20.07 million - U.S.; Other - $4.40 million) (2016 -$50.76 million - U.S.; Other - $3.69 million).

Deferred revenue at December 31, 2018 of $2.72 million (2017 - $2.47 million) relates to proceeds received on toll materials in advance of required activity.

The components of other (expense) income are as follows:

	Years ended December 31,		
	2018	2017	2016
Interest income	**$ 336**	$ 161	$ 143
Change in value of marketable securities	**769**	509	—
Change in value of warrant liabilities	**(3,469)**	784	420
Change in value of convertible Debentures	**(612)**	(940)	(407)
Gain on settlement of loans and borrowings	**—**	—	424
Gain on assets held for sale	**341**	—	—
Insurance settlement	**—**	—	223
Sales and property tax refunds	**—**	—	176
Gain on sale of mineral properties	**—**	—	316
Sale of surplus assets	**293**	1,913	—
Other	**14**	142	(96)
Other (expense) income	**$ (2,328)**	$ 2,569	$ 1,199

The components of accounts payable and accrued liabilities are as follows:

	December 31, 2018	December 31, 2017
Accounts payable	**$ 1,881**	**$ 762**
Payroll liabilities	**1,928**	835
Other accrued liabilities	**4,112**	4,852
Accounts payable and accrued liabilities	**$ 7,921**	$ 6,449

19. COMMITMENTS AND CONTINGENCIES

General legal matters

Other than routine litigation incidental to our business, or as described below, the Company is not currently a party to any material pending legal proceedings that management believes would be likely to have a material adverse effect on our financial position, results of operations or cash flows.

White Mesa Mill

In January 2013, the Ute Mountain Ute tribe filed a Petition to Intervene and Request for Agency Action challenging the Corrective Action Plan approved by the State of Utah Department of Environmental Quality ("**UDEQ**") relating to nitrate contamination in the shallow aquifer at the White Mesa Mill site. This challenge is currently being evaluated and may involve the appointment of an administrative law judge to hear the matter. The Company does not consider this action to have any merit. If the petition is successful, the likely outcome would be a requirement to modify or replace the existing Corrective Action Plan. At this time, the Company does not believe any such modification or replacement would materially affect our financial position, results of operations or cash flows. However, the scope and costs of remediation under a revised or replacement Corrective Action Plan have not yet been determined and could be significant.

On January 19, 2018, UDEQ renewed, and on February 16, 2018 reissued, the White Mesa Mill's license for another ten years and Groundwater Discharge Permit for another five years. In March of 2018, the Grant Canyon Trust, Ute Mountain Ute Tribe and Uranium Watch (the **"Petitioners"**) filed Petitions for Review challenging UDEQ's renewal of the license and permit. Petitioners subsequently filed with UDEQ Requests for Appointment of an Administrative Law Judge (**"ALJ"**), which they later agreed to suspend pursuant to a Stipulation and Agreement with UDEQ, effective June 4, 2018. The Company has met with representatives from all parties in order to determine whether pending administrative proceedings can be settled. Discussions are ongoing. The Company does not consider these challenges to have any merit. If such challenges are heard by the agency and are successful, the likely outcome would be a requirement to modify the renewed license and/or permit. At this time, the Company does not believe any such modification would materially affect its financial position, results of operations or cash flows.

Canyon Project

In March, 2013, the Center for Biological Diversity, the Grand Canyon Trust, the Sierra Club and the Havasupai Tribe (the "**Canyon Plaintiffs**") filed a complaint in the U.S. District Court for the District of Arizona (the "**District Court**") against the Forest Supervisor for the Kaibab National Forest and the USFS seeking an order (a) declaring that the USFS failed to comply with environmental, mining, public land, and historic preservation laws in relation to our Canyon Project, (b) setting aside any approvals regarding exploration and mining operations at the Canyon Project, and (c) directing operations to cease at the Canyon Project and enjoining the USFS from allowing any further exploration or mining-related activities at the Canyon Project until the USFS fully complies with all applicable laws. In April 2013, the Plaintiffs filed a Motion for Preliminary Injunction, which was denied by the District Court in September 2013. On April 7, 2015, the District Court issued its final ruling on the merits in favor of the Defendants and the Company and against the Canyon Plaintiffs on all counts. The Canyon Plaintiffs appealed the District Court's ruling on the merits to the Ninth Circuit Court of Appeals and filed motions for an injunction pending appeal with the District Court. Those motions for an injunction pending appeal were denied by the District Court on May 26, 2015. Thereafter, Plaintiffs filed urgent motions for an injunction pending appeal with the Ninth Circuit Court of Appeals, which were denied on June 30, 2015.

The hearing on the merits at the Court of Appeals was held on December 15, 2016. On December 12, 2017, the Ninth Circuit Court of Appeals issued its ruling on the merits in favor of the Defendants and the Company and against the Canyon Plaintiffs on all counts. The Canyon Plaintiffs then petitioned the Ninth Circuit Court of Appeals for a rehearing *en banc*. On October 25, 2018, the Ninth Circuit panel denied the petition for rehearing *en banc* but withdrew its prior opinion and filed a new opinion affirming three of the claims and remanding the fourth claim back to the District Court to hear on the merits. The Company does not consider this action to have any merit. If the petition is successful, the likely outcome would be a requirement to cease mining or mining-related projects at the Canyon Project until the USFS was found to have fully complied with all applicable laws. At this time, the scope and costs of ceasing work on the Canyon Project have not yet been determined and could significantly impact our future operations.

On December 26, 2018, the Havasupai Tribe filed an Application for an Extension of Time to File a Petition for a Writ of Certiorari with the Supreme Court of the United States. This Application is currently being evaluated. The Company does not consider this action to have any merit.

Daneros Mine

On February 23, 2018, the BLM issued the EA, Decision Record and FONSI for the Mine Plan of Operations Modification for the Daneros Mine. On March 29, 2018, the Southern Utah Wilderness Alliance and Grand Canyon Trust (together the **"Appellants"**) filed a Notice of Appeal to the Interior Board of Land Appeals (**"IBLA"**) regarding the BLM's Decision Record and FONSI and challenging the underlying EA, and the Company was subsequently permitted to intervene. This matter has been briefed and remains under consideration by IBLA at this time. The Company does not consider these challenges to have any merit; however, the scope and costs of amending or redoing the EA have not yet been determined and could be significant.

Mineral property commitments

The Company enters into commitments with federal and state agencies and private individuals to lease mineral rights. These leases are renewable annually and annual renewal costs are expected to total $1.43 million for the year ended December 31, 2019.

Surety bonds

The Company has indemnified third-party companies to provide surety bonds as collateral for the Company's ARO. The Company is obligated to replace this collateral in the event of a default and is obligated to repay any reclamation or closure costs due. The Company currently has $19.65 million posted against an undiscounted ARO of $41.32 million (December 2017 - $22.13 million posted against undiscounted asset retirement obligation of $43.46 million).

Commitments

The Company is contractually obligated under a non-material Sales and Agency Agreement appointing an exclusive sales and marketing agent for all vanadium pentoxide produced by the Company.

20. UNAUDITED SUPPLEMENTARY QUARTERLY INFORMATION

The following table summarizes unaudited supplementary quarterly information for the years ended December 31, 2018, and December 31 2017.

	Three months ended			
	March 31, 2018	June 30, 2018	September 30, 2018	December 31, 2018
	(unaudited) (in thousands, except share and per share amounts)			
Net Sales	$ 1,254	$ 26,973	$ 451	$ 3,043
Gross Profit (loss)	$ (994)	$ 14,964	$ (263)	$ (1,317)
Net (loss) income	$ (10,829)	$ 7,144	$ (13,897)	$ (7,780)
Basic Net (loss) income per share	$ (0.14)	$ 0.09	$ (0.16)	$ (0.09)
Diluted Net (loss) income per share	$ (0.14)	$ 0.08	$ (0.16)	$ (0.09)
Net (loss) income attributable to Owners of the Company	$ (10,822)	$ 7,149	$ (13,812)	$ (7,760)
Basic Net (loss) attributable to owners of the Company per share	(0.14)	0.09	(0.16)	(0.09)
Diluted Net (loss) income attributable to Owners of the Company per share	(0.14)	0.08	(0.16)	(0.09)
Weighted average shares outstanding Basic	75,209,456	77,513,180	87,197,294	91,105,260
Weighted average shares outstanding Diluted	75,209,456	86,534,484	87,197,294	91,105,260

	Three months ended			
	March 31, 2017	June 30, 2017	September 30, 2017	December 31, 2017
	(unaudited) (in thousands, except share and per share amounts)			
Net Sales	$ 3,756	$ 17,883	$ 5,499	$ 3,908
Gross Profit (loss)	$ 1,685	$ 4,855	$ 1,931	$ (135)
Net loss	$ (10,596)	$ (4,480)	$ (4,884)	$ (8,030)
Net loss per share	$ (0.15)	$ (0.06)	$ (0.07)	$ (0.11)
Net loss attributable to Owners of the Company	$ (10,508)	$ (4,470)	$ (4,766)	$ (8,022)
Net loss attributable to Owners of the Company per share	$ (0.15)	$ (0.06)	$ (0.07)	$ (0.11)
Weighted average shares outstanding Basic and Diluted	68,761,350	70,423,642	71,436,413	72,164,932

21. FAIR VALUE ACCOUNTING

Assets and liabilities measured at fair value on a recurring basis

The following tables set forth the fair value of the Company's assets and liabilities measured at fair value on a recurring basis (at least annually) by level within the fair value hierarchy as at December 31, 2018. As required by accounting guidance, assets and liabilities are classified in their entirety based on the lowest level of input that is significant to the fair value measurement.

Fair value accounting utilizes a fair value hierarchy that prioritizes the inputs to valuation techniques used to measure fair value. The hierarchy gives the highest priority to unadjusted quoted prices in active markets for identical assets and liabilities (Level 1 measurements) and the lowest priority to unobservable inputs (Level 3 measurements). The three levels of the fair value hierarchy are described below:

Level 1 - Unadjusted quoted prices in active markets that are accessible at the measurement date for identical, unrestricted assets or liabilities

Level 2 - Quoted prices in markets that are not active, or inputs that are observable, either directly or indirectly, for substantially the full term of the asset or liability; and

Level 3 - Prices or valuation techniques that require inputs that are both significant to the fair value measurement and unobservable (supported by little or no market activity).

Our financial instruments include cash and cash equivalents, restricted cash, accounts receivable, accounts payable and current accrued liabilities. These instruments are carried at cost, which approximates fair value due to the short-term maturities of the instruments. Allowances for doubtful accounts are recorded against the accounts receivable balance to estimate net realizable value. The fair value of the Company's Debentures are measured at fair value based on the closing price on the TSX (a Level 1 measurement) and changes are recognized in other income (expense). The Company's investments in marketable equity securities which are exchange traded and are valued using quoted market prices in active markets and as such are classified within Level 1 of the fair value hierarchy. The Company's investments are marketable debt securities which are exchange traded and are valued using quoted prices of a pricing service and such are classified within Level 2 of the fair value hierarchy. The Company's warrants are classified as liabilities. The warrants are subject to re-measurement at each balance sheet date, with any change in fair value recognized as a component of other income (expense), in the statements of operations. The warrants issued in September 2016 are classified as Level 1 under the fair value hierarchy using quoted market prices in active markets.

The warrants issued in March 2016 are classified as Level 3 under the fair value hierarchy as they are valued with Level 3 (Level 3 fair value is determined using the entity's own assumptions about the inputs that market participants would use in pricing an asset or liability) inputs and the Black-Scholes option model.

As at December 31, 2018 and 2017, the fair values of cash and cash equivalents, restricted cash, short-term deposits, receivables, accounts payable and accrued liabilities approximate their carrying values because of the short-term nature of these instruments.

December 31, 2018	Level 1	Level 2	Level 3	Total
Investments at fair value	$ 1,107	$ —	$ —	$ 1,107
Marketable equity securities	1,460	—	—	1,460
Marketable debt securities	—	25,601	—	25,601
Warrant liabilities (Note 14)	(5,621)	—	(662)	(6,283)
Convertible Debentures (Note 13)	(15,880)	—	—	(15,880)
	$ (18,934)	$ 25,601	$ (662)	$ 6,005

December 31, 2017	Level 1	Level 2	Level 3	Total
Investments	$ 1,937	$ —	$ —	$ 1,937
Warrant liabilities (Note 14)	(2,991)	—	(385)	(3,376)
Convertible debentures (Note 13)	(16,636)	—	—	(16,636)
	$ (17,690)	$ —	$ (385)	$ (18,075)

The following table presents the activity for those items measured at fair value on a recurring basis using Level 3 inputs for the year ended December 31, 2018:

	Level 3 Warrant Liabilities
Fair Value at December 31, 2017	385
Fair value of warrants exercised	(120)
Change in fair value (1)	397
Fair Value at December 31, 2018	**662**

(1) The gain (loss) recognized in included in Other Income (Expense) on the Consolidated Statement of Operations.

There were no transfers into or out of Level 3 during the year ended December 31, 2018.

22. REVENUE RECOGNITION AND CONTRACTS WITH CUSTOMERS

Adoption

On January 1, 2018, the Company adopted new guidance on revenue from contracts with customers using the modified retrospective method applied to contracts that were not completed as of January 1, 2018. Results for reporting periods beginning after January 1, 2018 are presented under the new guidance, while prior period amounts are not adjusted and continue to be reported in accordance with previous guidance.

We recorded a net decrease to opening accumulated deficit of $2.47 million as of January 1, 2018, for the cumulative impact of adopting the new guidance. The impact primarily related to the change in accounting for alternate feed contracts, resulting in the recognition of $2.47 million of deferred revenue.

	Balance at December 31, 2017	New Revenue Standard Adjustment	Balance at January 1, 2018
Liabilities			
Deferred revenue	$ 2,474	$ (2,474)	$ —
Equity			
Accumulated deficit	$ (309,287)	$ 2,474	$ (306,813)

Under the modified retrospective method of adoption, we are required to disclose the impact to revenues had we continued to follow our accounting policies under the previous revenue recognition guidance. There is no impact to revenues for the year ended December 31, 2018 as we did not receive any alternate feed material which would have been classified as deferred revenue in the period.

All revenue recognized is a result of contracts with customers either through sales contracts or alternate feed agreements.

The Company applied Topic 606 retrospectively using the practical expedient, under which the Company does not disclose the amount of consideration allocated to the remaining performance obligations or an explanation of when the Company expects to recognize that amount as revenue for all reporting periods presented before the date of the initial application – i.e. January 1, 2018. As of December 31, 2018, the Company has one customer contract with material performance obligations remaining. The Company's has yet to deliver material from its toll processing activities to the customer. At the time of delivery we will recognize the deferred revenue. The Company's remaining performance obligations are expected to be completed within 2019. The Company's estimated revenue expected to be recognized in the future related to performance obligations that are partially unsatisfied at December 31, 2018 is $2.74 million. The Company's existing long term contracts expired following the Company's 2018 deliveries, and all uranium sales after 2018 will be required to be made at spot prices until the Company enters into new long-term contracts at satisfactory prices in the future. Revenue beyond our current contracts will be affected by both spot and long-term U_3O_8 price fluctuations which are beyond our control, including: the demand for nuclear power; political and economic conditions; governmental legislation in uranium producing and consuming countries; and production levels and costs of production of other producing companies.

23. RELATED PARTY TRANSACTIONS

On May 17, 2017, the Board of Directors of the Company appointed Robert W. Kirkwood and Benjamin Eshleman III to the Board of Directors of the Company.

Mr. Kirkwood is a principal of the Kirkwood Companies, including Kirkwood Oil and Gas LLC, Wesco Operating, Inc., and United Nuclear LLC ("**United Nuclear**"). United Nuclear, owns a 19% interest in the Company's Arkose Mining Venture while the Company owns the remaining 81%. The Company acts as manager of the Arkose Mining Venture and has management and control over operations carried out by the Arkose Mining Venture. The Arkose Mining Venture is a contractual joint venture governed by a venture agreement dated as of January 15, 2008 entered into by Uranerz Energy Corporation (a subsidiary of the Company) and United Nuclear (the "**Venture Agreement**").

United Nuclear contributed $nil to the expenses of the Arkose Joint Venture based on the approved budget for the twelve months ended December 31, 2018.

Mr. Benjamin Eshleman III is President of Mesteña LLC, which became a shareholder of the Company through the Company's acquisition of Mesteña Uranium, L.L.C (now Alta Mesa LLC) in June 2016 through the issuance of 4,551,284 common shares of the Company to the direction of the Sellers (of which 4,303,032 common shares of the Company are currently held by the Sellers). In connection with the Purchase Agreement, one of the Acquired Companies, Leoncito Project, L.L.C. entered into an Amended and Restated Uranium Testing Permit and Lease Option Agreement with Mesteña Unproven, Ltd., Jones Ranch Minerals Unproven, Ltd and Mesteña Proven, Ltd. (collectively the "Grantors"), which requires Leoncito Project, L.L.C., to make a payment in the amount of $0.60 million to the Grantors in June 2019 (of which up to 50% may be paid in common shares of the Company at the Company's election). At December 31, 2018, the Company has accrued $0.50 million of this liability on the balance sheet. The Grantors are managed by Mesteña LLC.

Pursuant to the Purchase Agreement, the Alta Mesa Properties held by the Acquired Companies are subject to a royalty of 3.125% of the value of the recovered U_3O_8 from the Alta Mesa Properties sold at a price of $65.00 per pound or less, 6.25% of the value of the recovered U_3O_8 from the Alta Mesa Properties sold at a price greater than $65.00 per pound and up to and including $95.00 per pound, and 7.5% of the value of the recovered U_3O_8 from the Alta Mesa Properties sold at a price greater than $95.00 per pound. The royalties are held by the Sellers, and Mr. Eshleman and his extended family hold all of the ownership interests in the Sellers. In addition, Mr. Eshleman and certain members of his extended family are parties to surface use agreements that entitle them to surface use payments from the Acquired Companies in certain circumstances. The Alta Mesa Properties are currently being maintained on care and maintenance to enable the Company to restart operations as market conditions warrant. Due to the price of U_3O_8, the Company did not pay any royalty payments or surface use payments to the Sellers or to Mr. Eshleman or his immediate family members in the year ended December 31, 2018. Pursuant to the Purchase Agreement, surface use payments from June 2016 through December 31, 2018 have been deferred until June 30, 2019 at which time the Company will pay $1.35 million to settle this obligation. As of December 31, 2018, the Company has accrued $1.35 million of this liability on the balance sheet.

24. SUBSEQUENT EVENTS

Issuance of stock options and RSUs

On January 22, 2019 the Company granted 0.35 million stock options with an exercise price of $2.92 per share, 2.20 million stock appreciation rights ("**SARs**") at a grant price of $2.92 per share, and 0.72 million RSUs to its employees, directors and consultants. The options carry a five-year life and vest as follows: 50% immediately; 25% on January 23, 2019; 25% on January 23, 2020. The SARs have a term of five years and vest as follows: one-third of the SARs granted, automatically upon the volume weighted average price of the Company's common shares on the NYSE American equaling or exceeding US$5.00 for any continuous 90-day period; one-third of the SARs granted, automatically upon the volume weighted average price of the Company's common shares equaling or exceeding US$7.00 for any continuous 90-day period; and one-third of the SARs granted, automatically upon the volume weighted average price of the Company's common shares equaling or exceeding US$10.00 for any continuous 90-day period. None of the SARs may be exercised before January 22, 2020. The RSUs vest as follows: 50% on January 27, 2020; 25% on January 27, 2021; and 25% on January 27, 2022.

Exhibits

Where an exhibit is filed by incorporation by reference to a previously filed registration statement or report, such registration statement or report is identified in parentheses.

Exhibit No.	Document Description
23.1	Consent of KPMG LLP, Independent Registered Public Accountants, U.S.
23.23	Consent of KPMG LLP, Independent Registered Public Accountants, Canada
31.1	Certification of Chief Executive Officer pursuant to Rule 13a-14(a) of the Exchange Act
31.2	Certification of Chief Financial Officer pursuant to Rule 13a-14(a) of the Exchange Act
32.1	Certification of Chief Executive Officer pursuant to Rule 13a-14(b) of the Exchange Act and 18 U.S.C. Section 1350, as adopted pursuant to Section 906 of the Sarbanes-Oxley Act of 2002
32.2	Certification of Chief Financial Officer pursuant to Rule 13a-14(b) of the Exchange Act and 18 U.S.C. Section 1350, as adopted pursuant to Section 906 of the Sarbanes-Oxley Act of 2002

SIGNATURES

Pursuant to the requirements of Section 13 or 15(d) of the Securities Exchange Act of 1934, the registrant has duly caused this report to be signed on its behalf by the undersigned, thereunto duly authorized.

ENERGY FUELS INC.

By: /s/ Mark S. Chalmers

Mark S. Chalmers, President & Chief Executive Officer

Principal Executive Officer

Date: March 13, 2019

By: /s/ David C. Frydenlund

David C. Frydenlund

Chief Financial Officer

Date: March 13, 2019

EX 23.1

Consent of Independent Registered Public Accounting Firm

The Board of Directors
Energy Fuels Inc.:

We consent to the incorporation by reference in the registration statements (Nos. 333-217098, 333-205182, 333-194900, and No. 333-226654) on Form S-8 and registration statements (No. 333-226878, and No. 333-210782) on Form S-3 of Energy Fuels Inc. of our report dated March 11, 2019, with respect to the consolidated balance sheet of Energy Fuels Inc. as of December 31, 2018 and 2017, the related consolidated statements of operations and comprehensive loss, changes in equity, and cash flows for each of the years in the two-year period ended December 31, 2018, and the related notes (collectively, the consolidated financial statements), which report appears in the December 31, 2018 annual report on Form 10-K of Energy Fuels Inc.

