DEFENSE LOGISTICS AGENCY
Strategic Materials

Bold = Priority Material

ELECTRONIC MATERIALS | table data				
Antimony (Sb)	Arsenic (As)	Bismuth (Bi)	Cadmium (Cd)	Copper (Cu)
CZT	Gallium (Ga)	Germanium (Ge)	Gold (Au)	Indium (In)
Lead (Pb)	Selenium (Se)	Silicon (Si)	Silver (Ag)	Tellurium (Te)
Tin (Sn)	Zinc (Zn)			

LIGHTWEIGHT MATERIALS | table data				
Fused aluminum oxide (Al_2O_3)	Aluminum (Al)	Beryllium-aluminum alloy (Be-Al)	Bauxite	Beryl ore
Beryllium (Be)	Beryllium-copper alloy (Be-Cu)	Boron (B)	Carbon fibers (C)	Glass fibers
Graphite (C)	Lithium (Li)	Magnesium (Mg)	Silicon carbide (SiC)	Titanium (Ti)

ORES, MINERALS & COMPOUNDS | table data				
Fluorite				

PLATINIUM GROUP METALS | table data				
Iridium (Ir)	Osmium (Os)	Palladium (Pd)	Platinum (Pt)	Rhodium (Rh)
Ruthenium (Ru)				

RARE & OTHER EARTH MATERIALS | table data				
Barium (Ba)	**Cerium (Ce)**	**Dysprosium (Dy)**	**Erbium (Er)**	**Europium (Eu)**
Gadolinium (Gd)	**Holmium (Ho)**	**Lanthanum (La)**	Lutetium (Lu)	**Neodymium (Nd)**
Praseodymium (Pr)	Promethium (Pm)	**Samarium (Sm)**	Scandium (Sc)	Strontium (Sr)
Terbium (Tb)	Thulium (Tm)	Ytterbium (Yb)	**Yttrium**	

SUPERALLOYS | table data				
Chromium (Cr)	Cobalt (Co)	Hafnium (Hf)	**Manganese (Mn)**	Molybdenum (Mo)
Nickel (Ni)	**Niobium (Nb)**	**Rhenium (Re)**	**Tantalum (Ta)**	**Tungsten (W)**
Vanadium (V)	Zirconium (Zr)			

ANTIMONY

What is antimony?

Antimony (Sb, Z=51) is a silvery-gray, brittle semi-metal that rarely occurs in nature as a native element; rather it is usually found in minerals, primarily stibnite (SbS_3). Antimony is rarely used as a pure metal, but it can be alloyed with lead to strengthen and harden it. Also, it can be formed into antimony trioxide (SbO_3), then added to textiles as a flame retardant.

Where is antimony found?

Antimony is relatively abundant in the earth's crust and is extracted as a principal product or a by-product of smelting of base-metal ores. Nearly all antimony is extracted in China. The U.S. resources of antimony are primarily in Alaska, Idaho, Montana, and Nevada.

What are the common uses of antimony?

Antimony is a critical element in several compounds and alloys used in various industries:

- Automotive batteries (lead-acid)
- Ceramics and glass
- Flame retardants (flameproof fabrics)
- Automotive brake pads (additive to adjust co-efficient of friction)
- Cable sheathing

What are the important defense applications of antimony?

- Flame retardant textiles
- Lead-acid batteries
- Anti-friction alloys (Babbitt metal)
- Ammunition (small arms and tracer bullets)
- Solder
- Semiconductors (diodes, infrared detectors, and Hall-effect devices)

World Mine Production (Kg)		
	2010	2011
United States	0	0
Bolivia	5,000	5,000
China	150,000	150,000
Russia	3,000	3,000
South Africa	3,000	3,000
Tajikistan	2,000	2,000
Other countries	4,000	6,000
World Total	167,000	169,000

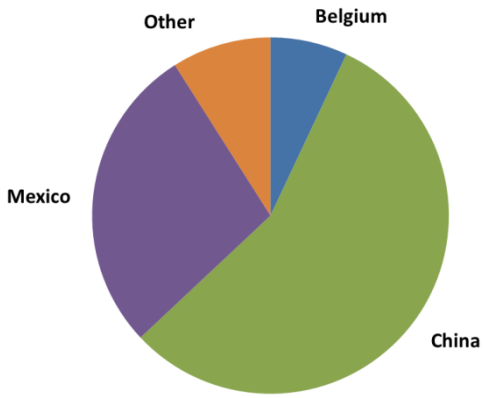
What are some of the energy-related uses of beryllium?

- Lead-acid batteries
- Semiconductors

What are the risks associated with the supply of antimony?

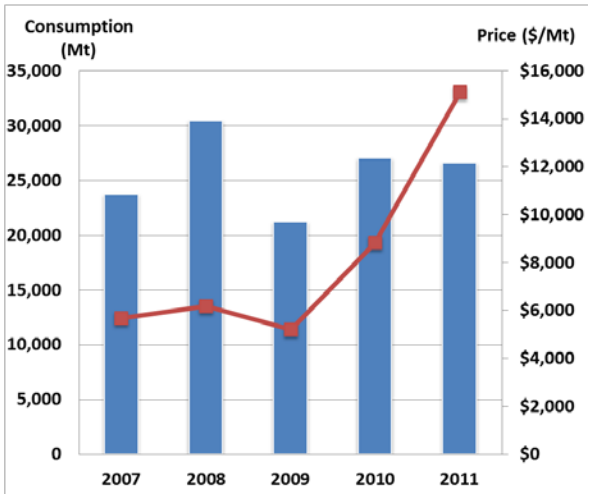
The United States is heavily reliant on the importation of antimony (e.g., concentrate and ore, metal, oxide, and other compounds). Greater than half is imported from China, with Mexico being the second largest supplier. Domestic production is primarily from recycled lead-acid batteries, but recycling provides only a minor portion of total domestic consumption (~15%). Small quantities of antimony have been mined domestically as recently as 2007.

Primary Sources of U.S. Sb Imports
U.S. Import Dependence = 87%* (2011)
*Includes Recycling



Domestically, antimony ore and concentrate can be processed into pure metal, oxide, and other compounds required for military applications. The military's consumption of antimony is primarily in small ammunition, lead-acid batteries, flame retardant textiles, and semiconductors.

U.S. Apparent Consumption and Metal Price



Stockpile Inventory
0 metric tons

Predicted Shortage
23,325 metric tons

Are there any substitutes for antimony?

Antimony can be substituted in most applications with other metals and compounds. Combinations of cadmium, calcium, copper, selenium, strontium, sulfur, and tin are substitutes for hardening lead for ammunition. Selected organic compounds and hydrated aluminum oxide are accepted substitutes for flame retardants. Lithium-ion batteries and antimony free lead-acid batteries can be substitutes for standard lead-acid batteries. Only a minor quantity of highly purified antimony (5N) is required for doping silicon wafers for semiconductors. Domestic recycling of antimony is more than adequate to fully satisfy demand.

Is antimony recycled, reused, or recovered?

Approximately 15% of U.S. apparent consumption is recycled, primarily from used automotive batteries.

Sources

http://en.wikipedia.org/wiki/Antimony

U.S. Geological Survey, Mineral Commodity Summaries, 2012 – Antimony

Antimony in Switzerland, Substance flow analysis, 2007

Iijima, Akihiro, et al. Emission factor for antimony in brake abrasion dusts as one of the major atmospheric antimony sources, 2007.

Prepared by Adam Carroll, 865-576-7505, carrollaj@ornl.gov

ARSENIC

Photo Courtesy of U.S. Army PEO Solder

What is arsenic?

Arsenic (As, Z=33) is a gray metalloid that occurs in several minerals, typically in conjunction with sulfur and metal ores. Arsenic is most commonly processed into arsenic trioxide, arsenic acid, arsenic sulfide, and high purity arsenic metal. Arsenic in pure form and most compounds is toxic to humans.

Where is arsenic found?

Arsenic is recovered as a byproduct of processing nonferrous ores and concentrates. Although arsenic is recoverable from some domestic mining operations, no domestic producers exist due to environmental and health concerns.

The United States ceased arsenic production in 1985 following the closure of the ASARCO Inc. copper smelter in Tacoma, Washington.

What are the common uses of arsenic?

Arsenic is mostly consumed as arsenic trioxide and high purity metal.