/s/ KPMG LLP

Denver, Colorado
March 11, 2019

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CONSENT OF INDEPENDENT REGISTERED PUBLIC ACCOUNTING FIRM

The Board of Directors

Energy Fuels Inc.

We consent to the incorporation by reference in the Registration Statements (No. 333-210782, No. 333-228158, and No. 333-226878) on Form S-3 and Registration Statements (No. 333-217098, 333-205182, 333-194900, and No. 333-226654) on Form S-8 of Energy Fuels Inc. of our report dated March 8, 2017, with respect to the consolidated statements of operations and comprehensive loss, changes in equity and cash flows for the year ended December 31, 2016, which report appears in the December 31, 2018 Annual Report on Form 10-K of Energy Fuels Inc.

/s/ KPMG LLP

Chartered Professional Accountants, Licensed Public Accountants
March 11, 2019
Toronto, Canada

EXHIBIT 31.1

CERTIFICATION OF CHIEF EXECUTIVE OFFICER
PURSUANT TO RULE 13a-14(a) OF THE
SECURITIES EXCHANGE ACT OF 1934

I, Mark S. Chalmers, certify that:

1. I have reviewed this annual report on Form 10-K/A (Amendment 2) of Energy Fuels Inc.;

2. Based on my knowledge, this report does not contain any untrue statement of a material fact or omit to state a material fact necessary to make the statements made, in light of the circumstances under which such statements were made, not misleading with respect to the period covered by this report;

3. Based on my knowledge, the financial statements, and other financial information included in this report, fairly present in all material respects the financial condition, results of operations and cash flows of the registrant as of, and for, the periods presented in this report;

4. The registrant's other certifying officer and I are responsible for establishing and maintaining disclosure controls and procedures (as defined in Exchange Act Rules 13a-15(e) and 15d-15(e)) and internal control over financial reporting (as defined in Exchange Act Rules 13a-15(f) and 15d-15(f)) for the registrant and have:

   (a) Designed such disclosure controls and procedures, or caused such disclosure controls and procedures to be designed under our supervision, to ensure that material information relating to the registrant, including its consolidated subsidiaries, is made known to us by others within those entities, particularly during the period in which this report is being prepared;

   (b) Designed such internal control over financial reporting, or caused such internal control over financial reporting to be designed under our supervision, to provide reasonable assurance regarding the reliability of financial reporting and the preparation of financial statements for external purposes in accordance with generally accepted accounting principles;

   (c) Evaluated the effectiveness of the registrant's disclosure controls and procedures and presented in this report our conclusions about the effectiveness of the disclosure controls and procedures, as of the end of the period covered by this report based on such evaluation; and

   (d) Disclosed in this report any change in the registrant's internal control over financial reporting that occurred during the registrant's most recent fiscal quarter (the registrant's fourth fiscal quarter in the case of an annual report) that has materially affected, or is reasonably likely to materially affect, the registrant's internal control over financial reporting; and

5. The registrant's other certifying officer and I have disclosed, based on our most recent evaluation of internal control over financial reporting, to the registrant's auditors and the audit committee of the registrant's board of directors (or persons performing the equivalent functions):

   (a) All significant deficiencies and material weaknesses in the design or operation of internal control over financial reporting which are reasonably likely to adversely affect the registrant's ability to record, process, summarize and report financial information; and

   (b) Any fraud, whether or not material, that involves management or other employees who have a significant role in the registrant's internal control over financial reporting.

/s/ Mark S. Chalmers

Date: March 13, 2019

Mark S. Chalmers
Chief Executive Officer
(Principal Executive Officer)

EXHIBIT 31.2

CERTIFICATION OF CHIEF FINANCIAL OFFICER
PURSUANT TO RULE 13a-14(a) OF THE
SECURITIES EXCHANGE ACT OF 1934

I, David C. Frydenlund, certify that:

1. I have reviewed this annual report on Form 10-K/A (Amendment 2) of Energy Fuels Inc.;

2. Based on my knowledge, this report does not contain any untrue statement of a material fact or omit to state a material fact necessary to make the statements made, in light of the circumstances under which such statements were made, not misleading with respect to the period covered by this report;

3. Based on my knowledge, the financial statements, and other financial information included in this report, fairly present in all material respects the financial condition, results of operations and cash flows of the registrant as of, and for, the periods presented in this report;

4. The registrant's other certifying officer and I are responsible for establishing and maintaining disclosure controls and procedures (as defined in Exchange Act Rules 13a-15(e) and 15d-15(e)) and internal control over financial reporting (as defined in Exchange Act Rules 13a-15(f) and 15d-15(f)) for the registrant and have:

   (a) Designed such disclosure controls and procedures, or caused such disclosure controls and procedures to be designed under our supervision, to ensure that material information relating to the registrant, including its consolidated subsidiaries, is made known to us by others within those entities, particularly during the period in which this report is being prepared;

   (b) Designed such internal control over financial reporting, or caused such internal control over financial reporting to be designed under our supervision, to provide reasonable assurance regarding the reliability of financial reporting and the preparation of financial statements for external purposes in accordance with generally accepted accounting principles;

   (c) Evaluated the effectiveness of the registrant's disclosure controls and procedures and presented in this report our conclusions about the effectiveness of the disclosure controls and procedures, as of the end of the period covered by this report based on such evaluation; and

   (d) Disclosed in this report any change in the registrant's internal control over financial reporting that occurred during the registrant's most recent fiscal quarter (the registrant's fourth fiscal quarter in the case of an annual report) that has materially affected, or is reasonably likely to materially affect, the registrant's internal control over financial reporting; and

5. The registrant's other certifying officer and I have disclosed, based on our most recent evaluation of internal control over financial reporting, to the registrant's auditors and the audit committee of the registrant's board of directors (or persons performing the equivalent functions):

   (a) All significant deficiencies and material weaknesses in the design or operation of internal control over financial reporting which are reasonably likely to adversely affect the registrant's ability to record, process, summarize and report financial information; and

   (b) Any fraud, whether or not material, that involves management or other employees who have a significant role in the registrant's internal control over financial reporting.

/s/ David C. Frydenlund

Date: March 13, 2019

David C. Frydenlund
Chief Financial Officer
(Principal Financial Officer)

EXHIBIT 32.1

CERTIFICATION PURSUANT TO
18 U.S.C. §1350
AS ADOPTED PURSUANT TO
SECTION 906 OF THE SARBANES-OXLEY ACT OF 2002

In connection with the Annual Report of Energy Fuels Inc. (the "Company") on Form 10-K/A (Amendment 2) for the period ended December 31, 2018 as filed with the Securities and Exchange Commission on the date hereof (the "Report"), I, Mark S. Chalmers, Chief Executive Officer, certify, pursuant to 18 U.S.C. §1350, as adopted pursuant to Section 906 of the Sarbanes-Oxley Act of 2002, that:

(1) The Report fully complies with the requirements of Section 13(a) or 15(d) of the Securities Exchange Act of 1934, as amended; and

(2) The information contained in the Report fairly presents, in all material respects, the financial condition and results of operations of the Company.

/s/ Mark S. Chalmers
Mark S. Chalmers
Chief Executive Officer
(Principal Executive Officer)

Date: March 13, 2019

A signed original of this written statement required by Section 906, or other document authenticating, acknowledging, or otherwise adopting the signature that appears in typed form within the electronic version of this written statement required by Section 906, has been provided to the Company and will be retained by the Company and furnished to the Securities and Exchange Commission or its staff upon request.

EXHIBIT 32.2

CERTIFICATION PURSUANT TO
18 U.S.C. §1350
AS ADOPTED PURSUANT TO
SECTION 906 OF THE SARBANES-OXLEY ACT OF 2002

In connection with the Annual Report of Energy Fuels Inc. (the "Company") on Form 10-K/A (Amendment 2) for the period ended December 31, 2018 as filed with the Securities and Exchange Commission on the date hereof (the "Report"), I, David C. Frydenlund, Chief Financial Officer, certify, pursuant to 18 U.S.C. §1350, as adopted pursuant to Section 906 of the Sarbanes-Oxley Act of 2002, that:

(1) The Report fully complies with the requirements of Section 13(a) or 15(d) of the Securities Exchange Act of 1934, as amended; and

(2) The information contained in the Report fairly presents, in all material respects, the financial condition and results of operations of the Company.

/s/ David C. Frydenlund

David C. Frydenlund
Chief Financial Officer
(Principal Financial Officer)

Date: March 13, 2019

A signed original of this written statement required by Section 906, or other document authenticating, acknowledging, or otherwise adopting the signature that appears in typed form within the electronic version of this written statement required by Section 906, has been provided to the Company and will be retained by the Company and furnished to the Securities and Exchange Commission or its staff upon request.

EXHIBIT 41

UNITED STATES
SECURITIES AND EXCHANGE COMMISSION
Washington, D.C. 20549

FORM 10-Q

[X] QUARTERLY REPORT PURSUANT TO SECTION 13 OR 15(d) OF THE SECURITIES EXCHANGE ACT OF 1934

For the quarterly period ended September 30, 2019

or

[ ] **TRANSITION REPORT PURSUANT TO SECTION 13 OR 15(d) OF THE SECURITIES EXCHANGE ACT OF 1934**

For the transition period from __________ to __________

Commission File Number: 001-36204

ENERGY FUELS INC.
(Exact name of registrant as specified in its charter)

Ontario, Canada	**98-1067994**
(State or other jurisdiction of incorporation or organization)	(I.R.S. Employer Identification No.)
225 Union Blvd., Suite 600	
Lakewood, Colorado	**80228**
(Address of principal executive offices)	(Zip Code)

(303) 974-2140
(Registrant's telephone number, including area code)

Securities registered pursuant to Section 12(b) of the Act:

Title of each class	Trading Symbol(s)	Name of each exchange on which registered
Common shares, no par value	UUUU	NYSE American
	EFR	Toronto Stock Exchange

Indicate by check mark whether the registrant (1) has filed all reports required to be filed by Section 13 or 15(d) of the Securities Exchange Act of 1934 during the preceding 12 months (or for such shorter period that the registrant was required to file such reports), and (2) has been subject to such filing requirements for the past 90 days. Yes [X] No [ ]

Indicate by check mark whether the registrant has submitted electronically every Interactive Data File required to be submitted pursuant to Rule 405 of Regulation S-T (§ 232.405 of this chapter) during the preceding 12 months (or for such shorter period that the registrant was required to submit such files). Yes [X] No [ ]

Indicate by check mark whether the registrant is a large accelerated filer, an accelerated filer, a non-accelerated filer, a smaller reporting company, or an emerging growth company. See the definitions of "large accelerated filer," "accelerated filer," "smaller reporting company," and "emerging growth company" in Rule 12b-2 of the Exchange Act.

Large accelerated filer [ ]	Accelerated filer [X]
Non-accelerated filer [ ]	Smaller reporting company [ ]
Emerging growth company [X]	

If an emerging growth company, indicate by check mark if the registrant has elected not to use the extended transition period for complying with any new or revised financial accounting standards provided pursuant to Section 13(a) of the Exchange Act. [ ]

Indicate by check mark whether the registrant is a shell company (as defined in Rule 12b-2 of the Act): Yes [ ] No [X]

As of November 1, 2019, the registrant had 99,338,926 common shares, without par value, outstanding.

ENERGY FUELS INC.
FORM 10-Q
For the Quarter Ended September 30, 2019
INDEX

CAUTIONARY STATEMENT REGARDING FORWARD-LOOKING STATEMENTS

This Quarterly Report and the exhibits attached hereto (the "Quarterly Report") contain "forward-looking statements" within the meaning of applicable United States ("U.S.") and Canadian securities laws, which are included but are not limited to statements with respect to Energy Fuels Inc.'s (the "Company" or "Energy Fuels") anticipated results and progress of the Company's operations in future periods, planned exploration, if warranted, development of its properties, plans related to its business, and other matters that may occur in the future. These statements relate to analyses and other information that are based on forecasts of future results, estimates of amounts not yet determinable and assumptions of management.

Any statements that express or involve discussions with respect to predictions, expectations, beliefs, plans, projections, objectives, schedules, assumptions, future events, or performance (often, but not always, using words or phrases such as "expects" or "does not expect," "is expected," "is likely," "budget," "scheduled,' forecasts," intends," "anticipates" or "does not anticipate," "continues," "plans," "estimates," "intends," or "believes," and similar expressions or variations of such words and phrases or statements stating that certain actions, events or results "may," "could," "would," "might," or "will" be taken, occur or be achieved) are not statements of historical fact and may be forward-looking statements.

Forward-looking statements are based on the opinions and estimates of management as of the date such statements are made. Energy Fuels believes that the expectations reflected in these forward-looking statements are reasonable, but no assurance can be given that these expectations will prove to be correct, and such forward-looking statements included in, or incorporated by reference into, this Quarterly Report should not be unduly relied upon. This information speaks only as of the date of this Quarterly Report.

Readers are cautioned that it would be unreasonable to rely on any such forward-looking statements and information as creating any legal rights, and that the statements and information are not guarantees and may involve known and unknown risks and uncertainties, and that actual results are likely to differ (and may differ materially) and objectives and strategies may differ or change from those expressed or implied in the forward-looking statements or information as a result of various factors. Such risks and uncertainties include risks generally encountered in the exploration, development, operation, and closure of mineral properties and processing and recovery facilities. Forward-looking statements are subject to a variety of known and unknown risks, uncertainties and other factors which could cause actual events or results to differ from those expressed or implied by the forward-looking statements, including, without limitation:

- risks associated with mineral reserve and resource estimates, including the risk of errors in assumptions or methodologies;
- risks associated with estimating mineral extraction and recovery, forecasting future price levels necessary to support mineral extraction and recovery, and the Company's ability to increase mineral extraction and recovery in response to any increases in commodity prices or other market conditions;
- uncertainties and liabilities inherent to conventional mineral extraction and recovery and/or in-situ uranium recovery operations;
- geological, technical and processing problems, including unanticipated metallurgical difficulties, less than expected recoveries, ground control problems, process upsets, and equipment malfunctions;
- risks associated with the depletion of existing mineral resources through mining or extraction, without replacement with comparable resources;
- risks associated with identifying and obtaining adequate quantities of alternate feed materials and other feed sources required for operation of the White Mesa Mill in Utah;
- risks associated with labor costs, labor disturbances, and unavailability of skilled labor;
- risks associated with the availability and/or fluctuations in the costs of raw materials and consumables used in the Company's production processes;
- risks and costs associated with environmental compliance and permitting, including those created by changes in environmental legislation and regulation, and delays in obtaining permits and licenses that could impact expected mineral extraction and recovery levels and costs;
- actions taken by regulatory authorities with respect to mineral extraction and recovery activities;
- risks associated with the Company's dependence on third parties in the provision of transportation and other critical services;
- risks associated with the ability of the Company to obtain, extend or renew land tenure, including mineral leases and surface use agreements, on favorable terms or at all;
- risks associated with the ability of the Company to negotiate access rights on certain properties on favorable terms or at all;
- the adequacy of the Company's insurance coverage;

- uncertainty as to reclamation and decommissioning liabilities;
- the ability of the Company’s bonding companies to require increases in the collateral required to secure reclamation obligations;
- the potential for, and outcome of, litigation and other legal proceedings, including potential injunctions pending the outcome of such litigation and proceedings;
- the ability of the Company to meet its obligations to its creditors;
- the ability of the Company to access credit facilities on favorable terms;
- risks associated with paying off indebtedness at its maturity;
- risks associated with the Company’s relationships with its business and joint venture partners;
- failure to obtain industry partner, government, and other third-party consents and approvals, when required;
- competition for, among other things, capital, mineral properties, and skilled personnel;
- failure to complete and integrate proposed acquisitions and incorrect assessments of the value of completed acquisitions;
- risks posed by fluctuations in share price levels, exchange rates and interest rates, and general economic conditions;
- risks inherent in the Company’s and industry analysts’ forecasts or predictions of future uranium, vanadium and copper price levels;
- fluctuations in the market prices of uranium, vanadium and copper, which are cyclical and subject to substantial price fluctuations;
- risks associated with the Company's uranium sales, if any, being required to be made at spot prices, unless the Company is able to enter into new long-term contracts at satisfactory prices in the future;
- risks associated with the Company's vanadium sales, if any, generally being required to be made at spot prices;
- failure to obtain suitable uranium sales terms at satisfactory prices in the future, including spot and term sale contracts;
- failure to obtain suitable vanadium sales terms at satisfactory prices in the future;
- risks associated with asset impairment as a result of market conditions;
- risks associated with lack of access to markets and the ability to access capital;
- the market price of Energy Fuels’ securities;
- public resistance to nuclear energy or uranium extraction and recovery;
- Governmental resistance to nuclear energy or uranium extraction or recovery;
- risks associated with inaccurate or nonobjective media coverage of the Company's activities and the impact such coverage may have on the public, the market for the Company's securities, government relations, permitting activities and legal challenges, as well as the costs to the Company of responding to such coverage;
- uranium industry competition, international trade restrictions and the impacts on world commodity prices of foreign state subsidized production;
- risks associated with the Company's involvement in industry petitions for trade remedies, including the costs of pursuing such remedies and the potential for negative responses or repercussions from various interest groups, consumers of uranium and participants in other phases of the nuclear fuel cycle;
- risks associated with governmental actions, policies, laws, rules and regulations with respect to nuclear energy or uranium extraction and recovery;
- risks that the President of the United States will not take any action or grant any remedies in response to recommendations from the United States Nuclear Fuel Working Group, or otherwise, that would result in meaningful support to the uranium mining industry;
- risks related to potentially higher than expected costs related to any of the Company's projects or facilities;

- risks associated with the Company’s ability to continue to recover vanadium from pond solutions at the White Mesa Mill, with potentially higher than expected costs for any such recoveries, and the Company’s ability to sell any recovered vanadium at satisfactory price levels;

- risks related to the Company’s ability to recover copper from our Canyon uranium project ores;

- risks related to securities regulations;

- risks related to stock price and volume volatility;

- risks related to the Company's ability to maintain our listing on the NYSE American and Toronto Stock Exchanges;

- risks related to the Company's ability to maintain our inclusion in various stock indices;

- risks related to dilution of currently outstanding shares, from additional share issuances, depletion of assets or otherwise;

- risks related to the Company's lack of dividends;

- risks related to recent market events;

- risks related to the Company's issuance of additional common shares under our At-the-Market ("**ATM**") program or otherwise to provide adequate liquidity in depressed commodity market circumstances;

- risks related to acquisition and integration issues;

- risks related to defects in title to the Company's mineral properties;

- risks related to the Company's outstanding debt; and

- risks related to the Company's securities.

This list is not exhaustive of the factors that may affect our forward-looking statements. Some of the important risks and uncertainties that could affect forward-looking statements are described further under the section heading: Item 2. Management's Discussion and Analysis of Financial Condition and Results of Operations of this Quarterly Report. Although we have attempted to identify important factors that could cause actual results to differ materially from those described in forward-looking statements, there may be other factors that cause results not to be as anticipated, estimated or intended. Should one or more of these risks or uncertainties materialize, or should underlying assumptions prove incorrect, actual results may vary materially from those anticipated, believed, estimated, or expected. We caution readers not to place undue reliance on any such forward-looking statements, which speak only as of the date made. Except as required by law, we disclaim any obligation to subsequently revise any forward-looking statements to reflect events or circumstances after the date of such statements or to reflect the occurrence of anticipated or unanticipated events. Statements relating to "Mineral Reserves" or "Mineral Resources" are deemed to be forward-looking statements, as they involve the implied assessment, based on certain estimates and assumptions that the Mineral Reserves and Mineral Resources described may be profitably extracted in the future.

We qualify all the forward-looking statements contained in this Quarterly Report by the foregoing cautionary statements.

Cautionary Note to United States Investors Concerning Disclosure of Mineral Resources

The Company is a U.S. Domestic Issuer for United States Securities and Exchange Commission ("SEC") purposes, most of its shareholders are U.S. residents, the Company is required to report its financial results under U.S. Generally Accepted Accounting Principles, and its primary trading market is the NYSE American. However, because the Company is incorporated in Canada and also listed on the Toronto Stock Exchange ("TSX"), this Quarterly Report contains certain disclosure that satisfies the additional requirements of Canadian securities laws, which differ from the requirements of United States' securities laws. Unless otherwise indicated, all reserve and resource estimates included in this Quarterly Report, and in the documents incorporated by reference herein, have been prepared in accordance with Canadian National Instrument 43-101 - *Standards of Disclosure for Mineral Projects* ("NI 43-101") and the Canadian Institute of Mining, Metallurgy and Petroleum ("CIM") classification system. NI 43-101 is a rule developed by the Canadian Securities Administrators (the "CSA"), which establishes standards for all public disclosure an issuer makes of scientific and technical information concerning mineral projects.

Canadian standards, including NI 43-101, differ significantly from the requirements of SEC Industry Guide 7, and reserve and resource information contained herein, or incorporated by reference in this Quarterly Report, and in the documents incorporated by reference herein, may not be comparable to similar information disclosed by companies reporting reserve and resource information under SEC Industry Guide 7. In particular, and without limiting the generality of the foregoing, the term "resource" does not equate to the term "reserve" under SEC Industry Guide 7. Under SEC Industry Guide 7 standards, mineralization may not be classified as a "reserve" unless the determination has been made that the mineralization could be economically and legally produced or extracted at the time the reserve determination is made. Under SEC Industry Guide 7 standards, a "final" or "bankable" feasibility study is required to report reserves; the three-year historical average price, to the extent possible, is used in any reserve or cash flow analysis to designate reserves; and the primary environmental analysis or report must be filed with the appropriate governmental authority.