- Automotive batteries (grids and posts in lead-acid)
- Wood preservative (chromated copper arsenate produced from arsenic trioxide)
- Semiconductors (GaAs, InAs; cell phones, wireless devices)

What are the important defense applications of arsenic?

- Lead-acid batteries
- Radar (active electronic scanning radar)
- Infrared imaging (short wave infrared tracking, Gen III night vision)

World Mine Production (Arsenic Trioxide, MT)

	2010	2011
United States	0	0
Belgium	1,000	1,000
Chile	11,000	11,500
China	25,000	25,000
Kazakhstan	1,500	0
Morocco	8,000	8,000
Peru	4,500	4,500
Russia	1,500	1,500
Other Countries	310	300
World Total	52,800	52,000

- Communications (tactical radios, satellite communications, cell phones)
- Ammunition (used to harden lead)

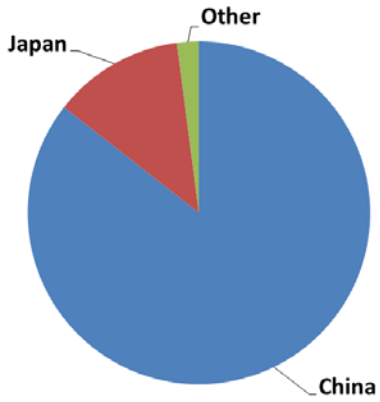
What are some of the energy-related uses of arsenic?

- Solar cells (GaAs)

What are the risks associated with the supply of arsenic?

Arsenic trioxide and arsenic metal are the primary forms important to the United States.

Primary Sources of U.S. As Imports
U.S. Import Dependence = 100% (2011)

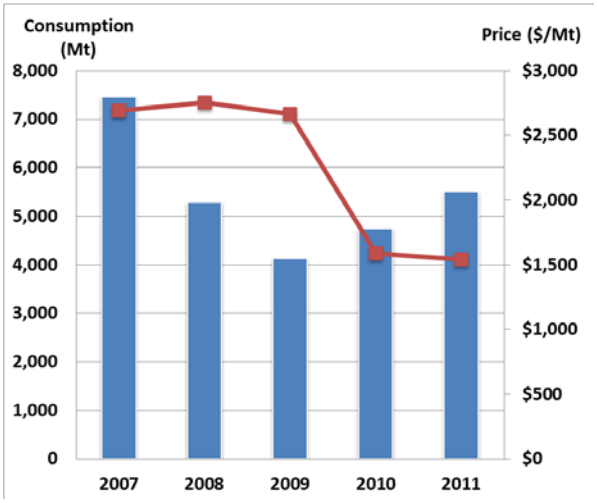


Trioxide accounts for approximately 90% of arsenic imports, however arsenic metal is more critical to military applications. The United States is fully reliant on importing trioxide and metal. For trioxide, the major import sources are Morocco (66%) and China (25%). For metal, China dominates the domestic market, supplying 83%; the remainder is primarily imported from Japan.

How are these risks being managed?

Arsenic is largely consumed in chromated copper arsenate, which is used as a wood preservative.

U.S. Apparent Consumption and Metal Price



Stockpile Inventory
0 metric tons

Predicted Shortage
0 metric tons

Are there any substitutes for arsenic?

There are several substitute wood preservatives and alternative materials that do not require arsenic. For arsenic metal, antimony can be substituted as a lead hardening agent in lead-acid batteries and ammunition.

Gallium arsenide is used in integrated circuits. In certain applications there are alternatives; for example, with solar cells, germanium wafers can be used instead of gallium arsenide. However, in most applications gallium arsenide's unique properties make it difficult or impossible to substitute without a reduction in performance.

Is arsenic recycled, reused, or recovered?

Domestically arsenic is not recovered or recycled and returned to the market. The only known recovery of arsenic is in gallium arsenide scrap generated during the manufacturing of wafers and substrates. That scrap is typically reprocessed and returned to the production process.

Sources

Nassar, N.T., et al. Criticality of Geological Copper Family, Environmental Science and Technology, 2012, 46, 1071-1078

http://en.wikipedia.org/wiki/Arsenic

U.S. Geological Survey, Mineral Commodity Summaries, 2012 – Arsenic

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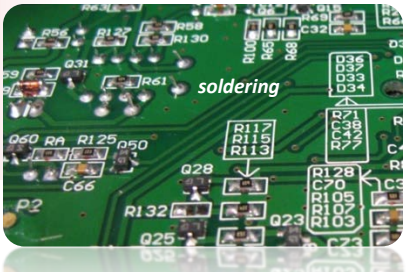
BISMUTH



What is bismuth?