SEC Industry Guide 7 disclosure standards historically have not permitted the inclusion of information concerning "Measured Mineral Resources," "Indicated Mineral Resources" or "Inferred Mineral Resources" or other descriptions of the amount of mineralization in mineral deposits that do not constitute "reserves" by SEC Industry Guide 7 standards. United States investors should also understand that "Inferred Mineral Resources" have a great amount of uncertainty as to their existence and as to their economic and legal feasibility. It cannot be assumed that all or any part of an "Inferred Mineral Resource" will ever be upgraded to a higher category. Under Canadian rules, estimated "Inferred Mineral Resources" may not form the basis of feasibility or pre-feasibility studies. **United States investors are cautioned not to assume that all or any part of Measured or Indicated Mineral Resources will ever be converted into mineral reserves. Investors are cautioned not to assume that all or any part of an "Inferred Mineral Resource" exists or is economically or legally mineable.**

Disclosure of "contained pounds" or "contained ounces" in a resource estimate is permitted and typical disclosure under Canadian regulations; however, SEC Industry Guide 7 historically only permitted issuers to report mineralization that does not constitute "reserves" by SEC standards as in-place tonnage and grade without reference to unit measures. The requirements of NI 43-101 for identification of "reserves" are also not the same as those of SEC Industry Guide 7, and reserves reported by the Company in compliance with NI 43-101 may not qualify as "reserves" under SEC Industry Guide 7 standards. Accordingly, information concerning mineral deposits set forth herein may not be comparable to information made public by companies that report in accordance with SEC Industry Guide 7 standards.

On October 31, 2018, the SEC adopted the Modernization of Property Disclosures for Mining Registrants (the "New Rule"), introducing significant changes to the existing mining disclosure framework to better align it with international industry and regulatory practice including NI 43-101. The SEC adopted a two-year transition period for registrants to come into compliance with the New Rule. Accordingly, the Company will need to bring its disclosure into compliance in 2021. At this time, the Company does not know the full effect of the New Rule on its mineral resources and reserves and therefore the disclosure related to the Company's mineral resources and reserves may be significantly different when computed using the requirements set forth in the New Rule.

PART I

ITEM 1. CONDENSED CONSOLIDATED FINANCIAL STATEMENTS.

ENERGY FUELS INC.
Condensed Consolidated Statements of Operations and Comprehensive Loss
(unaudited) (Expressed in thousands of U.S. dollars, except per share amounts)

	Three months ended September 30,		Nine months ended September 30,	
	2019	**2018**	**2019**	**2018**
Revenues				
Uranium concentrates	$ —	$ —	$ 66	$ 28,015
Vanadium concentrates	16	—	1,957	—
Alternate feed materials processing and other	407	451	3,141	663
Total revenues	423	451	5,164	28,678
Costs and expenses applicable to revenues				
Costs and expenses applicable to uranium concentrates	—	—	63	11,908
Costs and expenses applicable to vanadium concentrates	16	—	1,476	—
Costs and expenses applicable to alternate feed materials and other	—	—	2,079	—
Total costs and expenses applicable to revenues	16	—	3,618	11,908
Other operating costs				
Impairment of inventories	2,330	714	8,412	3,063
Development, permitting and land holding	2,310	4,971	8,051	7,569
Standby costs	869	1,296	3,204	5,194
Accretion of asset retirement obligation	484	459	1,478	1,376
Selling costs	30	33	167	121
Intangible asset amortization	—	—	—	2,502
General and administration	3,216	3,193	10,692	10,440
Total operating loss	(8,832)	(10,215)	(30,458)	(13,495)
Interest expense	(419)	(417)	(1,110)	(1,384)
Other income (loss)	2,312	(3,265)	3,181	(2,703)
Net loss	(6,939)	(13,897)	(28,387)	(17,582)
Items that may be reclassified in the future to profit and loss				
Foreign currency translation adjustment	241	895	(666)	657
Unrealized gain on available-for-sale assets	—	380	—	—
Other comprehensive income (loss)	241	1,275	(666)	657
Comprehensive loss	$ (6,698)	$ (12,622)	$ (29,053)	$ (16,925)
Net loss attributable to:				
Owners of the Company	$ (6,840)	$ (13,812)	$ (28,279)	$ (17,485)
Non-controlling interests	(99)	(85)	(108)	(97)
	$ (6,939)	$ (13,897)	$ (28,387)	$ (17,582)
Comprehensive loss attributable to:				
Owners of the Company	$ (6,599)	$ (12,537)	$ (28,945)	$ (16,828)
Non-controlling interests	(99)	(85)	(108)	(97)
	$ (6,698)	$ (12,622)	$ (29,053)	$ (16,925)
Basic and diluted loss per share	$ (0.07)	$ (0.16)	$ (0.30)	$ (0.20)

See accompanying notes to the condensed consolidated financial statements.

ENERGY FUELS INC.
Condensed Consolidated Balance Sheets
(unaudited)(Expressed in thousands of U.S. dollars, except share amounts)

	September 30, 2019	December 31, 2018
ASSETS		
Current assets		
Cash and cash equivalents	$ 14,728	$ 14,640
Marketable securities	7,776	27,061
Trade and other receivables, net	961	1,191
Inventories, net	22,492	16,550
Prepaid expenses and other assets	1,647	1,411
Total current assets	47,604	60,853
Inventories, net	1,772	1,772
Operating lease right of use asset	993	—
Investments accounted for at fair value	321	1,107
Plant, property and equipment, net	27,089	29,843
Mineral properties, net	83,539	83,539
Restricted cash	20,054	19,652
Total assets	$ 181,372	$ 196,766
LIABILITIES AND EQUITY		
Current liabilities		
Accounts payable and accrued liabilities	$ 5,496	$ 7,921
Current portion of operating lease liability	295	—
Current portion of warrant liabilities	—	662
Current portion of asset retirement obligation	32	270
Current portion of loans and borrowings	722	—
Total current liabilities	6,545	8,853
Warrant liabilities	3,177	5,621
Operating lease liability	828	—
Deferred revenue	—	2,724
Asset retirement obligation	20,701	18,834
Loans and borrowings	15,909	15,880
Total liabilities	47,160	51,912
Equity		
Share capital		
Common shares, without par value, unlimited shares authorized; shares issued and outstanding 98,188,502 at September 30, 2019 and 91,445,066 at December 31, 2018	487,668	469,303
Accumulated deficit	(360,337)	(332,058)
Accumulated other comprehensive income	3,177	3,843
Total shareholders' equity	130,508	141,088
Non-controlling interests	3,704	3,766
Total equity	134,212	144,854
Total liabilities and equity	$ 181,372	$ 196,766

Commitments and contingencies (Note 14)

See accompanying notes to the condensed consolidated financial statements.

ENERGY FUELS INC.
Condensed Consolidated Statements of Changes in Equity
(unaudited)(Expressed in thousands of U.S. dollars, except share amounts)

	Common Stock						
	Shares	**Amount**	**Deficit**	**Accumulated other comprehensive income**	**Total shareholders' equity**	**Non-controlling interests**	**Total equity**
Balance at December 31, 2018	91,445,066	$ 469,303	$ (332,058)	$ 3,843	$ 141,088	$ 3,766	$ 144,854
Net loss	—	—	(12,127)	—	(12,127)	(7)	(12,134)
Other comprehensive loss	—	—	—	(136)	(136)	—	(136)
Shares issued for cash by at-the-market offering	754,712	2,471	—	—	2,471	—	2,471
Share issuance cost	—	(62)	—	—	(62)	—	(62)
Share-based compensation	—	1,121	—	—	1,121	—	1,121
Shares issued for exercise of stock options	33,906	102	—	—	102	—	102
Shares issued for the vesting of restricted stock units	850,150	—	—	—	—	—	—
Shares issued for consulting services	18,848	52	—	—	52	—	52
Balance at March 31, 2019	93,102,682	$ 472,987	$ (344,185)	$ 3,707	$ 132,509	$ 3,759	$ 136,268
Net loss	—	—	(9,312)	—	(9,312)	(2)	(9,314)
Other comprehensive loss	—	—	—	(771)	(771)	—	(771)
Shares issued for cash by at-the-market offering	2,141,817	6,595	—	—	6,595	—	6,595
Shares issued to settle liabilities	266,272	847	—	—	847	—	847
Share issuance cost	—	(151)	—	—	(151)	—	(151)
Share-based compensation	—	663	—	—	663	—	663
Shares issued for exercise of stock options	20,899	44	—	—	44	—	44
Shares issued for exercise of warrants	1,450	5	—	—	5	—	5
Shares issued for consulting services	18,237	63	—	—	63	—	63
Contributions attributable to non-controlling interest	—	—	—	—	—	46	46
Balance at June 30, 2019	95,551,357	$ 481,053	$ (353,497)	$ 2,936	$ 130,492	$ 3,803	$ 134,295
Net loss	—	—	(6,840)	—	(6,840)	(99)	(6,939)
Other comprehensive loss	—	—	—	241	241	—	241
Shares issued for cash by at-the-market offering	2,618,297	5,978	—	—	5,978	—	5,978
Share issuance cost	—	(134)	—	—	(134)	—	(134)
Share-based compensation	—	714	—	—	714	—	714
Shares issued for consulting services	18,848	57	—	—	57	—	57
Balance at September 30, 2019	98,188,502	$ 487,668	$ (360,337)	$ 3,177	$ 130,508	$ 3,704	$ 134,212

	Common Stock						
	Shares	Amount	Deficit	Accumulated other comprehensive income	Total shareholders' equity	Non-controlling interests	Total equity
Balance at December 31, 2017	74,366,824	$ 430,383	$ (306,813)	$ 2,289	$ 125,859	$ 3,883	$ 129,742
Net loss	—	—	(10,822)	—	(10,822)	(7)	(10,829)
Other comprehensive loss	—	—	—	(687)	(687)	—	(687)
Shares issued for cash by at-the-market offering	711,253	1,176	—	—	1,176	—	1,176
Share issuance cost	—	(29)	—	—	(29)	—	(29)
Share-based compensation	—	1,202	—	—	1,202	—	1,202
Shares issued for the vesting of restricted stock units	899,192	—	—	—	—	—	—
Cash paid to fund employee income tax withholding due upon vesting of restricted stock units	—	(914)	—	—	(914)	—	(914)
Balance at March 31, 2018	75,977,269	$ 431,818	$ (317,635)	$ 1,602	$ 115,785	$ 3,876	$ 119,661
Net income	—	—	7,149	—	7,149	(5)	7,144
Other comprehensive income	—	—	—	69	69	—	69
Shares issued for cash by at-the-market offering	10,504,702	21,442	—	—	21,442	—	21,442
Share issuance cost	—	(536)	—	—	(536)	—	(536)
Share-based compensation	—	520	—	—	520	—	520
Shares issued for consulting services	164,538	311	—	—	311	—	311
Balance at June 30, 2018	86,646,509	$ 453,555	$ (310,486)	$ 1,671	$ 144,740	$ 3,871	$ 148,611
Net loss	—	—	(13,812)	—	(13,812)	(85)	(13,897)
Other comprehensive income	—	—	—	1,275	1,275	—	1,275
Shares issued for cash by at-the-market offering	1,357,719	3,677	—	—	3,677	—	3,677
Shares issued for acquisition of Royalties	1,102,840	3,739	—	—	3,739	—	3,739
Share issuance cost	—	(209)	—	—	(209)	—	(209)
Share-based compensation	—	519	—	—	519	—	519
Shares issued for exercise of stock options	290,210	619	—	—	619	—	619
Shares issued for exercise of warrants	111,270	366	—	—	366	—	366
Shares issued for consulting services	21,076	53	—	—	53	—	53
Balance at September 30, 2018	89,529,624	$ 462,319	$ (324,298)	$ 2,946	$ 140,967	$ 3,786	$ 144,753

See accompanying notes to the condensed consolidated financial statements.

ENERGY FUELS INC.
Condensed Consolidated Statements of Cash Flows
(unaudited)(Expressed in thousands of U.S. dollars)

	Nine months ended September 30, 2019	Nine months ended September 30, 2018
OPERATING ACTIVITIES		
Net loss for the period	$ (28,387)	$ (17,582)
Items not involving cash:		
Depletion, depreciation and amortization	921	3,480
Stock-based compensation	2,498	2,241
Change in value of convertible debentures	(447)	1,135
Change in value of warrant liabilities	(3,281)	3,802
Accretion of asset retirement obligation	1,478	1,376
Unrealized foreign exchange (gains) losses	(142)	447
Impairment of inventories	8,412	3,063
Revision of asset retirement obligation	151	—
Impairment of mineral properties held for sale	—	—
Acquisition of royalty interests, net of share issuance costs	—	3,622
Other non-cash expenses	2,367	392
Changes in assets and liabilities		
Increase in inventories	(12,854)	(214)
Decrease (increase) in trade and other receivables	234	(145)
Increase in prepaid expenses and other assets	(236)	(760)
Decrease in accounts payable and accrued liabilities	(2,688)	(2,678)
Cash paid for reclamation and remediation activities	—	(225)
Changes in deferred revenue	(2,724)	2,434
	(34,698)	388
INVESTING ACTIVITIES		
Purchase of mineral properties and plant, property and equipment	—	(55)
Maturities and sales of marketable securities	19,530	2,565
Cash received from sale of Reno Creek	—	2,940
Purchase of available for sale investments	—	(25,525)
	19,530	(20,075)
FINANCING ACTIVITIES		
Issuance of common shares for cash, net of issuance cost	14,696	25,638
Proceeds from notes payable	801	—
Cash paid to fund employee income tax withholding due upon vesting of restricted stock units	—	(914)
Repayment of loans and borrowings	(79)	(10,855)
Cash received from exercise of warrants	5	366
Cash received from exercise of stock options	146	619
Cash received for notes receivable	—	500
Cash received from non-controlling interest	46	—
	15,615	15,354
CHANGE IN CASH, CASH EQUIVALENTS AND RESTRICTED CASH DURING THE PERIOD	447	(4,333)
Effect of exchange rate fluctuations on cash held in foreign currencies	43	(38)
Cash, cash equivalents and restricted cash - beginning of period	34,292	40,701
CASH, CASH EQUIVALENTS AND RESTRICTED CASH - END OF PERIOD	$ 34,782	$ 36,330
Supplemental disclosure of cash flow information:		
Net cash paid during the period for:		
Interest	$ 1,110	$ 1,008
Warrant liability transferred to equity upon exercise	$ 2	$ —

See accompanying notes to the condensed consolidated financial statements.

1. THE COMPANY AND DESCRIPTION OF BUSINESS

Energy Fuels Inc. was incorporated under the laws of the Province of Alberta and was continued under the Business Corporations Act (Ontario).

Energy Fuels Inc. and its subsidiary companies (collectively "the Company" or "EFI") are engaged in uranium extraction, recovery and sales of uranium from mineral properties and the recycling of uranium bearing materials generated by third parties. As a part of these activities the Company also acquires, explores, evaluates and, if warranted, permits uranium properties. The Company's final uranium product, uranium oxide concentrate ("U_3O_8" or "uranium concentrate"), is sold to customers for further processing into fuel for nuclear reactors. The Company produces vanadium as a co-product of its uranium recovery from certain of its mines as market conditions warrant and from time to time from solutions in its tailing impoundment system.

The Company is an exploration stage mining company as defined by the United States ("U.S.") Securities and Exchange Commission ("SEC") Industry Guide 7 ("SEC Industry Guide 7") as it has not established the existence of proven or probable reserves on any of its properties.

2. BASIS OF PRESENTATION

The consolidated financial statements have been prepared in accordance with generally accepted accounting principles in the United States ("U.S. GAAP") and are presented in thousands of U.S. dollars, except per share amounts. Certain footnote disclosures have share prices which are presented in Canadian dollars ("Cdn$").

The condensed consolidated financial statements included herein have been prepared by the Company, without audit, pursuant to the rules and regulations of the SEC. Certain information and note disclosures normally included in financial statements prepared in accordance with U.S. GAAP have been condensed or omitted pursuant to such rules and regulations, although the Company believes that the disclosures included are adequate to make the information presented not misleading.

In management's opinion, these unaudited condensed consolidated financial statements reflect all adjustments, consisting solely of normal recurring items, which are necessary for the fair presentation of the Company's financial position, results of operations and cash flows on a basis consistent with that of the Company's audited consolidated financial statements for the year ended December 31, 2018. However, the results of operations for the interim periods may not be indicative of results to be expected for the full fiscal year. These unaudited condensed consolidated financial statements should be read in conjunction with the audited consolidated financial statements and notes thereto and summary of significant accounting policies included in the Company's annual report on Form 10-K for the year ended December 31, 2018 with the following addition to the inventory policy included below.

Inventories

In-process and concentrate inventories include the cost of the material processed from the stockpile, as well as production costs incurred to extract uranium bearing fluids from the wellfields, and all costs to recover the uranium into concentrates, recover vanadium concentrates from pond solutions or process through the White Mesa Mill. Finished uranium or vanadium concentrate inventories also include costs of any finished product purchased from the market. Recovery costs typically include labor, chemical reagents and directly attributable mill and plant overhead expenditures.

The condensed consolidated financial statements include the accounts of the Company and its subsidiaries. All inter-company accounts and transactions have been eliminated.

3. MARKETABLE SECURITIES

The following table summarizes our marketable securities by significant investment categories as of September 30, 2019:

	Cost Basis	Gross Unrealized Losses	Gross Unrealized Gains	Fair Value
Marketable debt securities[1]	$ 6,994	$ —	$ 64	$ 7,058
Marketable equity securities	1,062	(549)	205	718
Marketable securities	$ 8,056	$ (549)	$ 269	$ 7,776

(1) Marketable debt securities are comprised primarily of U.S. government notes, and also includes U.S. government agencies and tradeable certificates of deposits.

The following table summarizes our marketable securities by significant investment categories as of December 31, 2018:

	Cost Basis	Gross Unrealized Losses	Gross Unrealized Gains	Fair Value
Marketable debt securities [1]	$ 25,523	$ (5)	$ 83	$ 25,601
Marketable equity securities	1,062	(549)	947	1,460
Marketable securities	$ 26,585	$ (554)	$ 1,030	$ 27,061

(1) Marketable debt securities are comprised primarily of U.S. government notes, and also includes U.S. government agencies, and tradeable certificates of deposits.

During the nine months ended September 30, 2019 and 2018, we did not recognize any other-than-temporary impairment losses.

The following table summarizes the estimated fair value of our investments in marketable debt securities with stated contractual maturity dates, accounted for as available-for-sale securities and classified by the contractual maturity date of the securities:

Due in less than 12 months	$ 6,159
Due in 12 months to two years	899
Due in greater than two years	—
	$ 7,058

4. INVENTORIES

	September 30, 2019	December 31, 2018
Concentrates and work-in-progress	$ 20,790	$ 14,746
Inventory of ore in stockpiles	677	883
Raw materials and consumables	2,797	2,693
	$ 24,264	$ 18,322
Inventories - by duration		
Current	$ 22,492	$ 16,550
Long term - raw materials and consumables	1,772	1,772
	$ 24,264	$ 18,322

(a) For the three and nine months ended September 30, 2019, the Company recorded an impairment loss of $2.33 million and $8.41 million in the statement of operations related to concentrates and work in progress inventories and inventory of ore in stockpiles (September 30, 2018 - $0.71 million and $3.06 million).

5. PLANT AND EQUIPMENT AND MINERAL PROPERTIES

The following is a summary of plant and equipment:

	September 30, 2019			December 31, 2018		
	Cost	Accumulated Depreciation	Net Book Value	Cost	Accumulated Depreciation	Net Book Value
Plant and equipment						
Nichols Ranch	$ 29,210	$ (13,521)	$ 15,689	$ 29,210	$ (12,021)	$ 17,189
Alta Mesa	13,626	(3,017)	10,609	13,656	(2,319)	11,337
Equipment and other	12,907	(12,116)	791	13,444	(12,127)	1,317
Plant and equipment total	$ 55,743	$ (28,654)	$ 27,089	$ 56,310	$ (26,467)	$ 29,843

The following is a summary of mineral properties:

	September 30, 2019	December 31, 2018
Mineral properties		
Uranerz ISR properties	$ 25,974	$ 25,974
Sheep Mountain	34,183	34,183
Roca Honda	22,095	22,095
Other	1,287	1,287
Mineral properties total	$ 83,539	$ 83,539

6. ASSET RETIREMENT OBLIGATIONS AND RESTRICTED CASH

The following table summarizes the Company’s asset retirement obligations:

	September 30, 2019	December 31, 2018
Asset retirement obligation, beginning of period	$ 19,104	$ 18,280
Revision of estimate	151	(662)
Accretion of liabilities	1,478	1,835
Settlements	—	(349)
Asset retirement obligation, end of period	$ 20,733	$ 19,104
Asset retirement obligation:		
Current	$ 32	$ 270
Non-current	20,701	18,834
Asset retirement obligation, end of period	$ 20,733	$ 19,104

The asset retirement obligations of the Company are subject to legal and regulatory requirements. Estimates of the costs of reclamation are reviewed periodically by the Company and the applicable regulatory authorities. The above provision represents the Company’s best estimate of the present value of future reclamation costs, discounted using credit adjusted risk-free interest rates ranging from 9.5% to 11.5% and an inflation rate of 2.0%. The total undiscounted decommissioning liability at September 30, 2019 is $41.73 million (December 31, 2018 - $41.32 million).

The following table summarizes the Company’s restricted cash:

	September 30, 2019	December 31, 2018
Restricted cash, beginning of period	$ 19,652	$ 22,127
Additional collateral posted	402	117
Refunds of collateral	—	(2,592)
Restricted cash, end of period	$ 20,054	$ 19,652

The Company has cash, cash equivalents and fixed income securities as collateral for various bonds posted in favor of the applicable state regulatory agencies in Arizona, Colorado, New Mexico, Texas, Utah and Wyoming, and the U.S. Bureau of Land Management and U.S. Forest Service for estimated reclamation costs associated with the White Mesa Mill, Nichols Ranch, Alta Mesa and other mining properties. Cash equivalents are short-term highly liquid investments with original maturities of three months or less. The restricted cash will be released when the Company has reclaimed a mineral property or restructured the surety and collateral arrangements. See Note 14 for a discussion of the Company's surety bond commitments.

Cash, cash equivalents and restricted cash are included in the following accounts at September 30, 2019 and December 31, 2018:

	September 30, 2019	December 31, 2018
Cash and cash equivalents	$ 14,728	$ 14,640
Restricted cash included in other long-term assets	20,054	19,652
Total cash, cash equivalents and restricted cash	$ 34,782	$ 34,292

7. LOANS AND BORROWINGS

The Company's convertible debentures which are measured at fair value, are $15.91 million and $15.88 million as of September 30, 2019 and December 31, 2018, respectively.

On July 24, 2012, the Company completed a bought deal public offering of 22,000 floating-rate convertible unsecured subordinated debentures originally maturing June 30, 2017 (the "Debentures") at a price of Cdn$1,000 per Debenture for gross proceeds of Cdn$21.55 million (the "Offering"). The Debentures are convertible into Common Shares at the option of the holder. Interest is paid in cash and in addition, unless an event of default has occurred and is continuing, the Company may elect, from time to time, subject to applicable regulatory approval, to satisfy its obligation to pay interest on the Debentures, on the date it is payable under the indenture: (i) in cash; (ii) by delivering sufficient common shares to the debenture trustee, for sale, to satisfy the interest obligations in accordance with the indenture in which event holders of the Debentures will be entitled to receive a cash payment equal to the proceeds of the sale of such common shares; or (iii) any combination of (i) and (ii).

On August 4, 2016, the Company, by a vote of the Debentureholders, extended the maturity date of the Debentures from June 30, 2017 to December 31, 2020, and reduced the conversion price of the Debentures from Cdn$15.00 to Cdn$4.15 per Common Share of the Company. In addition, a redemption provision was added that will enable the Company, upon giving not less than 30 days' notice to Debentureholders, to redeem the Debentures, for cash, in whole or in part at any time after June 30, 2019, but prior to maturity, at a price of 101% of the aggregate principal amount redeemed, plus accrued and unpaid interest (less any tax required by law to be deducted) on such Debentures up to but excluding the redemption date. A right (in favor of each Debentureholder) was also added which gave the Debentureholders the option to require the Company to purchase, for cash, on the previous maturity date of June 30, 2017, up to 20% of the Debentures held by the Debentureholders at a price equal to 100% of the principal amount purchased plus accrued and unpaid interest (less any tax required by law to be deducted). In the three months ended June 30, 2017, Debentureholders elected to redeem Cdn$1.13 million ($0.87 million) under this right. No additional purchases are allowed under this right. In addition, certain other amendments were made to the Indenture, as required by the U.S. Trust Indenture Act of 1939, as amended, and with respect to the addition of a U.S. Trustee in compliance therewith, as well as to remove provisions of the Indenture that no longer apply, such as U.S. securities law restrictions.

The Debentures accrue interest, payable semi-annually in arrears on June 30 and December 31 of each year at a fluctuating rate of not less than 8.5% and not more than 13.5%, indexed to the simple average spot price of uranium as reported on the UxC, LLC ("UxC") Weekly Indicator Price. The Debentures may be redeemed in whole or part, at par plus accrued interest and unpaid interest by the Company between June 30, 2019 and December 31, 2020 subject to certain terms and conditions, provided the volume weighted average trading price of the common shares of the Company on the TSX during the 20 consecutive trading days ending five days preceding the date on which the notice of redemption is given is not less than 125% of the conversion price.

Upon redemption or at maturity, the Company will repay the indebtedness represented by the Debentures by paying to the debenture trustee in Canadian dollars an amount equal to the aggregate principal amount of the outstanding Debentures which are to be redeemed or which have matured, as applicable, together with accrued and unpaid interest thereon.

Subject to any required regulatory approval and provided no event of default has occurred and is continuing, the Company has the option to satisfy its obligation to repay the Cdn$1,000 principal amount of the Debentures, in whole or in part, due at redemption or maturity, upon at least 40 days' and not more than 60 days' prior notice, by delivering that number of common shares obtained by dividing the Cdn$1,000 principal amount of the Debentures maturing or to be redeemed as applicable, by 95% of the volume-weighted average trading price of the common shares on the TSX during the 20 consecutive trading days ending five trading days preceding the date fixed for redemption or the maturity date, as the case may be.

The Debentures are classified as fair value through profit or loss where the Debentures are measured at fair value based on the closing price on the TSX (a Level 1 measurement) and changes are recognized in earnings. For the three and nine months ended September 30, 2019, the Company recorded a gain on revaluation of convertible Debentures of $0.94 million and $0.45 million, respectively (September 30, 2018 – loss of $1.46 million and $1.14 million for the three and nine months ended).

8. LEASES

Effective January 1, 2019, the Company adopted ASU No. 2016-02, *Leases*, and the series of related Accounting Standards Updates that followed (collectively referred to as "ASC 842"). Most prominent among the changes in the standard is the recognition of right-of-use ("ROU") assets and lease liabilities by lessees for those leases classified as operating leases. The accounting for leases where the Company is the lessor remains largely unchanged. In addition, the new standard requires additional qualitative and quantitative disclosures to enable users of financial statements to assess the amount, timing and uncertainty of cash flows arising from leases.

The Company adopted the new standard using the modified retrospective approach with a cumulative effect adjustment on January 1, 2019. Prior comparative periods have not been restated and continue to be reported under the accounting standard in effect for those periods (ASC 840). The Company elected the package of practical expedients permitted under the transition guidance, which among other things, allows us to carry-forward historical lease classifications. The Company also elected the practical expedient to not separate lease components from nonlease components for all asset classes, and we elected the short-term lease recognition exemption whereby ROU assets and lease liabilities will not be recognized for leasing arrangements with terms less than one year.

The adoption of the new standard resulted in the recognition of operating lease ROU assets of $1.14 million, current operating lease liabilities of $0.27 million, and noncurrent operating lease liabilities of $0.96 million. Adoption of this standard had no impact on the statement of operations or retained earnings.

Lessee

The Company's leases primarily include operating leases for corporate offices. These leases have remaining lease terms of less than one year to four years, and include options to extend the leases for up to five years. Certain of our leases include variable payments for lessor operating expenses that are not included within ROU assets and lease liabilities in the Condensed Consolidated Balance Sheets. The Company's lease agreements do not contain any material residual value guarantees or restrictive covenants.

Beginning January 1, 2019, operating ROU assets and operating lease liabilities are recognized based on the present value of lease payments over the lease term at commencement date. Operating leases in effect prior to January 1, 2019 were recognized at the present value of the remaining payments on the remaining lease term as of January 1, 2019. Because most of the Company's leases do not provide an explicit rate of return, the Company's incremental secured borrowing rate based on lease term information available at the commencement date of the lease will be used in determining the present value of lease payments. For purposes of calculating operating lease liabilities, lease terms may be deemed to include options to extend or terminate the lease when it is reasonably certain that we will exercise that option. The Company's operating lease expense is recognized on a straight-line basis over the lease term and is recorded in General and Administration expenses. Short-term leases, which have an initial term of 12 months or less, are not recorded in the condensed Consolidated Balance Sheets.

Total lease cost includes the following components:

	Three months ended September 30,	Nine months ended September 30,
	2019	
Operating leases	$ 99	$ 309
Short-term leases	96	222
Sublease income	(9)	(65)
Total Lease Expense	$ 186	$ 466

Total lease expense was $0.19 million and $0.53 million for the three and nine months ended September 30, 2018.
The weighted average remaining lease term and weighted average discount rate were as follows:

	Nine months ended September 30, 2019
Weighted average remaining lease term of operating leases	3.5 years
Weighted average discount rate of operating leases	9.0%

Supplemental cash flow information related to leases was as follows:

	Three months ended September 30, 2019	Nine months ended September 30, 2019
Operating cash flow information:		
Cash paid for amounts included in the measurement of operating lease liabilities	$ 105	$ 243

Future minimum payments of operating lease liabilities as of September 30, 2019 are as follows:

Years ending December 31:	
2019 (excluding the nine months ended September 30, 2019)	$ 101
2020	367
2021	343
2022	350
2023	147
Thereafter	—
Total Lease Payments	$ 1,308
Less: Interest	(186)
Present Value of Lease Liabilities	$ 1,122

9. CAPITAL STOCK

Authorized capital stock

The Company is authorized to issue an unlimited number of Common Shares without par value, unlimited Preferred Shares issuable in series, and unlimited Series A Preferred Shares. The Series A Preferred Shares issuable are non-redeemable, non-callable, non-voting and with no right to dividends. The Preferred Shares issuable in series will have the rights, privileges, restrictions and conditions assigned to the particular series upon the Board of Directors approving their issuance.

Issued capital stock

In the nine months ended September 30, 2019, the Company issued 5,514,826 Common Shares under the Company's ATM for net proceeds of $14.70 million after share issuance cost.

Share Purchase Warrants

The following table summarizes the Company's share purchase warrants denominated in U.S. dollars. These warrants are accounted for as derivative liabilities as the functional currency of the entity issuing the warrants, Energy Fuels Inc., is Canadian dollars.

Month Issued	Expiry Date	Exercise Price USD$	Warrants Outstanding	Fair value at September 30, 2019
September 2016 (a)	September 20, 2021	2.45	4,166,030	$ 3,177

(a) The warrants issued in September 2016 are classified as Level 1 under the fair value hierarchy (Note 16).

On March 14, 2019, 2,328,925 warrants issued in March 2016 expired unexercised.

10. BASIC AND DILUTED LOSS PER COMMON SHARE

The calculation of basic and diluted earnings per share after adjustment for the effects of all potential dilutive common shares, is as follows:

	Three months ended September 30,		Nine months ended September 30,	
	2019	**2018**	**2019**	**2018**
Loss attributable to shareholders	$ (6,840)	$ (13,812)	$ (28,279)	$ (17,485)
Basic and diluted weighted average number of common shares outstanding	96,840,539	87,197,294	94,321,950	80,843,493
Loss per common share	$ (0.07)	$ (0.16)	$ (0.30)	$ (0.20)

For the nine months ended September 30, 2019, 5.66 million (September 30, 2018 - 8.44 million) options and warrants and the potential conversion of the Debentures have been excluded from the calculation as their effect would have been anti-dilutive.

11. SHARE-BASED PAYMENTS

The Company, under the 2018 Omnibus Equity Incentive Compensation Plan (the "Compensation Plan"), maintains an equity incentive plan for directors, executives, eligible employees and consultants. Equity incentive awards include employee stock options, restricted stock units ("RSUs") and stock appreciation rights ("SARs"). The Company issues new shares of common stock to satisfy exercises and vesting under all of its equity incentive awards. At September 30, 2019, a total of 9,818,850 Common Shares were authorized for equity incentive plan awards.

Employee Stock Options

The Company, under the Compensation Plan, may grant options to directors, executives, employees and consultants to purchase Common Shares of the Company. The exercise price of the options is set as the higher of the Company's closing share price on the day before the grant date or the five-day volume weighted average price. Stock options granted under the Compensation Plan generally vest over a period of two years or more and are generally exercisable over a period of five years from the grant date not to exceed 10 years. The value of each option award is estimated at the grant date using the Black-Scholes Option Valuation Model. There were 0.30 million options granted in the nine months ended September 30, 2019 (nine months ended September 30, 2018 – 0.42 million options). At September 30, 2019, there were 1.49 million options outstanding with 1.27 million options exercisable, at a weighted average exercise price of $3.43 and $3.60 respectively, with a weighted average remaining contractual life of 3.21 years. The aggregate intrinsic value of the fully vested options was $0.04 million.

The fair value of the options granted under the Compensation Plan for the nine months ended September 30, 2019 was estimated at the date of grant, using the Black-Scholes Option Valuation Model, with the following weighted average assumptions:

Risk-free interest rate	2.6%
Expected life	5.0 years
Expected volatility	59.4% *
Expected dividend yield	—%
Weighted average expected life of option	5.00
Weighted average grant date fair value	$1.54

* Expected volatility is measured based on the Company's historical share price volatility over a period equivalent to the expected life of the options.

The summary of the Company's stock options at September 30, 2019 and December 31, 2018, and the changes for the fiscal periods ending on those dates is presented below:

	Range of Exercise Prices	Weighted Average Exercise Price	Number of Options
Balance, December 31, 2017	$1.77 - $15.61	$ 4.48	2,028,847
Granted	1.70 - 2.88	1.75	442,956
Exercised	1.70 - 2.55	2.15	(355,092)
Forfeited	1.70 - 6.63	3.96	(213,393)
Expired	5.86 - 10.36	8.18	(170,564)
Balance, December 31, 2018	$1.70 - $15.61	$ 3.84	1,732,754
Granted	2.92	2.92	296,450
Exercised	1.70 - 2.92	2.27	(54,805)
Forfeited	1.70 - 7.42	4.41	(337,766)
Expired	6.83	6.83	(144,100)
Balance, September 30, 2019	$1.70 - $15.61	$ 3.43	1,492,533

A summary of the status and activity of non-vested stock options for the nine months ended September 30, 2019 is as follows:

	Number of shares	Weighted Average Grant-Date Fair Value
Non-vested December 31, 2018	297,044	$ 1.06
Granted	296,450	1.54
Vested	(345,921)	1.28
Forfeited	(22,551)	1.47
Non-vested September 30, 2019	225,022	$ 1.31

Restricted Stock Units

The Company grants RSUs to executives and eligible employees. Awards are determined as a target percentage of base salary and generally vest over periods of three years. Prior to vesting, holders of restricted stock units do not have the right to vote the underlying shares. The RSUs are subject to forfeiture risk and other restrictions. Upon vesting, the employee is entitled to receive one share of the Company’s common stock for each RSU for no additional payment. During the nine months ended September 30, 2019, the Company's Board of Directors issued 0.72 million RSUs under the Compensation Plan (September 30, 2018 - 1.19 million).

A summary of the status and activity of non-vested RSUs at September 30, 2019 is as follows:

	RSU	
	Number of shares	Weighted Average Grant-Date Fair Value
Non-vested December 31, 2018	1,580,187	$ 1.99
Granted	721,750	2.92
Vested	(862,378)	2.00
Forfeited	(168,004)	2.32
Non-vested September 30, 2019	1,271,555	$ 2.47

The total intrinsic value and fair value of RSUs that vested and were settled for equity in the nine months ended September 30, 2019 was $2.51 million (September 30, 2018 – $2.41 million).

Stock Appreciation Rights

During the nine months ended September 30, 2019, the Company's Board of Directors issued 2.20 million SARs under the Compensation Plan (September 30, 2018 - nil) with a fair value of $1.25 per SAR. These SARs are intended to provide additional long-term performance-based equity incentives for the Corporation’s senior management. The SARs are purely performance based, because they only vest upon the achievement of aggressive performance goals designed to significantly increase shareholder value.

Each SAR granted entitles the holder, on exercise, to a payment in cash or shares (at the election of the Company) equal to the difference between the market price of the Common Shares at the time of exercise and $2.92 (the market price at the time of grant) over a five-year period, but vest only upon the achievement of the following performance goals: as to one-third of the SARs granted upon the volume weighted average price (“**VWAP**”) of the Common Shares on the NYSE American equaling or exceeding $5.00 for any continuous 90-calendar day period; as to an additional one-third of the SARs granted, upon the VWAP of the Common Shares on the NYSE American equaling or exceeding $7.00 for any continuous 90 calendar-day period; and as to the final one-third of the SARs granted, upon the VWAP of the Common Shares on the NYSE American equaling or exceeding $10.00 for any continuous 90 calendar-day period. Further, notwithstanding the foregoing vesting schedule, no SARs may be exercised by the holder for an initial period of one year from the Date of Grant; the date first exercisable being January 22, 2020.

The share-based compensation recorded during the three and nine months ended September 30, 2019 was $0.71 million and $2.50 million (three and nine months ended September 30, 2018 - $0.52 million and $2.24 million, respectively).

At September 30, 2019, there were $0.07 million, $0.95 million and $1.71 million of unrecognized compensation costs related to the unvested stock options, RSU awards and SARs, respectively. These costs are expected to be recognized over a period of approximately two years.

12. INCOME TAXES

As of September 30, 2019, the Company does not believe it is more likely than not that it will fully realize the benefit of the deferred tax assets. As such, the Company recognized a full valuation allowance against the net deferred tax assets as of September 30, 2019 and December 31, 2018.

13. SUPPLEMENTAL FINANCIAL INFORMATION

The components of other income are as follows:

	Three months ended September 30,		Nine months ended September 30,	
	2019	**2018**	**2019**	**2018**
Interest income	$ 134	$ 84	$ 386	$ 157
Change in value of investments accounted for at fair value	(589)	1,127	(576)	1,570
Change in value of warrant liabilities	2,166	(2,722)	3,281	(3,802)
Change in value of convertible debentures	940	(1,455)	447	(1,135)
Sale of surplus assets	—	—	—	293
Foreign exchange loss	(15)	(170)	(34)	(60)
Gain on sale of assets held for sale	—	—	—	341
Other	(324)	(129)	(323)	(67)
Other income (loss)	$ 2,312	$ (3,265)	$ 3,181	$ (2,703)

14. COMMITMENTS AND CONTINGENCIES

General legal matters

Other than routine litigation incidental to our business, or as described below, the Company is not currently a party to any material pending legal proceedings that management believes would be likely to have a material adverse effect on our financial position, results of operations or cash flows.

White Mesa Mill

In January 2013, the Ute Mountain Ute Tribe filed a Petition to Intervene and Request for Agency Action challenging the Corrective Action Plan approved by the State of Utah Department of Environmental Quality ("UDEQ") relating to nitrate contamination in the shallow aquifer at the White Mesa Mill site. This challenge is currently being evaluated and may involve the appointment of an administrative law judge to hear the matter. The Company does not consider this action to have any merit. If the petition is successful, the likely outcome would be a requirement to modify or replace the existing Corrective Action Plan. At this time, the Company does not believe any such modification or replacement would materially affect our financial position, results of operations or cash flows. However, the scope and costs of remediation under a revised or replacement Corrective Action Plan have not yet been determined and could be significant.

On January 19, 2018, UDEQ renewed, and on February 16, 2018 reissued with minor corrections, the Company's White Mesa Mill license for another ten years, and Groundwater Discharge Permit for another five years, after which renewal periods further applications for renewal for the license and permit will need to be submitted. During the review period for each application for renewal, the Mill can continue to operate under its then existing license and permit until such time as the renewed license or permit is issued. In March 2018, the Grand Canyon Trust, Ute Mountain Ute Tribe and Uranium Watch served Petitions for Review challenging UDEQ's renewal of the license and permit. Then, in May and June 2018, Uranium Watch, the Grand Canyon Trust and the Ute Mountain Ute Tribe filed with UDEQ Requests for Appointment of an Administrative Law Judge, which they subsequently agreed to suspend pursuant to a Stipulation and Agreement with UDEQ, effective June 4, 2018. The Company has met with representatives from all parties in order to determine whether the pending administrative proceedings can be settled. Discussions are ongoing. The Company does not consider these challenges to have any merit. If the challenges are successful, the likely outcome would be a requirement to modify the renewed license and/or permit. At this time, the Company does not believe any such modification would materially affect our financial position, results of operations or cash flows.

Canyon Project

In March of 2013, the Center for Biological Diversity, the Grand Canyon Trust, the Sierra Club and the Havasupai Tribe (the "Canyon Plaintiffs") filed a complaint in the U.S. District Court for the District of Arizona (the "District Court") against the Forest Supervisor for the Kaibab National Forest and the U.S. Forest Service ("USFS") seeking an order (a) declaring that the USFS failed to comply with environmental, mining, public land, and historic preservation laws in relation to our Canyon Project, (b) setting aside any approvals regarding exploration and mining operations at the Canyon Project, and (c) directing operations to cease at the Canyon Project and enjoining the USFS from allowing any further exploration or mining-related activities at the Canyon Project until the USFS fully complies with all applicable laws. In April 2013, the Plaintiffs filed a Motion for Preliminary Injunction, which was denied by the District Court in September 2013. On April 7, 2015, the District Court issued its final ruling on the merits in favor of the Defendants and the Company and against the Canyon Plaintiffs on all counts. The Canyon Plaintiffs appealed the District Court's ruling on the merits to the Ninth Circuit Court of Appeals and filed motions for an injunction pending appeal with the District Court. Those motions for an injunction pending appeal were denied by the District Court on May 26, 2015. Thereafter, Plaintiffs filed urgent motions for an injunction pending appeal with the Ninth Circuit Court of Appeals, which were denied on June 30, 2015.

The hearing on the merits at the Court of Appeals was held on December 15, 2016. On December 12, 2017, the Ninth Circuit Court of Appeals issued its ruling on the merits in favor of the Defendants and the Company and against the Canyon Plaintiffs on all counts. The Canyon Plaintiffs petitioned the Ninth Circuit Court of Appeals for a rehearing *en banc*. On October 25, 2018, the Ninth Circuit panel ruled on the petition for rehearing en banc. The panel withdrew its prior opinion and filed a new opinion, which affirmed with one exception the District Court's decision. The one exception relates to Plaintiffs' fourth claim, which was dismissed by the District Court for lack of standing. The Ninth Circuit panel reversed itself on its standing analysis, concluded that the Plaintiffs have standing to assert this claim and remanded the claim back to the District Court to hear the merits of Plaintiffs' claim. Briefing on the matter is currently in progress and is expected to be completed during the fourth quarter of 2019. If the Canyon Plaintiffs are successful on their fourth claim, the Company may be required to maintain the Canyon Project on standby pending resolution of the matter. Such a required prolonged stoppage of mining activities could have a significant impact on our future operations.

On March 21, 2019, the Havasupai Tribe filed a Petition for a Writ of Certiorari regarding its claims in this matter with the Supreme Court of the United States, requesting that the Supreme Court hear this case. The Petition was placed on the docket on March 25, 2019 and, on May 20, 2019, the Supreme Court of the United States denied the Havasupai Tribe's March 21, 2019 Petition. That portion of the case is now over.