Bismuth (Bi, Z=83) is a brittle metal with a silver-pink hue. Bismuth can occur naturally uncombined, but, has little commercial use in pure form.

Where is bismuth found?

Bismuth is produced as a primary product from the Tasna Mine in Bolivia, but it is also produced in a mine in China. More commonly, bismuth is recovered as a by-product of processing lead ore. In China, it is also recovered as a by-product of fluorspar, tin, and tungsten production.

What are the common uses of bismuth?

Bismuth is a critical element in several compounds and alloys used in various industries:

- Cosmetics (bismuth oxychloride)
- Pharmaceuticals (compounds used in over-the-counter medicine to treat stomach illness, burns, intestinal disorders, and stomach ulcers)
- Metal alloys
- Solder
- Thermoelectric devices (bismuth telluride)
- Fireworks
- Plastics with opacity to X-rays (implanted medical devices)
- Ammunition (replacement for lead shot used for hunting, “less-lethal” riot projectile)

What are the important defense applications of bismuth?

- Solder
- Metal alloys
- Thermoelectrics (temperature control of sensitive equipment, power generation)
- Work holding of turbine blade during machining

World Mine Production (Mt)		
	2010	2011
United States	0	0
Bolivia	90	100
Canada	90	100
China	6,500	6,000
Kazakhstan	150	0
Mexico	850	1,000
Peru	1,100	1,100
Other Countries	120	200
World Total	8,900	8,500

What are some of the energy-related uses of bismuth?

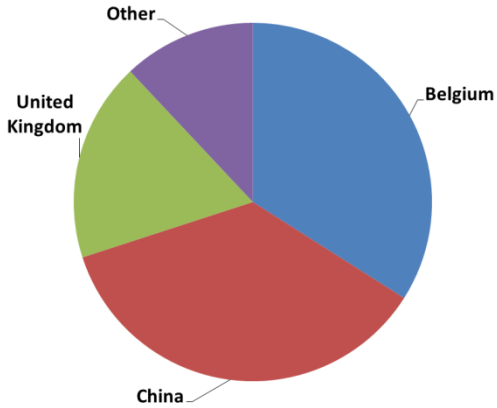
- Solder
- Solid oxide fuel cell (bismuth oxide)
- Lead-bismuth eutectic (coolant in some experimental nuclear reactors)
- Scintillator (detector in particle physics, nuclear medicine, geology exploration)

What are the risks associated with the supply of bismuth?

The United States is heavily dependent on imports of bismuth to satisfy consumption. Domestic production of primary refined bismuth ceased in 1997.

Bismuth is imported by multiple countries primarily located in Asia, Europe, and North America.

Primary Sources of U.S. Bi Imports
U.S. Import Dependence = 89% (2011)*
***Domestic recycling is included as a bismuth source**

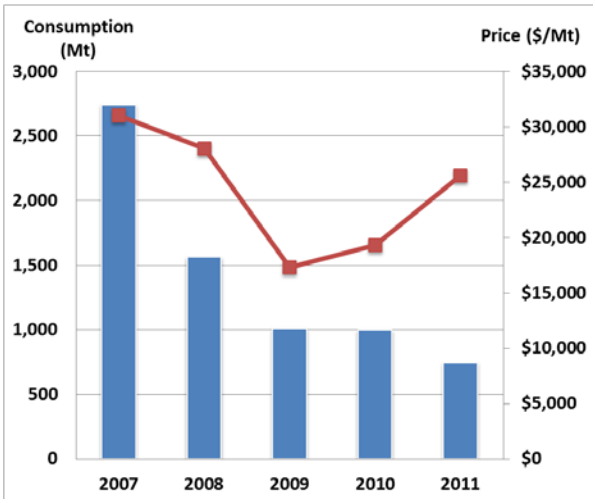


Bismuth imported to Europe is largely mined in Asia and then refined in Europe. China is the single largest bismuth producer, accounting for nearly three-quarters of global mining production.