Daneros Project

On February 23, 2018, the BLM issued the Environmental Assessment ("EA"), Decision Record and FONSI for the Mine Plan of Operations Modification for the Daneros Mine. On March 29, 2018, the Southern Utah Wilderness Alliance and Grand Canyon

Trust (together, the “Appellants”) filed a Notice of Appeal to the Interior Board of Land Appeals (“IBLA”) regarding the BLM’s Decision Record and FONSI and challenging the underlying EA, and the Company was subsequently permitted to intervene. This matter has been briefed and remains under consideration by IBLA at this time. The Company does not consider these challenges to have any merit; however, the scope and costs of amending or redoing the EA have not yet been determined and could be significant.

Surety Bonds

The Company has indemnified third-party companies to provide surety bonds as collateral for the Company’s asset retirement obligation. The Company is obligated to replace this collateral in the event of a default, and is obligated to repay any reclamation or closure costs due. The Company currently has $20.05 million posted against an undiscounted asset retirement obligation of $41.73 million (December 31, 2018 - $19.65 million posted against an undiscounted asset retirement obligation of $41.32 million).

Commitments

The Company is contractually obligated under a Sales and Agency Agreement appointing an exclusive sales and marketing agent for all vanadium pentoxide produced by the Company.

15. RELATED PARTY TRANSACTIONS

On May 17, 2017, the Board of Directors of the Company appointed Robert W. Kirkwood and Benjamin Eshleman III to the Board of Directors of the Company.

Mr. Kirkwood is a principal of the Kirkwood Companies, including Kirkwood Oil and Gas LLC, Wesco Operating, Inc., and United Nuclear LLC (“United Nuclear”). United Nuclear, owns a 19% interest in the Company’s Arkose Mining Venture while the Company owns the remaining 81%. The Company acts as manager of the Arkose Mining Venture and has management and control over operations carried out by the Arkose Mining Venture. The Arkose Mining Venture is a contractual joint venture governed by a venture agreement dated as of January 15, 2008 entered into by Uranerz Energy Corporation (a subsidiary of the Company) and United Nuclear (the “Venture Agreement”).

United Nuclear contributed $46 thousand to the expenses of the Arkose Joint Venture based on the approved budget for the nine months ended September 30, 2019.

Mr. Benjamin Eshleman III is President of Mesteña LLC, which became a shareholder of the Company through the Company’s acquisition of Mesteña Uranium, L.L.C. (now EFR Alta Mesa LLC) in June 2016 through the issuance of 4,551,284 common shares of the Company to the direction of the Sellers. In connection with the Purchase Agreement, one of the acquired companies under the purchase agreement ("acquired companies"), Leoncito Project, L.L.C.,entered into an Amended and Restated Uranium Testing Permit and Lease Option Agreement with Mesteña Unproven, Ltd., Jones Ranch Minerals Unproven, Ltd and Mesteña Proven, Ltd. (collectively the “Grantors”), which required Leoncito Project, L.L.C., to make a payment in the amount of $0.60 million to the Grantors in June 2019 (of which up to 50% may be paid in common shares of the Company at the Company’s election). As of September 30, 2019, the Company paid the Grantors $0.30 million in cash and $0.30 million in common stock, representing 97,786 shares. The Grantors are managed by Mesteña LLC.

Pursuant to the Purchase Agreement, the Alta Mesa Properties held by the Acquired Companies are subject to a royalty of 3.125% of the value of the recovered U_3O_8 from the Alta Mesa Properties sold at a price of $65.00 per pound or less, 6.25% of the value of the recovered U_3O_8 from the Alta Mesa Properties sold at a price greater than $65.00 per pound and up to and including $95.00 per pound, and 7.5% of the value of the recovered U_3O_8 from the Alta Mesa Properties sold at a price greater than $95.00 per pound. The royalties are held by the Sellers, and Mr. Eshleman and his extended family hold all of the ownership interests in the Sellers. In addition, Mr. Eshleman and certain members of his extended family are parties to surface use agreements that entitle them to surface use payments from the Acquired Companies in certain circumstances. The Alta Mesa Properties are currently being maintained on care and maintenance to enable the Company to restart operations as market conditions warrant. Due to the price of U_3O_8, the Company did not pay any royalty payments to the Sellers or to Mr. Eshleman or his immediate family members in the three or nine months ended September 30, 2019 and does not anticipate paying any royalty payments to the Sellers or to Mr. Eshleman or his immediate family members during the remainder of 2019. Pursuant to the Purchase Agreement, surface use payments from June 2016 through December 31, 2018 were deferred until June 2019 at which time the Company made a payment totaling $1.03 million consisting $0.51 million in cash and $0.51 million in common stock, representing 168,486 shares, to settle this obligation. The Company will now make surface use payments on an annual basis to Mr. Eshleman and his immediate family members and has accrued $0.28 million as of September 30, 2019.

16. FAIR VALUE ACCOUNTING

Assets and liabilities measured at fair value on a recurring basis

The following tables set forth the fair value of the Company's assets and liabilities measured at fair value on a recurring basis (at least annually) by level within the fair value hierarchy as of September 30, 2019. As required by accounting guidance, assets and liabilities are classified in their entirety based on the lowest level of input that is significant to the fair value measurement.

As of September 30, 2019, the fair values of cash and cash equivalents, restricted cash, short-term deposits, receivables, accounts payable and accrued liabilities approximate their carrying values because of the short-term nature of these instruments.

	Level 1	Level 2	Level 3	Total
Investments at fair value	$ 321	$ —	$ —	$ 321
Marketable equity securities	718	—	—	718
Marketable debt securities	—	7,058	—	7,058
Warrant liabilities	3,177		—	3,177
Convertible debentures	15,909	—	—	15,909
	$ 20,125	$ 7,058	$ —	$ 27,183

The Company's investments are marketable equity securities which are exchange traded and are valued using quoted market prices in active markets and as such are classified within Level 1 of the fair value hierarchy. The fair value of the investments is calculated as the quoted market price of the marketable equity security multiplied by the quantity of shares held by the Company.

17. SUBSEQUENT EVENTS

Sale of shares in the Company's 'At-the-Market' program ("ATM").

From October 1, 2019 through November 1, 2019, the Company issued 1.13 million common shares at an average price of $2.01 for proceeds of $2.28 million using the ATM.

ITEM 2. MANAGEMENT'S DISCUSSION AND ANALYSIS OF FINANCIAL CONDITION AND RESULTS OF OPERATIONS.

The following discussion and analysis should be read in conjunction with our unaudited condensed consolidated financial statements for the three and nine month periods ended September 30, 2019, and the related notes thereto, which have been prepared in accordance with U.S. GAAP. Additionally, the following discussion and analysis should be read in conjunction with Management's Discussion and Analysis of Financial Condition and Results of Operations and the audited consolidated financial statements included in Part II of our Annual Report on Form 10-K for the year ended December 31, 2018. This Discussion and Analysis contains forward-looking statements and forward-looking information that involve risks, uncertainties and assumptions. Our actual results may differ materially from those anticipated in these forward-looking statements and information as a result of many factors. See "Cautionary Statement Regarding Forward-Looking Statements" above.

While the Company has uranium extraction and recovery activities and generates revenue, it is considered to be in the Exploration Stage (as defined by SEC Industry Guide 7) as it has no Proven or Probable Reserves within the meaning of SEC Industry Guide 7. Under U.S. GAAP, for a property that has no Proven or Probable Reserves, the Company capitalizes the cost of acquiring the property (including mineral properties and rights) and expenses all costs related to the property incurred subsequent to the acquisition of such property. Acquisition costs of a property are depreciated over its estimated useful life for a revenue generating property or expensed if the property is sold or abandoned. Acquisition costs are subject to impairment if so indicated.

All dollar amounts stated herein are in U.S. dollars, except per share amounts and currency exchange rates unless specified otherwise. References to Cdn$ refer to Canadian currency, and $ to United States currency.

Overview

We provide the raw materials for the generation of clean nuclear electricity. Our primary product is a uranium concentrate ("U_3O_8"), or yellowcake, which when further processed becomes the fuel for nuclear energy. According to the Nuclear Energy Institute, nuclear energy provides nearly 20% of the total electricity, and 55% of the clean, carbon-free electricity, generated in the United States. The Company generates revenues from extracting and processing materials for our own account, as well as from toll processing for others.

Our uranium concentrate is produced from multiple sources:

- Conventional recovery operations at our White Mesa Mill (the "Mill") including:
  - Processing ore from uranium mines;
  - Recycling of uranium bearing materials that are not derived from conventional ore ("Alternate Feed Materials"); and
- In-situ recovery ("ISR") operations.

In addition, the Company has a long history of conventional vanadium recovery at the Mill, when vanadium prices support those activities. The Company commenced a campaign to recover vanadium from pond solutions at the Mill in December 2018 and has been recovering vanadium from pond solutions since that time. The Company is also evaluating opportunities for copper recovery from our Canyon Project.

The Mill, located near Blanding, Utah, processes ore mined from the Four Corners region of the United States, as well as Alternate Feed Materials that can originate worldwide. We have the only operating uranium mill in the United States, which is also the last operating facility left in the U.S. with the ability to recover vanadium from primary ore sources. The Mill is licensed to process an average of 2,000 tons of ore per day and to extract approximately 8.0 million pounds of U_3O_8 per year. The Mill has separate circuits to process conventional uranium and vanadium ores as well as Alternate Feed Materials.

For the last several years, no mines have operated commercially in the vicinity of the Mill due to low uranium prices. As a result, in recent years, Mill activities have focused on processing Alternate Feed Materials for the recovery of uranium, under multiple toll processing arrangements as well as Alternate Feed Materials for our own account. Additionally, in recent years, the Mill has recovered dissolved uranium and vanadium from the Mill's tailings management system that was not fully recovered during the Mill's prior thirty-five-plus years of operations ("Pond Return"). During the nine months ended September 30, 2019, Mill activities focused primarily on the recovery of vanadium, along with relatively small amounts of uranium, from Pond Returns. The Company is actively pursuing additional toll and Alternate Feed Materials for processing at the Mill, as well as additional clean-up materials from third party mines.

The Mill also continues to pursue additional sources of feed materials. For example, a significant opportunity exists for the Company to potentially participate in the clean-up of abandoned uranium mines in the Four Corners Region of the U.S. The U.S. Justice

Department and Environmental Protection Agency has announced settlements in various forms in excess of $1.5 billion to fund certain clean-up activities on the Navajo Nation. Additional settlements with other parties are also pending. Our Mill is within close trucking distance and is uniquely positioned in this region to receive uranium-bearing materials from these cleanups and thus recycle the contained U_3O_8, while at the same time permanently disposing of the cleanup materials outside the boundaries of the Navajo Nation. There are no other facilities in the U.S capable of providing this service. In addition, as previously announced, during Q2-2019, the Company began receiving shipments of ore generated in the cleanup of a large, historically producing conventional uranium mine located in northwest New Mexico. The Company expects to generate significant revenue from this project, as well as demonstrate the responsible operations of the Mill for cleanup projects similar to what is required on the Navajo Nation.

The Company's ISR operations consist of our currently producing Nichols Ranch Project and our standby operation at the Alta Mesa Project. At our Nichols Ranch Project, the Company placed its ninth header house into production in March 2017. In order to save cash and resources, the Company is deferring additional wellfield development until uranium prices recover. The Alta Mesa Project will remain on standby in the current uranium price environment.

We believe the current spot price of uranium does not support production for the majority of global uranium producers and, accordingly, we believe that prices will recover at some point in the future, either as a result of improving market fundamentals or in response to U.S. government action to support domestic uranium production which began with the Company's Section 232 Petition submitted on January 16, 2018 (see **Recent Developments** - *U.S. Nuclear Fuel Working Group Update*). In anticipation of potential price recoveries or other actions that could support increased U.S. uranium mining, we continue to maintain and advance our resource portfolio. Once prices recover or other supportive actions are taken, we stand ready to resume wellfield construction at our Nichols Ranch Project; resume wellfield construction, perform plant upgrades, conduct exploration, and resume production at our Alta Mesa facility; and mine and process resources from our Canyon Project, Daneros Project, La Sal Project and/or Whirlwind Project. The Company believes we could start bringing this new production to the market within approximately six to eighteen months of a positive production decision. Longer term, we expect to resume production at our other conventional mines on standby and develop our large conventional mines at Roca Honda, Henry Mountains, and/or Sheep Mountain.

Recent Developments

White Mesa Processing Agreement

As previously announced, on June 10, 2019, the Company, through its wholly owned subsidiaries EFR White Mesa LLC and Energy Fuels Resources (USA) Inc., entered into a Processing Agreement (the "Agreement") with the owner of a formerly operating uranium mine in New Mexico. The owner is currently completing various cleanup and reclamation activities at the mine, including the removal and disposal of low-grade uranium ore (the "Ore") located at the site. Beginning in Q2-2019 and continuing during Q3-2019, the Company has accepted delivery of 4,591 tons of material. Revenues payable to the Company are expected to be between $700,000 and approximately $3,500,000, depending on the amount of Ore ultimately delivered to the White Mesa Mill. As additional consideration, the Company will retain title to any uranium (or other minerals) recovered from the Ore for its own account, currently estimated to be approximately 8,000-70,000 lbs. of U_3O_8, valued at approximately $200,000-$1,750,000 at current uranium prices. Energy Fuels has proposed similar processing and disposal services to assist in the cleanup of Cold War era abandoned uranium mines on the Navajo Nation and other nearby lands. The Agreement represents the first agreement for the processing and disposal of those types of clean-up materials at the White Mesa Mill. The Ore is currently being stockpiled at the Mill for recovery in a future conventional mill processing campaign.

U.S. Nuclear Fuel Working Group Update

On January 16, 2018, the Company participated in the joint filing of a Petition for Relief under Section 232 of the Trade Expansion Act of 1962 (as amended) from Imports of Uranium Products that Threaten National Security (the "Petition"). The Petition describes how uranium and nuclear fuel from state-owned and state-subsidized enterprises in Russia, Kazakhstan, Uzbekistan and China are believed to represent a threat to U.S. national security.

On July 18, 2018, the U.S. Department of Commerce ("DOC") initiated the investigation (the "Section 232 Investigation").

On April 14, 2019, the DOC completed the Section 232 Investigation, and the Secretary of Commerce submitted a report to the President of the United States (the "President") containing his findings (the "Section 232 Report").

On July 12, 2019, in response to the Section 232 Report, the President issued a memorandum, where he stated that "I agree with the Secretary that the United States uranium industry faces significant challenges in producing uranium domestically and that this is an issue of national security." In order "to address the concerns identified by the Secretary regarding domestic uranium production and to ensure a comprehensive review of the entire domestic nuclear supply chain," the President formed the United States Nuclear Fuel Working Group (the "Working Group") to "examine the current state of domestic nuclear fuel production to reinvigorate the entire nuclear fuel supply chain, consistent with United States national security and nonproliferation goals." The President instructed the Working Group to "develop recommendations for reviving and expanding domestic nuclear fuel production," and to submit a report to the President within 90 days "setting forth the Working Group's findings and making recommendations to further enable domestic nuclear fuel production if needed."

Although an official announcement has not been made by the administration, it appears that the deadline for the Working Group to make recommendations to the President, originally set for October 10, 2019, has been extended for what is widely believed to be 30 days. The Company looks forward to the Working Group's study and recommendations. The Company believes this initiative has the potential to result in actions that could provide meaningful support to the uranium mining industry. It should be noted, however, that there can be no certainty of the outcome of the Working Group's study and recommendations. No action could be taken or remedies granted and any actions taken may not result in a meaningful or material remedy to the uranium mining industry. Therefore, the outcome of this process is uncertain.

Uranium Market Update

According to monthly price data from TradeTech LLC ("TradeTech"), uranium spot prices were relatively flat during Q3-2019. The uranium spot price began the quarter at $24.50 per pound on June 30, 2019 and rose slightly (5%) to $25.70 per pound by the end of the quarter on September 30, 2019. The uranium spot price reached a high of $25.80 per pound during the week of September 20, 2019, and a low of $24.50 during the week of July 5, 2019. TradeTech price data also indicates that long-term U_3O_8 prices were flat, beginning the quarter at $31.00 per pound and ending the quarter at $31.00 per pound. On October 25, 2019, TradeTech reported a spot price of $24.10 per pound and a long-term price of $31.00 per pound. According to TradeTech, July 2019 uranium prices "rose steadily in mid July, then declined on limited transactions in anticipation of US President Donald Trump's decision on the Section 232 investigation into uranium imports. Although the decision to not impose trade restrictions brought some clarity to the market, limited direct activity with a spread of prices linked to various origin restrictions, locations, and form resulted in low price volatility through the end of the month." (TradeTech, NMR, July 31, 2019). TradeTech also indicated that "the industry was confronted with additional uncertainty as the August 1 deadline approached for issuance of waivers to Iran's trading partners … US National Security Advisor announced [in late July] that the USA will renew existing waivers for Iranian nuclear programs that allow Russia, China, and European nations to continue their civilian cooperation with Iran. Bolton noted, however, that the administration would continue to watch nuclear activities during a short 90-day extension of the waivers." (TradeTech, NMR, July 31, 2019). August 2019 saw "limited transaction activity … [and] concerns over lingering international trade issues, combined with uncertainty regarding forthcoming recommendations of the US Nuclear Fuel Working Group, [that] further chilled the market and kept prices below $25.00 per pound for nearly a week. Downward pressure on the uranium spot price abated in the last week of [August] as uranium producer Kazatomprom announced its intention to extend 20 percent reductions to planned production through 2021. The announcement, combined with existing expectations among market observers that increased utility demand is on the horizon, brought an uptick in both spot market and term activity with traders, financial entities, utilities, and producers all returning to the market this month." (TradeTech, NMR, August 31, 2019). "While mid-September saw a brief uptick in buying activity, with 30 spot transactions involving approximately 6 million pounds U_3O_8 equivalent traded over the course of the month, several buyers remain preoccupied with ongoing trade issues in the USA. Market participants continue to await the potential outcome of the US Nuclear Fuel Working Group and increasing Iran sanctions, as well as the pending expiration of the Russian Suspension Agreement (RSA)." (TradeTech, NMR, September 30, 2019). The Company believes considerable uncertainty remains in the market, and participants may not make significant moves in the market until more certainty materializes around the possible outcomes of the Working Group.

The Company believes that certain uranium supply and demand fundamentals are pointing to higher prices in the future, including significant production cuts, as was announced by Kazatomprom in August 2019, and increased demand from utilities, financial entities, traders, and producers. However, the Company also believes that while uranium market conditions have improved over the past year, they still remain weak primarily as a result of excess uranium supplies caused by large quantities of secondary uranium supplies, excess inventories, and thus far insufficient primary production cut-backs, particularly from State owned Enterprises. The Company continues to believe a large degree of uncertainty continues in the market with the President's creation of the Working Group, along with the potential for sanctions on Iran and/or Russia, which could affect deliveries to U.S. utilities from Russian-backed entities.

Vanadium Market Update

During Q3-2019, the disparity between V_2O_5 prices in China versus Europe continued. According to weekly price data from Metal Bulletin, the mid-point spot price for V_2O_5 in China was $8.00 per pound on June 27, 2019 and $8.25 per pound of V_2O_5 on September 26, 2019, representing a small increase of 3% during the quarter. By October 31, 2019, the spot price in China was $6.35 per pound of V_2O_5. During the same period, according to weekly price data from Metal Bulletin, the mid-point spot price for V_2O_5 in Europe was $7.48 per pound on June 28, 2019 and $6.98 per pound of V_2O_5 on September 27, 2019, representing a drop of 7%. By October 25, 2019, the spot price in Europe had further dropped to $4.73 per pound of V_2O_5. As can be seen from the month-end data for September, vanadium prices in China were approximately 18% higher than in Europe.

After the announcement of the new rebar standards in China, global vanadium prices rose significantly to $28.83 per pound in Europe and $32.00 per pound in China. However, as vanadium prices rose to multi-year highs, the Company believes Chinese steel mills began to substitute niobium for vanadium, thereby causing demand for vanadium, and hence prices, to drop off their highs. At the same time, the Company believes that the European and Russian steel industries are stressed, mainly due to the effects of sanctions on Russia and tariffs in the U.S., and there have been insufficient production cutbacks in Russia and Europe, and new production from Asia, thereby causing continued vanadium price weakness.

The Company believes that in 2018, global production cutbacks caused vanadium supply to fall below demand, thereby creating a deficit in the market, leading to significant price increases. In the short term, the Company believes that the market dynamics that led to the increased prices in 2018 generally still exist, including increased demand due to new Chinese rebar standards, continued economic growth in China, and decreased supply due to environmental regulations. However, as vanadium prices rise, substitution (primarily niobium) is likely to continue to occur, thereby moderating potential price increases somewhat. In addition, Russian, European, and US steel industries are experiencing lower levels of activity, which is also likely to have a moderating influence on further price increases. Longer-term, the Company expects vanadium prices to continue to be volatile, and mainly dictated by policies in, and the economy of, China. The Company also believes there could be increased demand for vanadium in the energy storage industry.

Operations Update and Outlook for Year Ending December 31, 2019

Overview

Operations and Sales Outlook Overview

The Company plans to extract and recover uranium from its Nichols Ranch Project in 2019 at reduced levels as its existing wellfields become depleted. This will continue until such time as the incremental cost of production exceeds the value of the pounds recovered. In addition, the Company expects to continue to extract and recover vanadium from pond solutions at its White Mesa Mill and to build its vanadium inventory at current price levels, which are close to the Company's incremental cost of producing vanadium.

As a result of current low uranium market conditions, both ISR and conventional uranium recovery are being maintained at reduced levels until such time as market conditions improve sufficiently, either as a result of potential relief from the U.S. government, or through improved uranium market fundamentals. Until such time as improvements in uranium market conditions are observed or suitable sales contracts can be entered into, the Company expects to defer further wellfield development at its Nichols Ranch Project. In addition, the Company will keep the Alta Mesa Project and its conventional mining properties on standby. The Company is also seeking new sources of revenue, including new sources of Alternate Feed Materials and new fee processing opportunities at the Mill that can be processed under existing market conditions, largely unrelated to uranium sales prices. The Company will also continue its efforts to receive U.S. government support for domestic uranium production, and will evaluate additional acquisition and disposition opportunities that may arise.

Extraction and Recovery Activities Overview

During the nine months ended September 30, 2019, the Company recovered approximately 56,000 pounds of U_3O_8. In the year ending December 31, 2019, the Company expects to recover a quantity of uranium within its previously published guidance of 50,000 to 125,000 pounds of U_3O_8. The Company also recovered approximately 1,300,000 pounds of high-purity vanadium pentoxide ("V_2O_5" or "black flake") during the nine months ended September 30, 2019 and expects to continue to recover approximately 160,000 to 200,000 pounds of V_2O_5 per month while vanadium recovery operations continue.

The Company has entered into no uranium sales commitments for 2019 thus far. Therefore, all 2019 uranium production is expected to be added to existing inventories. All V_2O_5 production is expected to be sold on the spot market, if prices rise significantly above current levels, or maintained in inventory.

ISR Activities

During the nine months ended September 30, 2019, we extracted and recovered approximately 56,000 pounds of U_3O_8 from the Nichols Ranch Project. In the year ending December 31, 2019, the Company expects to recover a quantity of uranium within its previously published guidance of 50,000 to 70,000 pounds of U_3O_8 from Nichols Ranch.

As of September 30, 2019, the Nichols Ranch wellfields had nine header houses extracting uranium. Until such time as improvement in uranium market conditions is observed or suitable sales contracts can be procured, the Company intends to defer development of further header houses at its Nichols Ranch Project. The Company currently holds 34 fully-permitted, undeveloped wellfields at Nichols Ranch, including four additional wellfields at the Nichols Ranch wellfields, 22 wellfields at the adjacent Jane Dough wellfields, and eight wellfields at the Hank Project, which is fully permitted to be constructed as a satellite facility to the Nichols Ranch Plant. The Company currently expects to continue running the Nichols Ranch Project through the end of 2019. However, if market conditions do not improve significantly by that time as a result of U.S. government support or otherwise, the Company expects to place this project on standby in early 2020.

The Company expects to continue to keep the Alta Mesa Project on standby until such time as improvements in uranium market conditions are observed or suitable sales contracts can be procured.

Conventional Activities

Conventional Extraction and Recovery Activities

During the nine months ended September 30, 2019, the Company produced 1,300,000 pounds of high-purity V_2O_5 from its Mill Pond Return program, as well as captured 30,000 pounds of U_3O_8 in the mill circuit through September 19, 2019. The Company is currently producing at full production rates of 160,000 to 200,000 pounds of V_2O_5 per month. On September 19, 2019, the company ceased uranium recovery operations from Pond Returns in order to lower its cost of production for vanadium. The Company expects to continue to recover vanadium at these rates during the fourth quarter of 2019, taking into account seasonal considerations. Despite currently low vanadium prices, the Company plans to continue this program, rather than place it on standby at this time, for three reasons. First, the Company believes vanadium prices are likely to rise in the future and the Company will be well-positioned to take advantage of any future price increases if it has readily saleable inventory. Second, the Company's vanadium recovery process is running smoothly, and it makes sense to continue producing efficiently and at the lowest possible cost under current conditions. Finally, maintaining vanadium production will allow the Mill to retain its current highly skilled workforce, which will be able to switch over to uranium production if the Company ramps up its uranium production in response to U.S. government support for domestic uranium production or improved market conditions. The Company will continue to monitor its vanadium recoveries, which are expected to decrease during the colder winter months, its costs of production, current and expected vanadium prices, and its uranium production schedule, and may vary these plans, including shutting down its vanadium production, as circumstances warrant. If vanadium prices increase, or other opportunities arise, the Company may sell all or a portion of its vanadium inventory.

If vanadium recovery operations from the current Mill Pond Return program are put on standby during Q4-2019, the Company plans to utilize the resulting available Mill capacity by processing stockpiled Alternate Feed Materials in the fourth quarter of 2019.

The White Mesa Mill has historically operated on a campaign basis whereby uranium and/or vanadium recovery is scheduled as mill feed, cash needs, contract requirements, and/or market conditions may warrant. The Company currently expects that planned vanadium and other processing activities will keep the Mill in operation through the end of 2019 and into 2020. The Company is also actively pursuing opportunities to process new and additional Alternate Feed Material sources and low-grade ore from third parties in connection with various uranium clean-up requirements. Successful results from these activities would allow the Mill to extend the current campaign through 2020 and beyond. In addition, if improvements in uranium market conditions are observed as a result of U.S. government support for domestic uranium mining or otherwise, the Company would expect to be able to procure suitable long term sales contracts to keep the Mill operating over a considerably longer period of time.

However, in the event the Company is unable to justify full operation of the Mill at any time, the Company would expect to place uranium and/or vanadium recovery activities at the Mill on standby at that time. While on standby, the Mill would continue to dry and package material from the Nichols Ranch Plant and continue to receive and stockpile Alternate Feed Materials for future milling campaigns. Each future milling campaign would be subject to receipt of sufficient mill feed and resulting cash flow that would allow the Company to operate the Mill on a profitable basis or to recover all or a portion of the Mill's standby costs.

Conventional Standby, Permitting and Evaluation Activities

During the nine months ended September 30, 2019, the Company completed its test-mining and refurbishment program targeting vanadium at the fully-permitted La Sal Complex located on the Colorado Plateau. We completed the test-mining by the end of April 2019 and continued to pursue enhanced operational readiness targeting future commercial production. The goal of the test-mining program was to evaluate different mining approaches in previously mined out areas that selectively target high-grade vanadium zones, thereby potentially increasing productivity and mined grades for vanadium and decreasing mining costs per pound of V_2O_5 and U_3O_8. During this program, the Company refurbished the La Sal and Pandora mines within the La Sal Complex and extracted approximately 11,000 tons of mineralized material. The Company expects to continue readiness activities through the fourth quarter of 2019.

During 2019, the Company plans to continue carrying out engineering, metallurgical testing, procurement and construction management activities at its Canyon Project, including additional bench and pilot plant scale metallurgical test work of the uranium/ copper mineralization, and to continue pursuing any additional permitting actions that may be required to potentially recover copper at the White Mesa Mill. The timing of the Company's plans to extract and process mineralized materials from this project will be based on the results of this additional evaluation work, along with market conditions, available financing, sales requirements, and/or permits required for copper recovery at the Mill.

The Company is selectively advancing certain permits at its other major conventional uranium projects. The Company plans to accelerate the licensing and permitting of the Roca Honda Project, a large, high-grade conventional project in New Mexico, with the Record of Decision currently scheduled to be completed in 2021. The Company will also maintain required permits at the Company's conventional projects, including the Sheep Mountain Project and the Daneros Project. In addition, the Company will continue to evaluate the Bullfrog Property at its Henry Mountains Project. Expenditures for certain of these projects have been adjusted to coincide with expected dates of price recoveries based on the Company's forecasts. All of these projects serve as important pipeline assets for the Company's future conventional production capabilities, as market conditions warrant.

Sales

During the nine months ended September 30, 2019, the Company completed $0.07 million of uranium sales. The Company currently has no remaining contracts and is therefore fully unhedged to future uranium price increases.

At the current time, the Company is selling only small quantities of vanadium, while mainly focusing on building V_2O_5 inventory for sale in the future as prices are expected to increase. During the nine months ended September 30, 2019, the Company completed sales of 152,000 pounds of vanadium at an average price of $12.88 per pound. The Company expects to continue to sell finished vanadium product when justified into the metallurgical industry, as well as other markets that demand a higher purity product, including the aerospace, chemical, and potentially the vanadium battery industries. The Company expects to sell to a diverse group of customers in order to maximize revenues and profits. The Company is continuing to produce a high-purity vanadium product of 99.6%-99.7% V_2O_5. The Company believes there may be opportunities to sell certain quantities of this high-purity material at a premium to reported spot prices. The Company may also retain vanadium product in inventory for future sale, depending on vanadium spot prices at the time of production.

The Company also continues to pursue new sources of revenue, including additional Alternate Feed Materials and other sources of feed for the White Mesa Mill.

Unites States Nuclear Fuel Working Group

As described above the Company believes the deadline for the Working Group to make recommendations to the President originally set for October 10, 2019 has been extended for 30 days. The Company looks forward to learning the recommendations, and believes this initiative has the potential to result in actions that could provide meaningful support to the uranium mining industry. It should be noted, however, that there can be no certainty of the outcome of the Working Group's study and recommendations. No action could be taken or remedies granted, and any actions taken may not result in a meaningful or material remedy to the uranium mining industry. Therefore, the outcome of this process is uncertain.

If the President does not take actions to support the U.S. nuclear production industry and uranium and vanadium markets do not otherwise improve, the Company will evaluate reducing its operation activities as required in order to minimize its cash expenditures while preserving its asset base for increased production in the future as market conditions may warrant.

Results of Operations

The following table summarizes the results of operations for the three and nine months ended September 30, 2019 and 2018 (in thousands of U.S. dollars):

	Three Months Ended September 30,		Nine Months Ended September 30,	
	2019	2018	2019	2018
Revenues				
Uranium concentrates	$ —	$ —	$ 66	$ 28,015
Vanadium concentrates	16	—	1,957	—
Alternate feed materials processing and other	407	451	3,141	663
Total revenues	423	451	5,164	28,678
Costs and expenses applicable to revenues				
Costs and expenses applicable to uranium concentrates	—	—	63	11,908
Costs and expenses applicable to vanadium concentrates	16	—	1,476	—
Costs and expenses applicable to alternate feed materials and other	—	—	2,079	—
Total costs and expenses applicable to revenues	16	—	3,618	11,908
Impairment of inventories	2,330	714	8,412	3,063
Gross (loss) profit	(1,923)	(263)	(6,866)	13,707
Other operating costs and expenses				
Development, permitting and land holding	2,310	4,971	8,051	7,569
Standby costs	869	1,296	3,204	5,194
Accretion of asset retirement obligation	484	459	1,478	1,376
Total other operating costs and expenses	3,663	6,726	12,733	14,139
Selling, general and administration				
Selling costs	30	33	167	121
Intangible asset amortization	—	—	—	2,502
General and administration	3,216	3,193	10,692	10,440
Total selling, general and administration	3,246	3,226	10,859	13,063
Total operating loss	(8,832)	(10,215)	(30,458)	(13,495)
Interest expense	(419)	(417)	(1,110)	(1,384)
Other income (loss)	2,312	(3,265)	3,181	(2,703)
Net loss	$ (6,939)	$ (13,897)	$ (28,387)	$ (17,582)
Basic and diluted loss per share	$ (0.07)	$ (0.16)	$ (0.30)	$ (0.20)

Revenues

The Company’s revenues from uranium were previously based on delivery schedules under long-term contracts, which could vary from quarter to quarter. As of December 31, 2018, the Company no longer has any uranium sales contacts. Any future sales of uranium will be subject to sale in the spot market until a time when the Company can agree to terms for long-term sales contracts. In the nine months ended September 30, 2019, the Company initiated the selling of vanadium recovered from its pond solution at the White Mesa Mill under a Sales and Agency Agreement appointing an exclusive sales and marketing agent for all vanadium pentoxide produced by the Company.

Revenues for the three months ended September 30, 2019 totaled $0.42 million compared with $0.45 million in the three months ended September 30, 2018. Of the revenues for the three months ended September 30, 2019, $0.02 million was related to sales of 2,000 pounds of vanadium concentrates and $0.41 million related to toll processing of uranium concentrates.

Revenues for the three months ended September 30, 2018 were all related to processing of Alternate Feed Materials.

Revenues for the nine months ended September 30, 2019 totaled $5.16 million; $1.96 million was related to sales of 152,000 pounds of vanadium concentrates and $3.14 million was related to toll processing of uranium concentrates.

Revenues for the nine months ended September 30, 2018 totaled $28.68 million, which included sales of 400,000 pounds of U_3O_8 pursuant to a term contract at an average price of $61.30, sales of 50,000 pounds of U_3O_8 at a price of $24.75 per pound and sales of 100,000 pounds of U_3O_8 pursuant to a contract where the price was based on the spot market at a price of $22.57 per pound and Alternate Feed Materials processing revenue of $0.66 million.

Operating Expenses

Uranium and Vanadium recovered and costs and expenses applicable to revenue

In the three months ended September 30, 2019, the Company recovered 16,000 pounds of U_3O_8 from ISR recovery activities for the Company's own account and 530,000 pounds of V_2O_5 from Pond Return. In the three months ended September 30, 2018, the Company recovered 33,000 pounds of U_3O_8 from ISR recovery activities for the Company's own account, and 128,000 pounds from the Company's Alternate Feed Material sources.

Costs and expenses applicable to revenue for the three months ended September 30, 2019 were $0.02 million, compared with nil for the three months ended September 30, 2018. Costs and expenses applicable to revenue for the three months ended September 30, 2019 consisted of $0.02 million from V_2O_5 and nil related to Alternate Feed Materials.

In the nine months ended September 30, 2019, the Company recovered 56,000 pounds of U_3O_8 from ISR recovery activities for the Company's own account and 1,300,000 pounds of V_2O_5 from Pond Returns. In the nine months ended September 30, 2018, the Company recovered 115,000 pounds of U_3O_8 from the Nichols Ranch Project and 213,000 pounds from the Company's Alternate Feed Material sources.

Costs and expenses applicable to revenue for the nine months ended September 30, 2019 were $3.62 million, compared with $11.91 million for the nine months ended September 30, 2018. Costs and expenses applicable to revenue for the nine months ended September 30, 2019 consisted of $1.48 million from V_2O_5 and $2.08 million related to Alternate Feed Materials. All costs and expenses applicable to revenue for 2018 were related to uranium concentrates.

The decrease in the cost of sales was primarily attributable to having no significant uranium sales as well as just beginning to sell vanadium from the Company's vanadium program.

Other Operating Costs and Expenses

Development, permitting and land holding

For the three months ended September 30, 2019, the Company spent $2.31 million for development of the Company's properties. This is primarily due to the development of the V_2O_5 test-mining program at the La Sal Project as well as expenses associated with ramping up V_2O_5 production at the White Mesa Mill. For the three months ended September 30, 2018, the Company spent $4.97 million for development of the Canyon Project and permitting and land holding costs related to this and other projects.

For the nine months ended September 30, 2019, the Company spent $8.05 million for development of the Company's properties. This is primarily due to the development of the V_2O_5 test-mining program at the La Sal Project as well as expenses associated with ramping up V_2O_5 production at the White Mesa Mill. For the nine months ended September 30, 2018, the Company spent $7.57 million for development of the Canyon Project and permitting and land holding costs related to this and other projects.

While we expect the amounts relative to the items listed above have added future value to the Company, we expense these amounts as we do not have proven or probable reserves at any of the Company's projects under SEC Industry Guide 7.

Standby costs

The Company’s La Sal and Daneros Projects were placed on standby in 2012, as a result of market conditions. In February 2014, the Company placed its Arizona 1 Project on standby. In the beginning of 2018, the White Mesa Mill was operated at lower levels of uranium recovery, including prolonged periods of standby. Costs related to the care and maintenance of the standby mines, along with standby costs incurred while the White Mesa Mill was operating at low levels of uranium recovery or on standby, are expensed.

For the three months ended September 30, 2019, standby costs totaled $0.87 million compared with $1.30 million in the prior year. For the nine months ended September 30, 2019, standby costs totaled $3.20 million compared with $5.19 million in the prior year. The decrease is primarily related to vanadium recovery activities at the White Mesa Mill.

Accretion

Accretion related to the asset retirement obligation for the Company's properties increased for the three and nine months ended September 30, 2019, which were $0.48 million and $1.48 million compared with the three and nine months ended September 30, 2018, which were $0.46 million and $1.38 million, respectively. This increase is primarily due to normal accretion activity.

Selling, general and administrative

Selling, general and administrative expenses include costs associated with marketing uranium, corporate and general and administrative costs and intangible asset amortization from favorable contracts. Selling, general and administrative expenses consist primarily of payroll and related expenses for personnel, contract and professional services, stock-based compensation expense and other overhead expenditures. Selling, general and administrative expenses totaled $3.25 million and $10.86 million for the three and nine months ended September 30, 2019 compared to $3.23 million and $13.06 million for the three and nine months ended September 30, 2018, respectively. The decrease is a result of the Company not recognizing any intangible amortization cost from favorable contracts in the nine months ended September 30, 2019 as the Company does not have any additional contract sales, offset by an increase in spending on the Section 232 Petition and related working group activities of $0.86 million.

Impairment of Inventories

For the three and nine months ended September 30, 2019, the Company recognized $2.33 million and $8.41 million, respectively, in impairment charges related to inventory. Included in impairment were non cash expenses of $0.52 million and $1.55 million. For the three and nine months ended September 30, 2018, the Company recognized $0.71 million and $3.06 million, respectively, in inventory impairment. Included in impairment were non cash expenses of $0.54 million and $1.61 million. The impairment of inventories is due to continued lower uranium prices versus our cost to produce at the Nichols Ranch Project, and the decrease in the market price of vanadium recovered from Pond Return.

Interest Expense and Other Income and Expenses

Interest expense

Interest expense for the three months ended September 30, 2019 was $0.42 million compared with $0.42 million for the three months ended September 30, 2018, respectively. Interest expense for the nine months ended September 30, 2019 was $1.11 million compared with $1.38 million for the nine months ended September 30, 2018, respectively. This decrease was due to the payoff of the Wyoming revenue bond loan and the put option conversion of the Company's Convertible Debentures (the "Debentures").

Other income and expense

For the three months ended September 30, 2019, other income and expense totaled $2.31 million income, net. These amounts primarily consist of a gain on the change in the mark-to-market values of the Debentures of $0.94 million, the increase in value of warrant liabilities of $2.17 million, and interest income of $0.13 million, offset by $0.59 million loss in investments accounted for at fair value.

For the three months ended September 30, 2018, other income and expense totaled $3.27 million expense, net. These amounts primarily consist of a loss on the change in the mark-to-market values of the Debentures of $1.46 million, loss on the decrease in warrant liabilities of $2.72 million, and other expense of $0.13 million, foreign exchange loss of $0.17 million, offset by $1.13 million gain in investments accounted for at fair value and interest income of $0.08 million.

For the nine months ended September 30, 2019, other income and expense totaled $3.18 million income, net. These amounts primarily consist of a gain on the change in the mark-to-market values of the Debentures of $0.45 million, the increase in value of warrant liabilities of $3.28 million, and interest income of $0.39 million, offset by $0.58 million loss in investments accounted for at fair value.

For the nine months ended September 30, 2018, other income and expense totaled $2.70 million expense, net. These amounts primarily consist of a loss on the change in the mark-to-market values of the Debentures of $1.14 million, loss on the decrease in warrant liabilities of $3.80 million, and other expense of $0.07 million, foreign exchange loss of $0.06 million, offset by $1.57 million gain in investments accounted for at fair value and interest income of $0.16 million, income of $0.29 million from the sale of surplus assets and gain of $0.34 million on assets held for sale.

LIQUIDITY AND CAPITAL RESOURCES

Funding of major business and property acquisitions

Over the past six years the Company has funded major business and property acquisitions with capital provided by issuance of its common shares. In 2012 we acquired Titan Uranium Inc. and the US Mining Division of Denison Mines Corp., in 2013 we acquired Strathmore Minerals Corp, in 2015 we acquired Uranerz and in 2016 we acquired Mesteña, each in exchange for newly issued shares.

We intend to continue to acquire assets utilizing common shares when we can do so under attractive terms.

Shares issued for cash

On December 29, 2017, the Company filed a prospectus supplement to its U.S. registration statement, qualifying for distribution up to $30.00 million in additional common shares under the ATM. On November 5, 2018, the Company filed a prospectus supplement to its U.S. registration statement, qualifying for distribution up to $24.50 million in aggregate common shares under the ATM. Then, on the same date, the Company filed a base shelf prospectus whereby the Company may sell any combination of the "Securities" as defined thereunder in one or more offerings up to an initial aggregate offering price of $150.00 million. On May 5, 2019, the prospectus supplement to its U.S. registration statement expired, and was replaced on May 7, 2019 by a new prospectus supplement in the same amount, qualifying for distribution up to $24.50 million in aggregate common shares under the ATM.

From January 1, 2019 to November 1, 2019 a total of 6,646,402 Common Shares have been sold under the ATM, for net proceeds to the Company of $16.92 million.

Working capital at September 30, 2019 and future requirements for funds

At September 30, 2019, the Company had working capital of $41.06 million, including $14.73 million in cash, $7.78 million of marketable securities, 500,000 pounds of uranium finished goods inventory and approximately 1,150,000 pounds of vanadium finished goods inventory. The Company believes it has sufficient cash and resources to carry out its business plan for at least the next twelve months.

The Company is actively focused on its forward-looking liquidity needs, especially in light of the current depressed uranium markets. The Company is evaluating its ongoing fixed cost structure as well as decisions related to project retention, advancement and development. If current uranium prices persist for any extended period of time, the Company will likely be required to raise capital or take other measures to fund its ongoing operations. Significant development activities, if warranted, will require that we arrange for financing in advance of planned expenditures. In addition, we expect to continue to augment our current financial resources with external financing as our long-term business needs require.

The Company manages liquidity risk through the management of its capital structure. Accounts payable and accrued liabilities, current portion of notes payable and current taxes payable are due within the current operating year.