How are these risks being managed?

China is the single largest producer of bismuth; however, there are multiple mines and refineries in Canada and Mexico to meet U.S. military needs.

U.S. Apparent Consumption and Metal Price



Stockpile Inventory
0 metric tons

Predicted Shortage
2,392 metric tons

Are there any substitutes for bismuth?

There are several substitutes for bismuth in pharmaceutical applications, solders, and machining. Bismuth's unique properties are required for thermoelectric devices and some metal alloys. Historically, bismuth-based magnets (Bismanol) were used in small electric motors, but they have now mostly been replaced by neodymium magnets in most applications.

Is bismuth recycled, reused, or recovered?

Secondary production (recycling) in the United States accounts for approximately 5% of total consumption.

Sources

Azad, A.M, et al. *Review bismuth oxide-based solid electrolytes for fuel cells*, 1994.

http://en.wikipedia.org/wiki/Bismuth

Jasinski, S.M., *Bismuth- uses, supply, and technology*, 1992

U.S. Geological Survey, Mineral Commodity Summaries, 2012 – Bismuth

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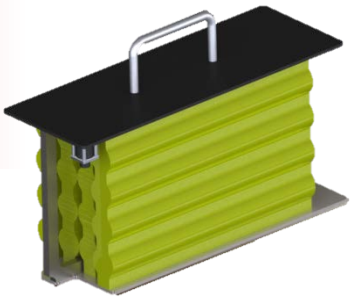
CADMIUM



What is cadmium?

Cadmium (Cd, Z=48) is a soft, bluish-white metal that is highly corrosion resistant and is toxic to humans in certain forms.

Where is cadmium found?

Cadmium is generally recovered from zinc concentrates and is currently domestically produced at a zinc mine in Clarksville, TN. Cadmium's toxicity is in part the justification for not recovering the material at other zinc mining operations in Alaska, Idaho, and Missouri.

Cadmium is produced in over a dozen nations. China is the single largest producer accounting for approximately 25% of global supply.

What are the common uses of cadmium?

Cadmium is mostly consumed in the production of batteries.

- Batteries (NiCd)
- Pigments (yellow, orange, and red)
- Plating (provides better rust resistance than zinc, especially in salt water environments)

What are the important defense applications of cadmium?

- Batteries (NiCd used in portable transceiver, hand-held radio, sensors, night vision, and tow guns)
- CZT (infrared focal plane array, radiation detector)
- Plating (certain airplane parts, fasteners, electrical connectors)

World Mine Production (MT)		
	2010	2011
United States	637	600
Canada	1,300	1,300
China	7,200	7,500
Japan	2,050	2,000
Kazakhstan	1,800	1,800
Mexico	1,480	1,500
Other Countries	6,600	6,800
World Total	21,100	21,500

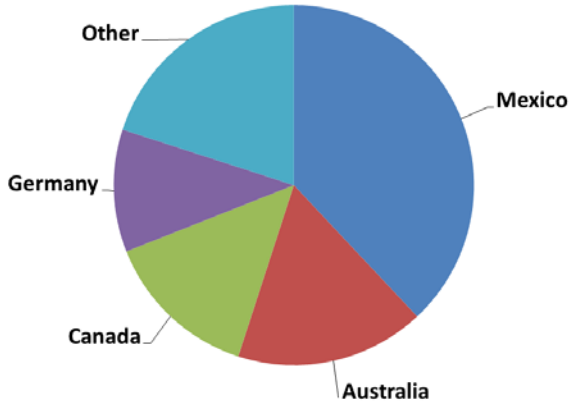
What are some of the energy-related uses of cadmium?

- Solar cells (CdTe)
- Nuclear control rods

What are the risks associated with the supply of cadmium?

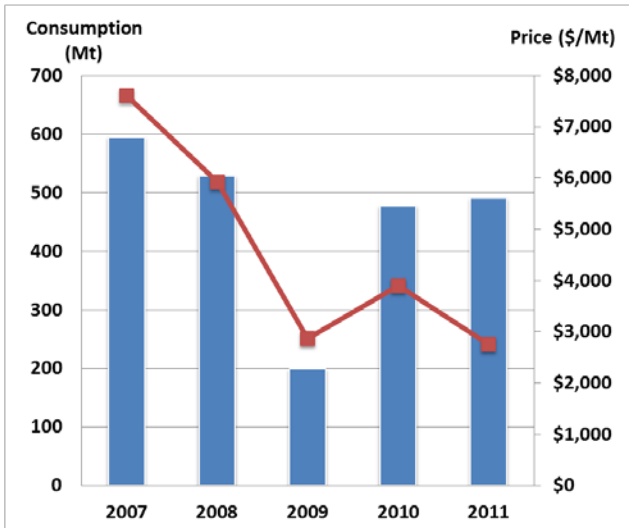
The United States is a net exporter of cadmium. Domestic consumption is less than the current estimated refinery production. There are three domestic cadmium production facilities. One company recovers primary cadmium as a byproduct of zinc leaching from roasted sulfide concentrates. The other two companies recover secondary cadmium metal from spent nickel-cadmium batteries and cadmium bearing scrap.

Primary Sources of U.S. Metal Cd Imports
U.S. Import Dependence = 0% (2011)



Beyond the U.S., China is the single largest producer accounting for about 35% of global production, however, there are numerous other producing nations and no one nation fully dominates production.

U.S. Apparent Consumption and Metal Price



Stockpile Inventory
0 metric tons

Predicted Shortage
0 metric tons for base case

How are these risks being managed?

There is very little risk to the supply of cadmium. Domestic production is in excess of domestic capacity, and there are currently three domestic production sources.

In addition to domestic sources, there is significant production of cadmium in Canada and Mexico. Both countries each produce about twice the U.S. consumption.

Due to the material's toxicity, over the last decade the U.S. Department of Defense has been attempting to reduce cadmium consumptions and substitute where possible.

Is cadmium recycled, reused, or recovered?

Cadmium is recycled from nickel-cadmium batteries by two domestic facilities.

Sources

Ellor, J. A. and Stemniski, P., *Sustainable practices concerning the use of cadmium and hexavalent chromium as corrosion control products*, Tri-Service Corrosion Conference 2007.

http://en.wikipedia.org/wiki/Cadmium

http://www.maifl.com/recharge.htm

U.S. Geological Survey, Mineral Commodity Summaries, 2012– Cadmium

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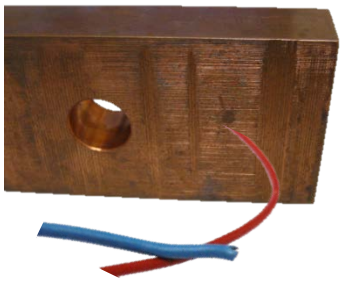
COPPER



What is copper?

Copper (Cu, Z=29) is a reddish-orange metal that is ductile and malleable making it easy roll into wire and sheet. In addition, it has a very high thermal and electrical conductivity making it useful for electrical wires and other uses.

Where is copper found?

Copper is an abundant metal that occurs either as a native metal or as part of a mineral. Copper is primarily extracted as copper sulfides from large open pit mines. The largest producers are Chili (34%), Peru (8%), United States (7%), and China (7%).

The U.S. resources of copper are primarily mined in Arizona, Utah, Nevada, New Mexico, and Montana.

What are the common uses of copper?

Copper is primarily used in electrical wires, roofing and plumbing, industrial machinery, alloyed with other metals, and chemicals.

- Electric wire (motors, electromagnets, integrated circuits)
- Plumbing (tubing, fittings)
- Architectural roofing and features on buildings
- Alloys (brass, bronze)

What are the important defense applications of copper?

- Electrical wire (motors, electromagnets, integrated circuits)
- Ammunition (copper jacketed bullets)
- Anti-friction alloys (Babbitt metal)
- Ammunition (small arms and tracer bullets)
- Aerospace applications (beryllium copper alloys)

WORLD MINE PRODUCTION (THOUSAND METRIC TONS)		
	2010	2011
United States	1,110	1,120
Australia	870	940
Chile	5,420	5,420
China	1,190	1,190
Indonesia	872	625
Peru	1,250	1,220
Russia	703	710
Zambia	690	715
Other Countries	3,800	4,200
World Total	15,900	16,100

What are some of the energy-related uses of copper?