Cash and cash flows

Nine months ended September 30, 2019

Cash, cash equivalents and restricted cash were $34.78 million at September 30, 2019, compared to $34.29 million at December 31, 2018. The increase of $0.49 million was due primarily to cash provided by financing activities of $15.62 million, cash provided by investing activities of $19.53 million, offset by cash used in operating activities of $34.70 million and loss on foreign exchange on cash held in foreign currencies of $0.04 million.

Net cash used in operating activities of $34.70 million is comprised of the net loss of $28.39 million for the period adjusted for non-cash items and for changes in working capital items. Significant items not involving cash were $0.92 million of depreciation and amortization of property, plant and equipment, $8.41 million impairment on inventory, stock based compensation expense of $2.50 million, accretion of asset retirement obligation ("ARO") of $1.48 million, $3.28 million change in warrant liabilities, $0.45 million change in value of the debentures, other non-cash expenses of $2.37 million, a decrease in trade and other receivables of $0.23 million, an increase in prepaid expenses and other assets of $0.24 million, unrealized foreign exchange gain of $0.14 million, offset by a decrease in accounts payable and accrued liabilities of $2.69 million, an increase in inventories of $12.85 million and changes in deferred revenue of $2.72 million.

Net cash provided by investing activities was $19.53 million, related to cash received from the sale and maturities of marketable securities.

Net cash provided by financing activities totaled $15.62 million consisting of $14.70 million proceeds from the issuance of stock using the Company's ATM offering, $0.80 million in proceeds from notes payable and $0.15 million cash received from exercise of stock options.

Nine months ended September 30, 2018

Cash, cash equivalents and restricted cash were $36.33 million at September 30, 2018, compared to $40.70 million at December 31, 2017. The decrease of $4.37 million was due primarily to cash provided by financing activities of $15.35 million, cash provided by operating activities of $0.39 million offset by cash used in investing activities of $20.08 million and loss on foreign exchange on cash held in foreign currencies of $0.04 million.

Net cash provided by operating activities of $0.39 million is comprised of the net loss of $17.58 million for the period adjusted for non-cash items and for changes in working capital items. Significant items not involving cash were $3.48 million of depreciation and amortization of property, plant and equipment, $3.62 million related to acquisition of royalty interests, net of share issuance costs, $3.06 million impairment on inventory, stock based compensation expense of $2.24 million, accretion of ARO of $1.38 million, $3.80 million change in warrant liabilities, $1.14 million change in value of the debentures, other non-cash expenses of $0.39 million, changes in deferred revenue of $2.43 million offset by an increase in trade and other receivables of $0.15 million, an increase in inventories of $0.21 million, an increase in prepaid expenses and other assets of $0.76 million, a decrease in accounts payable and accrued liabilities of $2.68 million and $0.23 million in cash paid for reclamation activities.

Net cash provided by financing activities totaled $15.35 million consisting primarily of $25.64 million proceeds from the issuance of stock using the Company's ATM offering, $0.37 million cash received from exercise of warrants, $0.62 million cash received from exercise of stock options and $0.50 million cash received for Notes Receivable offset by $10.86 million to repay loans and borrowings including repaying and retiring the Wyoming Industrial Revenue Bond and $0.91 million cash paid for tax withholding.

Net cash used in investing activities was $20.08 million, of which $2.94 million related to cash received for the sale of the Company's Reno Creek property, $2.57 million related to cash received from the sale of marketable securities offset by $25.53 million cash used for the purchase of available for sale investments and $0.06 million of cash used for the purchase of mineral properties, plant, property and equipment.

Critical accounting estimates and judgments

The preparation of these consolidated financial statements in accordance with U.S. GAAP requires the use of certain critical accounting estimates and judgments that affect the amounts reported. It also requires management to exercise judgment in applying the Company’s accounting policies. These judgments and estimates are based on management’s best knowledge of the relevant facts and circumstances taking into account previous experience. Although the Company regularly reviews the estimates and judgments made that affect these financial statements, actual results may be materially different.

Significant estimates made by management include:

a. Exploration Stage

SEC Industry Guide 7 defines a reserve as “that part of a mineral deposit which could be economically and legally extracted or produced at the time of the reserve determination”. The classification of a reserve must be evidenced by a bankable feasibility study using the latest three-year price average. While the Company has established the existence of mineral resources and has successfully extracted and recovered saleable uranium from certain of these resources, the Company has not established proven or probable reserves, as defined under SEC Industry Guide 7, for these operations or any of its uranium projects. As a result, the Company is in the Exploration Stage as defined under Industry Guide 7. Furthermore, the Company has no plans to establish proven or probable reserves for any of its uranium projects.

While in the Exploration Stage, among other things, the Company must expense all amounts that would normally be capitalized and subsequently depreciated or depleted over the life of the mining operation on properties that have proven or probable reserves.

Items such as the construction of wellfields and related header houses, additions to our recovery facilities and advancement of properties will all be expensed in the period incurred. As a result, the Company’s consolidated financial statements may not be directly comparable to the financial statements of mining companies in the development or production stages.

b. Resource estimates utilized

The Company utilizes estimates of its mineral resources based on information compiled by appropriately qualified persons. The information relating to the geological data on the size, depth and shape of the deposits requires complex geological judgments to interpret the data. The estimation of future cash flows related to resources is based upon factors such as estimates of future uranium prices, future construction and operating costs along with geological assumptions and judgments made in estimating the size and grade of the resource. Changes in the mineral resource estimates may impact the carrying value of mining and recovery assets, goodwill, reclamation and remediation obligations and depreciation and impairment.

c. Depreciation of mining and recovery assets acquired

For mining and recovery assets actively extracting and recovering uranium we depreciate the acquisition costs of the mining and recovery assets on a straight line basis over our estimated lives of the mining and recovery assets. The process of estimating the useful life of the mining and recovery assets requires significant judgment in evaluating and assessing available geological, geophysical, engineering and economic data, projected rates of extraction and recovery, estimated commodity price forecasts and the timing of future expenditures, all of which are, by their very nature, subject to interpretation and uncertainty.

Changes in these estimates may materially impact the carrying value of the Company's mining and recovery assets and the recorded amount of depreciation.

d. Impairment testing of mining and recovery assets

The Company undertakes a review of the carrying values of its mining and recovery assets whenever events or changes in circumstances indicate that their carrying values may exceed their estimated net recoverable amounts determined by reference to estimated future operating results and net cash flows. An impairment loss is recognized when the carrying value of a mining or recovery asset is not recoverable based on this analysis. In undertaking this review, the management of the Company is required to make significant estimates of, among other things, future production and sale volumes, forecast commodity prices, future operating and capital costs and reclamation costs to the end of the mining asset's life. These estimates are subject to various risks and uncertainties, which may ultimately have an effect on the expected recoverability of the carrying values of mining and recovery assets.

e. Asset retirement obligations

Asset retirement obligations are recorded as a liability when an asset that will require reclamation and remediation is initially acquired. For disturbances created on a property owned that will require future reclamation and remediation the Company records asset retirement obligations for such disturbance when occurred. The Company has accrued its best estimate of its share of the cost to decommission its mining and milling properties in accordance with existing laws, contracts and other policies. The estimate of future costs involves a number of estimates relating to timing, type of costs, mine closure plans, and review of potential methods and technical advancements. Furthermore, due to uncertainties concerning environmental remediation, the ultimate cost of the Company's decommissioning liability could differ from amounts provided. The estimate of the Company's obligation is subject to change due to amendments to applicable laws and regulations and as new information concerning the Company's operations becomes available. The Company is not able to determine the impact on its financial position, if any, of environmental laws and regulations that may be enacted in the future. Additionally, the expected cash flows in the future are discounted at the Company's estimated cost of capital based on the periods the Company expects to complete the reclamation and remediation activities. Differences in the expected periods of reclamation or in the discount rates used could have a material difference in the actual settlement of the obligations compared with the amounts provided.

Recently Adopted Accounting Pronouncements

Leases

In February 2016, the Financial Accounting Standards Board ("FASB") issued Accounting Standards Update ("ASU") 2016-02, "Leases (Topic 842)." ASU 2016-02 requires leases to be recognized as assets and liabilities on the balance sheet for the rights and obligations created by all leases with terms of more than 12 months. Under the new requirements, a lessee will recognize in the balance sheet a liability to make lease payments (the lease liability) and the right-of-use asset representing the right to the underlying asset for the lease term. For leases with a term of twelve months or less, the lessee is permitted to make an accounting policy election by class of underlying asset not to recognize lease assets and lease liabilities. The recognition, measurement, and presentation of expenses and cash flows arising from a lease by a lessee have not significantly changed from the previous GAAP.

The Company adopted the standard effective January 1, 2019 using the modified retrospective transition approach and elected not to adjust prior comparative periods. Upon adoption, the Company recognized right-of-use assets and lease liabilities of $1.22 million at January 1, 2019. See Footnote 8 for further discussion.

Non-employee Share-Based Payment

In June 2018, the FASB issued ASU 2018-07, which more closely aligns the accounting for employee and non-employee share-based payments. This standard more closely aligns the accounting for non-employee share-based payment transactions to the guidance for awards to employees except for specific guidance on certain inputs to an option-pricing model and the attribution of cost. The Company adopted this standard effective January 1, 2019 and adoption will not have a significant impact on our net earnings.

Recently Issued Accounting Pronouncements Not Yet Adopted

Fair Value Measurement

In August 2018, the FASB issued ASU 2018-13, which amended the fair value measurement guidance by removing and modifying certain disclosure requirements, while also adding new disclosure requirements. The amendments on changes in unrealized gains and losses, the range and weighted average of significant unobservable inputs used to develop Level 3 fair value measurements, and the narrative description of measurement uncertainty should be applied prospectively for only the most recent interim or annual period presented in the initial fiscal year of adoption. All other amendments should be applied retrospectively to all periods presented upon their effective date. The amendments are effective for all companies for fiscal years, and interim periods within those years, beginning after December 15, 2019. Early adoption is permitted for all amendments. Further, a company may elect to early adopt the removal or modification of disclosures immediately and delay adoption of the new disclosure requirements until the effective date. The Company plans to adopt all disclosure requirements effective January 1, 2020.

ITEM 3. QUANTITATIVE AND QUALITATIVE DISCLOSURES ABOUT MARKET RISK.

The Company is exposed to risks associated with commodity prices, interest rates, foreign currency exchange rates and credit. Commodity price risk is defined as the potential loss that we may incur as a result of changes in the market value of uranium or vanadium. Interest rate risk results from our debt and equity instruments that we issue to provide financing and liquidity for our business. The foreign currency exchange risk relates to the risk that the value of financial commitments, recognized assets or liabilities will fluctuate due to changes in foreign currency rates. Credit risk arises from the extension of credit throughout all aspects of our business. Industry-wide risks can also affect our general ability to finance exploration, and development of exploitable resources; such effects are not predictable or quantifiable. Market risk is the risk to the Company of adverse financial impact due to change in the fair value or future cash flows of financial instruments as a result of fluctuations in interest rates and foreign currency exchange rates. The success of the Company's campaign to recover V_2O_5 from existing Pond Returns at the White Mesa Mill continues to depend, in large part, on the Company's ability to sell V_2O_5 at satisfactory prices in the future. The Company currently does not have any contracts in place for the sale of vanadium.

Commodity Price Risk

The Company is subject to market risk related to the market price of U_3O_8 and V_2O_5. The Company's existing long term uranium contracts have expired, following the Company's April 2018 deliveries, and all uranium sales will now be required to be made at spot prices until the Company enters into new long-term contracts at satisfactory prices in the future. Future revenue beyond our current contracts will be affected by both spot and long-term U_3O_8 price fluctuations, which are affected by factors beyond our control, including: the demand for nuclear power; political and economic conditions; governmental legislation in uranium producing and consuming countries; and production levels and costs of production of other producing companies. The Company continuously monitors the market to determine its level of extraction and recovery of uranium and vanadium in the future.

Interest Rate Risk

The Company is exposed to interest rate risk on its cash equivalents, deposits, restricted cash, and debt. Our interest earned is not material and, thus, not subject to significant risk. The Company is exposed to an interest rate risk associated with its Debentures, which is based on the spot market price of U_3O_8. These Debentures mature in December 2020. Subject to the following sentance, the Company does not currently expect the spot market price of U_3O_8 to exceed $54.99 per pound prior to the Debentures’ maturity and, accordingly, does not believe there is any significant interest rate risk related to these Debentures. In the event any relief is granted under the federal administration’s U.S. Nuclear Fuel Working Group formed July 12th in response to the Company’s Section 232 Petition, the spot price of uranium could potentially increase, but the risk of any resulting increase in interest rates on the Debentures would be likely offset, at least in part, by other cash-flow improvements for the Company. The Company does not use derivatives to manage interest rate risk. The following chart displays the interest rate applicable to our Debentures at various U_3O_8 per pound price levels.

$UxC\ U_3O_8$ Weekly Indicator Price	Annual Interest Rate
Up to $54.99	8.5%
$55.00–$59.99	9%
$60.00–$64.99	9.5%
$65.00–$69.99	10%
$70.00–$74.99	10.5%
$75.00–$79.99	11%
$80.00–$84.99	11.5%
$85.00–$89.99	12%
$90.00–$94.99	12.5%
$95.00–$99.99	13%
$100 and above	13.5%

Currency Risk

The foreign exchange risk relates to the risk that the value of financial commitments, recognized assets or liabilities will fluctuate due to changes in foreign currency rates. The Company does not use any derivative instruments to reduce its exposure to fluctuations in foreign currency exchange rates. As the U.S. Dollar is the functional currency of our U.S. operations, the currency risk has been reduced. We maintain a nominal balance in foreign currency, resulting in a low currency risk relative to our cash balances. Our Debentures are denominated in Canadian Dollars and, accordingly, are exposed to currency risk.

The following table summarizes, in United States dollar equivalents, the Company's major foreign currency (Cdn$) exposures as of September 30, 2019 ($000):

Cash and cash equivalents	$	1,075
Accounts payable and accrued liabilities		(878)
Loans and borrowings		(15,909)
Total	$	(15,712)

The table below summarizes a sensitivity analysis for significant unsettled currency risk exposure with respect to our financial instruments as of September 30, 2019 with all other variables held constant. It shows how net income would have been affected by changes in the relevant risk variables that were reasonably possible at that date.

('000s)	Change for Sensitivity Analysis	Increase (decrease) in other comprehensive income
Strengthening net earnings	+1% change in US dollar $	(208)
Weakening net earnings	-1% change in U.S. dollar $	208

Credit Risk

Credit risk relates to cash and cash equivalents, investments available for sale, trade, and other receivables that arise from the possibility that any counterparty to an instrument fails to perform. The Company only transacts with highly rated counterparties and a limit on contingent exposure has been established for any counterparty based on that counterparty's credit rating. The Company's sales are attributable mainly to multinational utilities. The Company carries credit risk insurance relating to its vanadium sales, which it considers to be adequate. As of September 30, 2019, the Company's maximum exposure to credit risk was the carrying value of cash and cash equivalents, investments available for sale, trade receivables and taxes recoverable.

ITEM 4. CONTROLS AND PROCEDURES.

Disclosure Controls and Procedures.

At the end of the period covered by this quarterly report on Form 10-Q for the period ended September 30, 2019, an evaluation was carried out under the supervision of and with the participation of our management, including the Chief Executive Officer ("CEO") and Chief Financial Officer ("CFO"), of the effectiveness of the design and operations of our disclosure controls and procedures (as defined in Rule 13a-15(e) and Rule 15d-15(e) under the United States Securities Exchange Act of 1934, as amended (the "Exchange Act"). Based on that evaluation, the CEO and the CFO have concluded that as of the end of the period covered by this Quarterly Report, our disclosure controls and procedures were effective in ensuring that: (i) information required to be disclosed by us in reports that we file or submit to the SEC under the Exchange Act is recorded, processed, summarized and reported within the time periods specified in applicable rules and forms and (ii) material information required to be disclosed in our reports filed under the Exchange Act is accumulated and communicated to our management, including our CEO and CFO, as appropriate, to allow for accurate and timely decisions regarding required disclosure.

Changes in Internal Control over Financial Reporting

There has been no change in our internal control over financial reporting during the quarter ended September 30, 2019 that has materially affected, or is reasonably likely to materially affect, our internal control over financial reporting.

PART II

ITEM 1. LEGAL PROCEEDINGS.

We are not aware of any material pending or threatened litigation or of any proceedings known to be contemplated by governmental authorities that are, or would be, likely to have a material adverse effect upon us or our operations, taken as a whole that was not disclosed in the Company's Form 10-K for the year ended December 31, 2018, in its Form 10-Q for the quarter ended March 31, 2019, in its Form 10-Q for the quarter ended June 30, 2019, or in this Form 10-Q for the quarter ended September 30, 2019.

ITEM 1A. RISK FACTORS.

There have been no material changes from the risk factors set forth in our Annual Report on Form 10-K for the year ended December 31, 2018.

ITEM 2. UNREGISTERED SALES OF EQUITY SECURITIES AND USE OF PROCEEDS.

On June 20, 2019, the Company issued 168,486 common shares to several parties pursuant to an Amended and Restated Surface Use Agreement by and between Alto Colorado Ranches Ltd., et al., as owner and Leoncito Project, LLC, et al., as operator, dated May 1, 2016 ("Surface Use Agreement") and an Amended and Restated Uranium Testing Permit and Lease Option Agreement by and between Mestena Unproven, Ltd, Jones Ranch Minerals Unproven, Ltd. and Mestena Proven Ltd. and Leoncito Project, LLC signed May 27, 2016 ("Permit and Lease Agreement"). Both the Surface Use Agreement and Permit and Lease Agreement were previously filed as part of exhibit 10.1 to the Company’s current report on Form 8-K dated March 8, 2016.

Pursuant to subsection 3.1.6 of the Surface Use Agreement and subsection 2 of the "Term" of the Permit and Lease Agreement, the Company had the option, in its sole discretion, to pay up to $300,000 in the form of Energy Fuels common shares, to be valued based on the VWAP of the Company’s common shares on the NYSE American for the ten trading days ending on the last trading day prior to the date of payment. Pursuant to this option, the Company issued 97,786 common shares.

The issuance of our common shares pursuant to the Surface Use Agreement and Permit and Lease Agreement was exempt from registration under the U.S. Securities Act of 1933, as amended, pursuant to Section 4(a)(2) thereunder.

ITEM 3. DEFAULTS UPON SENIOR SECURITIES.

None.

ITEM 4. MINE SAFETY DISCLOSURE.

The mine safety disclosures required by section 1503(a) of the Dodd-Frank Wall Street Reform and Consumer Protection Act and Item 104 of Regulation S-K are included in Exhibit 95.1 of this Quarterly Report, which is incorporated by reference into this Item 4.

ITEM 5. OTHER INFORMATION.

None.

ITEM 6. EXHIBITS.

Exhibits

The following exhibits are filed as part of this report:

Exhibit Number	Description
3.1	Articles of Continuance dated September 2, 2005 (1)
3.2	Articles of Amendment dated May 26, 2006 (2)
3.3	Bylaws (3)
4.1	The Amended and Restated Convertible Debenture Indenture dated August 4, 2016 between Energy Fuels Inc., BNY Trust Company of Canada and the Bank of New York Mellon providing for the issuance of debentures (4)
4.2	Shareholder Rights Plan between Energy Fuels Inc. and CIBC Mellon Trust Company dated February 3, 2009 (5)
4.3	Warrant Indenture between Energy Fuels Inc. and CST Trust Co. providing for the issue of common share purchase warrants dated March 14, 2016 (6)
4.4	First Supplemental Indenture among Energy Fuels Inc., CST Trust Company and American Stock Transfer & Trust Company, LLC dated April 14, 2016 (7)
4.5	Warrant Indenture between Energy Fuels Inc., CST Trust Company and American Stock Transfer & Trust Company, LLC dated September 20, 2016 (8)
4.6	Energy Fuels Inc. Omnibus Compensation Plan dated January 28, 2015 (9)
4.7	Amended and Restated Shareholder Rights Plan Agreement between Energy Fuels Inc. and AST Trust Company, dated March 29, 2018 and effective as of May 30, 2018 by shareholder vote (10)
4.8	2018 Omnibus Equity Incentive Compensation Plan, as amended and restated as of March 29, 2018 (11)
4.9	Release of Mortgage, Assignment of Revenues, Security Agreement, Fixture Filing and Financing Statement, dated September 11, 2018 (12)
10.1	Sales Agreement by and among Energy Fuels Inc., Cantor Fitzgerald & Co., H.C. Wainwright & Co., LLC and Roth Capital Partners, LLC, dated May 6, 2019 (13)
10.2	Employment Agreement by and between Energy Fuels Inc. and Mark Chalmers dated March 28, 2019 (14)
10.3	Employment Agreement by and between Energy Fuels Inc. and David C. Frydenlund dated March 28, 2019 (15)
10.4	Employment Agreement by and between Energy Fuels Inc. and W. Paul Goranson dated March 28, 2019 (16)
23.1	Consent of Mark S. Chalmers
31.1	Certification of Chief Executive Officer pursuant to Rule 13a-14(a)) under the Securities Exchange Act of 1934, as amended
31.2	Certification of Chief Financial Officer pursuant to Rule 13a-14(a) under the Securities Exchange Act of 1934, as amended
32.1	Certification of Chief Executive Officer pursuant to 18 U.S.C. Section 1350, as adopted pursuant to Section 906 of the Sarbanes-Oxley Act of 2002
32.2	Certification of Chief Financial Officer pursuant to 18 U.S.C. Section 1350, as adopted pursuant to Section 906 of the Sarbanes-Oxley Act of 2002
95.1	Mine Safety Disclosure
101.INS	XBRL Instance Document
101.SCH	XBRL Taxonomy Extension – Schema
101.CAL	XBRL Taxonomy Extension – Calculations
101.DEF	XBRL Taxonomy Extension – Definitions
101.LAB	XBRL Taxonomy Extension – Labels
101.PRE	XBRL Taxonomy Extension – Presentations

(1) Incorporated by reference to Exhibit 3.1 of Energy Fuels’ Form F-4 filed with the SEC on May 8, 2015.

(2) Incorporated by reference to Exhibit 3.2 of Energy Fuels’ Form F-4 filed with the SEC on May 8, 2015.

(3) Incorporated by reference to Exhibit 3.3 of Energy Fuels’ Form F-4 filed with the SEC on May 8, 2015.

(4) Incorporated by reference to Exhibit 4.1 of Energy Fuels' Form 10-Q filed with the SEC on August 5, 2016.

(5) Incorporated by reference to Exhibit 10.9 to Energy Fuels’ Form F-4 filed on May 8, 2015.

(6) Incorporated by reference to Exhibit 4.1 to Energy Fuels’ Form 8-K filed on March 14, 2016.

(7) Incorporated by reference to Exhibit 4.1 to Energy Fuels’ Form 8-K filed on April 20, 2016.

(8) Incorporated by reference to Exhibit 4.1 to Energy Fuels' Form 8-K filed on September 20, 2016.

(9) Incorporated by reference to Exhibit 4.12 to Energy Fuels' Form S-8 filed on June 24, 2015.

(10) Incorporated by reference to Schedule B to Energy Fuels' Schedule 14A filed on April 11, 2018.

(11) Incorporated by reference to Schedule C to Energy Fuels’ Schedule 14A filed on April 11, 2018.

(12) Incorporated by reference to Exhibit 4.15 to Energy Fuels’ Form 10-Q filed with the SEC on November 2, 2018.

(13) Incorporated by reference to Exhibit 10.1 to Energy Fuels’ Form 10-Q filed with the SEC on August 5, 2019.

(14) Incorporated by reference to Exhibit 10.3 to Energy Fuels’ Form 10-Q filed with the SEC on May 8, 2019.

(15) Incorporated by reference to Exhibit 10.4 to Energy Fuels’ Form 10-Q filed with the SEC on May 8, 2019.

(16) Incorporated by reference to Exhibit 10.5 to Energy Fuels’ Form 10-Q filed with the SEC on May 8, 2019.

SIGNATURES

Pursuant to the requirements of Section 13 or 15(d) of the *Securities Exchange Act of 1934*, the registrant has duly caused this report to be signed on its behalf by the undersigned, thereunto duly authorized.

ENERGY FUELS INC.
(Registrant)

Dated: November 1, 2019	By:	/s/ Mark S. Chalmers
		Mark S. Chalmers
		President & Chief Executive Officer
Dated: November 1, 2019	By:	/s/ David C. Frydenlund
		David C. Frydenlund
		Chief Financial Officer

EXHIBIT 23.1

CONSENT OF MARK S. CHALMERS

I consent to the inclusion in the Quarterly Report on Form 10-Q of Energy Fuels Inc. (the “Company”) for the quarter ended September 30, 2019 (the “Quarterly Report”) of technical disclosure regarding the properties of the Company, including sampling, analytical and test data underlying such disclosure (the “Technical Information”) and of references to my name with respect to the Technical Information being filed with the United States Securities and Exchange Commission (the “SEC”) under cover of Form 10-Q.

I also consent to the filing of this consent under cover of Form 10-Q with the SEC and of the incorporation by reference of this consent and the Technical Information into the Company’s Registration Statement on Form S-3 (No. 333-228158), as amended, and into the Company's Registration Statements on Form S-8 (Nos. 333-217098, 333-205182, 333-194900 and 333-22654), and any amendments thereto, filed with the SEC.

/s/ Mark S. Chalmers
Name: Mark S. Chalmers
Title: President and Chief Executive Officer,
Energy Fuels Inc.

Date: November 1, 2019

EXHIBIT 31.1

**CERTIFICATION OF CHIEF EXECUTIVE OFFICER
PURSUANT TO RULE 13a-14(a) OF THE
SECURITIES EXCHANGE ACT OF 1934**

I, Mark S. Chalmers, certify that:

1. I have reviewed this quarterly report on Form 10-Q of Energy Fuels Inc.;
2. Based on my knowledge, this report does not contain any untrue statement of a material fact or omit to state a material fact necessary to make the statements made, in light of the circumstances under which such statements were made, not misleading with respect to the period covered by this report;
3. Based on my knowledge, the financial statements, and other financial information included in this report, fairly present in all material respects the financial condition, results of operations and cash flows of the registrant as of, and for, the periods presented in this report;
4. The registrant's other certifying officer and I are responsible for establishing and maintaining disclosure controls and procedures (as defined in Exchange Act Rules 13a-15(e) and 15d-15(e)) and internal control over financial reporting (as defined in Exchange Act Rules 13a-15(f) and 15d-15(f)) for the registrant and have:
   (a) Designed such disclosure controls and procedures, or caused such disclosure controls and procedures to be designed under our supervision, to ensure that material information relating to the registrant, including its consolidated subsidiaries, is made known to us by others within those entities, particularly during the period in which this report is being prepared;
   (b) Designed such internal control over financial reporting, or caused such internal control over financial reporting to be designed under our supervision, to provide reasonable assurance regarding the reliability of financial reporting and the preparation of financial statements for external purposes in accordance with generally accepted accounting principles;
   (c) Evaluated the effectiveness of the registrant's disclosure controls and procedures and presented in this report our conclusions about the effectiveness of the disclosure controls and procedures, as of the end of the period covered by this report based on such evaluation; and
   (d) Disclosed in this report any change in the registrant's internal control over financial reporting that occurred during the registrant's most recent fiscal quarter (the registrant's fourth fiscal quarter in the case of an annual report) that has materially affected, or is reasonably likely to materially affect, the registrant's internal control over financial reporting; and
5. The registrant's other certifying officer and I have disclosed, based on our most recent evaluation of internal control over financial reporting, to the registrant's auditors and the audit committee of the registrant's board of directors (or persons performing the equivalent functions):
   (a) All significant deficiencies and material weaknesses in the design or operation of internal control over financial reporting which are reasonably likely to adversely affect the registrant's ability to record, process, summarize and report financial information; and
   (b) Any fraud, whether or not material, that involves management or other employees who have a significant role in the registrant's internal control over financial reporting.

/s/ Mark S. Chalmers

Date: November 1, 2019

Mark S. Chalmers
President and Chief Executive Officer
(Principal Executive Officer)

EXHIBIT 31.2

CERTIFICATION OF CHIEF FINANCIAL OFFICER
PURSUANT TO RULE 13a-14(a) OF THE
SECURITIES EXCHANGE ACT OF 1934

I, David C. Frydenlund, certify that:

1. I have reviewed this quarterly report on Form 10-Q of Energy Fuels Inc.;
2. Based on my knowledge, this report does not contain any untrue statement of a material fact or omit to state a material fact necessary to make the statements made, in light of the circumstances under which such statements were made, not misleading with respect to the period covered by this report;
3. Based on my knowledge, the financial statements, and other financial information included in this report, fairly present in all material respects the financial condition, results of operations and cash flows of the registrant as of, and for, the periods presented in this report;
4. The registrant's other certifying officer and I are responsible for establishing and maintaining disclosure controls and procedures (as defined in Exchange Act Rules 13a-15(e) and 15d-15(e)) and internal control over financial reporting (as defined in Exchange Act Rules 13a-15(f) and 15d-15(f)) for the registrant and have:
   (a) Designed such disclosure controls and procedures, or caused such disclosure controls and procedures to be designed under our supervision, to ensure that material information relating to the registrant, including its consolidated subsidiaries, is made known to us by others within those entities, particularly during the period in which this report is being prepared;
   (b) Designed such internal control over financial reporting, or caused such internal control over financial reporting to be designed under our supervision, to provide reasonable assurance regarding the reliability of financial reporting and the preparation of financial statements for external purposes in accordance with generally accepted accounting principles;
   (c) Evaluated the effectiveness of the registrant's disclosure controls and procedures and presented in this report our conclusions about the effectiveness of the disclosure controls and procedures, as of the end of the period covered by this report based on such evaluation; and
   (d) Disclosed in this report any change in the registrant's internal control over financial reporting that occurred during the registrant's most recent fiscal quarter (the registrant's fourth fiscal quarter in the case of an annual report) that has materially affected, or is reasonably likely to materially affect, the registrant's internal control over financial reporting; and
5. The registrant's other certifying officer and I have disclosed, based on our most recent evaluation of internal control over financial reporting, to the registrant's auditors and the audit committee of the registrant's board of directors (or persons performing the equivalent functions):
   (a) All significant deficiencies and material weaknesses in the design or operation of internal control over financial reporting which are reasonably likely to adversely affect the registrant's ability to record, process, summarize and report financial information; and
   (b) Any fraud, whether or not material, that involves management or other employees who have a significant role in the registrant's internal control over financial reporting.

Date: November 1, 2019

/s/ David C. Frydenlund
David C. Frydenlund
Chief Financial Officer
(Principal Financial Officer)

EXHIBIT 32.1

CERTIFICATION PURSUANT TO
18 U.S.C. §1350
AS ADOPTED PURSUANT TO
SECTION 906 OF THE SARBANES-OXLEY ACT OF 2002

In connection with the Quarterly Report of Energy Fuels Inc. (the "Company") on Form 10-Q for the period ended September 30, 2019 as filed with the Securities and Exchange Commission on the date hereof (the "Report"), I, Mark S. Chalmers, President and Chief Executive Officer, certify, pursuant to 18 U.S.C. §1350, as adopted pursuant to Section 906 of the Sarbanes-Oxley Act of 2002, that:

(1) The Report fully complies with the requirements of Section 13(a) or 15(d) of the Securities Exchange Act of 1934, as amended; and

(2) The information contained in the Report fairly presents, in all material respects, the financial condition and results of operations of the Company.

/s/ Mark S. Chalmers
Mark S. Chalmers
President and Chief Executive Officer
(Principal Executive Officer)

Date: November 1, 2019

A signed original of this written statement required by Section 906, or other document authenticating, acknowledging, or otherwise adopting the signature that appears in typed form within the electronic version of this written statement required by Section 906, has been provided to the Company and will be retained by the Company and furnished to the Securities and Exchange Commission or its staff upon request.

EXHIBIT 32.2

CERTIFICATION PURSUANT TO
18 U.S.C. §1350
AS ADOPTED PURSUANT TO
SECTION 906 OF THE SARBANES-OXLEY ACT OF 2002

In connection with the Quarterly Report of Energy Fuels Inc. (the "Company") on Form 10-Q for the period ended September 30, 2019 as filed with the Securities and Exchange Commission on the date hereof (the "Report"), I, David C. Frydenlund, Chief Financial Officer, certify, pursuant to 18 U.S.C. §1350, as adopted pursuant to Section 906 of the Sarbanes-Oxley Act of 2002, that:

(1) The Report fully complies with the requirements of Section 13(a) or 15(d) of the Securities Exchange Act of 1934, as amended; and

(2) The information contained in the Report fairly presents, in all material respects, the financial condition and results of operations of the Company.

/s/ David C. Frydenlund
David C. Frydenlund
Chief Financial Officer
(Principal Financial Officer)

Date: November 1, 2019

A signed original of this written statement required by Section 906, or other document authenticating, acknowledging, or otherwise adopting the signature that appears in typed form within the electronic version of this written statement required by Section 906, has been provided to the Company and will be retained by the Company and furnished to the Securities and Exchange Commission or its staff upon request.

Exhibit 95.1

Mine Safety Disclosure

Pursuant to Section 1503(a) of the Dodd-Frank Wall Street Reform and Consumer Protection Act of 2010 (the "**Dodd-Frank Act**"), issuers that are operators, or that have a subsidiary that is an operator, of a coal or other mine in the United States, and that is subject to regulation by the Federal Mine Safety and Health Administration under the Mine Safety and Health Act of 1977 ("**Mine Safety Act**"), are required to disclose in their periodic reports filed with the SEC information regarding specified health and safety violations, orders and citations, related assessments and legal actions, and mining-related fatalities.

The following table sets out the information concerning mine safety violations or other regulatory matters required by Section 1503(a) of the Dodd Frank Wall Street Reform and Consumer Protection Act for the period July 1, 2019 through September 30, 2019 covered by this report:

Property	**Section 104(a) S&S Citations[2] (#)**	**Section 104(b) Orders[3] (#)**	**Section 104(d) Citations and Orders[4] (#)**	**Section 110(b) (2) Violations[5] (#)**	**Section 107(a) Orders[6] (#)**	**Total Dollar Value of MSHA Assess-ments Proposed[7] ($)**	**Total Number of Mining Related Fatalities (#)**	**Received Notice of Pattern of Violations or Potential Thereof Under Section 104(e)[8] (yes/no)**	**Legal Actions Pending as of Last Day of Period[9] (#)**	**Legal Actions Initiated During Period (#)**	**Legal Actions Resolved During Period (#)**
Arizona 1	Nil	Nil	Nil	Nil	Nil	$0.00	Nil	No	Nil	Nil	Nil
Beaver/ La Sal[1]	1	Nil	Nil	Nil	Nil	Non-Assessed at this time	Nil	No	Nil	Nil	Nil
Canyon	Nil	Nil	Nil	Nil	Nil	$0.00	Nil	No	Nil	Nil	Nil
Daneros[1]	Nil	Nil	Nil	Nil	Nil	$0.00	Nil	No	Nil	Nil	Nil
Energy Queen[1]	Nil	Nil	Nil	Nil	Nil	$0.00	Nil	No	Nil	Nil	Nil
Pandora[1]	Nil	Nil	Nil	Nil	Nil	$0.00	Nil	No	Nil	Nil	Nil
Rim[1]	Nil	Nil	Nil	Nil	Nil	$0.00	Nil	No	Nil	Nil	Nil
Tony M[1]	Nil	Nil	Nil	Nil	Nil	$0.00	Nil	No	Nil	Nil	Nil
Whirlwind[1]	Nil	Nil	Nil	Nil	Nil	$0.00	Nil	No	Nil	Nil	Nil

1. The Company's Arizona 1 Mine, Canyon Mine, Daneros Project, Energy Queen Property, Rim Project, Tony M Property and Whirlwind Project were each on standby and were not mined during the period. At the Company's Beaver/La Sal Property and Pandora Property, mining activities from the previous period, which included rehabilitation of the La Sal decline and commencement of a vanadium test-mining program, ceased except for reclamation work.

2. Citations and Orders are issued under Section 104 of the Federal Mine Safety and Health Act of 1977 (30 U.S.C. 814) ("**MSHA**") for violations of MSHA or any mandatory health or safety standard, rule, order or regulation promulgated under MSHA. A Section 104(a) "Significant and Substantial" or "S&S" citation is considered more severe than a non-S&S citation and generally is issued in a situation where the conditions created by the violation do not cause imminent danger, but the violation is of such a nature as could significantly and substantially contribute to the cause and effect of a mine safety or health hazard. It should be noted that, for purposes of this table, S&S citations that are included in another column, such as Section 104(d) citations, are not also included as Section 104(a) S&S citations in this column.

3. A Section 104(b) withdrawal order is issued if, upon a follow up inspection, an MSHA inspector finds that a violation has not been abated within the period of time as originally fixed in the violation and determines that the period of time for the abatement should not be extended. Under a withdrawal order, all persons, other than those required to abate the violation and certain others, are required to be withdrawn from and prohibited from entering the affected area of the mine until the inspector determines that the violation has been abated.

4. A citation is issued under Section 104(d) where there is an S&S violation and the inspector finds the violation to be caused by an unwarrantable failure of the operator to comply with a mandatory health or safety standard. Unwarrantable failure is a special negligence finding that is made by an MSHA inspector and that focuses on the operator's conduct. If during the same inspection or any subsequent inspection of the mine within 90 days after issuance of the citation, the MSHA inspector finds another violation caused by an unwarrantable failure of the operator to comply, a withdrawal order is issued, under which all persons, other than those required to abate the violation and certain others, are required to be withdrawn from and prohibited from entering the affected area until the inspector determines that the violation has been abated.

5. A flagrant violation under Section 110(b)(2) is a violation that results from a reckless or repeated failure to make reasonable efforts to eliminate a known violation of a mandatory health or safety standard that substantially and proximately caused, or reasonable could have been expected to cause, death or serious bodily injury.

6. An imminent danger order under Section 107(a) is issued when an MSHA inspector finds that an imminent danger exists in a mine. An imminent danger is the existence of any condition or practice which could reasonably be expected to cause death or serious physical harm before such condition or practice can be abated. Under an imminent danger order, all persons, other than those required to abate the condition or practice and certain others, are required to be withdrawn from and are prohibited from entering the affected area until the inspector determines that such imminent danger and the conditions or practices which caused the imminent danger no longer exist.

7. These dollar amounts include the total amount of all proposed assessments under MSHA relating to any type of violation during the period, including proposed assessments for non-S&S citations that are not specifically identified in this exhibit, regardless of whether the Company has challenged or appealed the assessment.

8. A Notice is given under Section 104(e) if an operator has a pattern of S&S violations. If upon any inspection of the mine within 90 days after issuance of the notice, or at any time after a withdrawal notice has been given under Section 104(e), an MSHA inspector finds another S&S violation, an order is issued, under which all persons, other than those required to abate the violation and certain others, are required to be withdrawn from and prohibited from entering the affected area until the inspector determines that the violation has been abated.

9. There were no legal actions pending before the Federal Mine Safety and Health Review Commission as of the last day of the period covered by this report. In addition, there were no pending actions that are (a) contests of citations and orders referenced in Subpart B of 29 CFR Part 2700; (b) complaints for compensation referenced in subpart D of 29 CFR Part 2700; (c) complaints of discharge, discrimination or interference referenced in Subpart E of 29 CFR Part 2700; (d) applications for temporary relief referenced in Subpart F of 29 CFR Part 2700; or (e) appeals of judges’ decisions or orders to the Federal Mine Safety and Health Review Commission referenced in Subpart H of 29 CFR Part 2700.

EXHIBIT 42

ENTIRE EXHIBIT NOT SUSCEPTIBLE TO PUBLIC SUMMARY

EXHIBIT 43

Source: *AMG Advanced Metallurgical Group N.V.*

October 16, 2018 16:32 ET

AMG Advanced Metallurgical Group N.V. Completes Feasibility Study to Expand Spent Catalyst Processing Capacity

Amsterdam, 16 October 2018 (Regulated Information) --- AMG Advanced Metallurgical Group N.V. ("AMG", EURONEXT AMSTERDAM: "AMG") is pleased to announce that AMG Vanadium has completed the feasibility study to replicate its existing Cambridge, Ohio recycling facility. The AMG Management Board has approved the commencement of engineering work for the twin facility, and several potential locations within the operational vicinity of AMG Vanadium's existing plant are under final consideration. Once completed, the new facility will more than double AMG Vanadium's spent catalyst processing capability.

Subject to permitting, construction is expected to commence mid-2019 with a completion date in early 2021, resulting in over 35,000 tons of incremental spent catalyst processing capacity and over 6 million pounds of incremental vanadium production capacity.

The construction of a second recycling facility in North America replaces the previously announced 30% expansion of the existing AMG Vanadium facility in Cambridge, Ohio.

"The new facility will help AMG meet customer demand for management of spent catalyst, a listed hazardous waste, and provide proven sustainable recycling of the valuable metals contained in the waste. This expansion has been in the making for over a year and would not be possible without the AMG teams' depth of experience, local and state governmental and agency support, and our stakeholders' commitment to the industry," said Hoy Frakes, President of AMG Vanadium LLC.

This press release contains inside information within the meaning of Article 7(1) of the EU Market Abuse Regulation.

This press release contains regulated information as defined in the Dutch Financial Markets Supervision Act (Wet op het financieel toezicht).

About AMG

AMG is a global critical materials company at the forefront of CO_2 reduction trends. AMG produces highly engineered specialty metals and mineral products and provides related vacuum furnace systems and services to the transportation, infrastructure, energy, and specialty metals & chemicals end markets.

AMG Critical Materials produces aluminum master alloys and powders, titanium alloys and coatings, ferrovanadium, natural graphite, chromium metal, antimony, lithium, tantalum, niobium and silicon metal. AMG Engineering designs, engineers, and produces advanced vacuum furnace systems and operates vacuum heat treatment facilities, primarily for the transportation and energy industries.

With approximately 3,300 employees, AMG operates globally with production facilities in Germany, the United Kingdom, France, the Czech Republic, the United States, China, Mexico, Brazil, India, Sri Lanka and Mozambique, and has sales and customer service offices in Russia and Japan (www.amg-nv.com).

About AMG Vanadium LLC

Located in Cambridge, Ohio, AMG Vanadium specializes in the environmentally beneficial conversion of oil refinery and power plant waste products into ferrovanadium, nickel and molybdenum primarily used by global steel producers in automotive, energy transmission and infrastructure applications. By using materials that would otherwise be discarded as waste, AMG Vanadium creates environmental stewardship, energy conservation and resource recovery.

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Disclaimer

Certain statements in this press release are not historical facts and are "forward looking". Forward looking statements include statements concerning AMG's plans, expectations, projections, objectives, targets, goals, strategies, future events, future revenues or performance, capital expenditures, financing needs, plans and intentions relating to acquisitions, AMG's competitive strengths and weaknesses, plans or goals relating to forecasted production, reserves, financial position and future operations and development, AMG's business strategy and the trends AMG anticipates in the industries and the political and legal environment in which it operates and other information that is not historical information. When used in this press release, the words "expects," "believes," "anticipates," "plans," "may," "will," "should," and similar expressions, and the negatives thereof, are intended to identify forward looking statements. By their very nature, forward looking statements involve inherent risks and uncertainties, both general and specific, and risks exist that the predictions, forecasts, projections and other forward looking statements will not be achieved. These forward looking statements speak only as of the date of this press release. AMG expressly disclaims any obligation or undertaking to release publicly any updates or revisions to any forward looking statement contained herein to reflect any change in AMG's expectations with regard thereto or any change in events, conditions, or circumstances on which any forward looking statement is based.

Attachments:

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