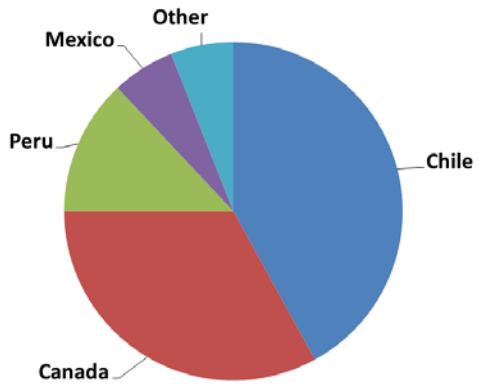
- Electric motors
- Electrical wires

What are the risks associated with the supply of copper?

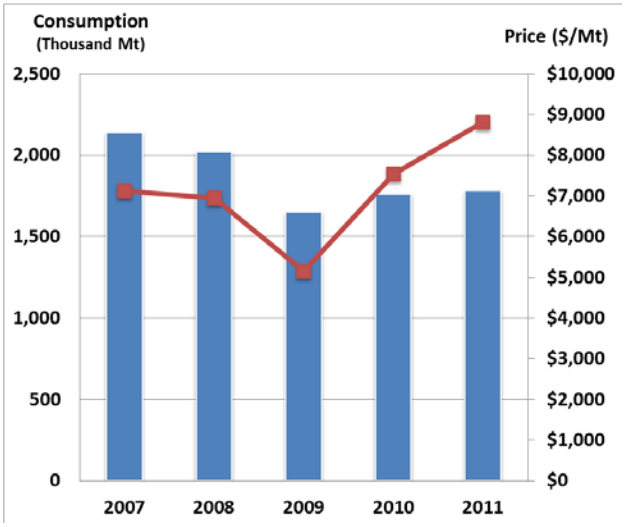
The United States is the third largest producer of copper; however domestic consumption still exceeds production. About one-third of copper consumed is imported from Chile, Canada, and Peru.

Primary Sources of Unmanufactured Cu U.S. Imports
U.S. Import Dependence = 35%* (2011)

*Includes recycling



U.S. Apparent Consumption and Metal Price



Stockpile Inventory
0 metric tons

Predicted Shortage
0 metric tons

Are there substitutes for copper?

There are several substitutes for copper products:

- Aluminum can substitute for copper in power cables, electrical equipment, and tubing
- Titanium and steel can be used in heat exchangers, but at a lower conduction coefficient reducing performance
- Fiber optic telecommunication lines can be used instead of copper at higher cost but improved performance
- Plastic can replace copper in water pipe, drain pipe, and plumbing applications

Is copper recycled, reused, or recovered?

Approximately 7% of apparent consumption is from recycled scrap that is reprocessed and returned to the market. Copper can be indefinitely recycled in most applications (i.e., the recycled metal can be processed back to equivalent purity as primary copper).

Sources

Arizona Mining Association – Copper as Commodity

http://en.wikipedia.org/wiki/Copper

U.S. Geological Survey, Mineral Commodity Summaries, 2012– Copper

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CZT

What is CZT?

CZT (cadmium-zinc-telluride, CdZnTe) is an alloy of cadmium telluride and zinc telluride used as a room temperature semiconductor capable of converting X-rays or gamma-rays into electrons.

Where are CZT substrates manufactured?

Cadmium is produced as by-product of zinc mining in Tennessee and from recycling nickel-cadmium (NiCd) batteries.

Zinc is mined domestically in 4 states at 12 mines.

A Texas refinery extracts and purifies tellurium from copper anode slimes, but this material is largely imported from China.

CZT is produced in at least two domestic facilities (one commercial, one defense).

What are the common uses of CZT?

- Radiation detector (capable of determining type of radiation source)
- Medical imaging

What are the important defense applications of CZT?

- Radiation detector
- Baggage inspection (capable of determining materials being scanned)
- Night vision
- Weapons guidance (substrates for IR focal plane array detectors

What are some of the energy-related uses of CZT?

- Radiation detectors (particle physics)
- Scintallators

World Mine Production (kg)		
	2009	2010
United States	100	100
Canada	30	100
China	20	20
France	20	20
Israel	50	50
Japan	35	35
World Total	260	330

What are the risks associated with the supply of CZT?

For the production of CZT, high-purity cadmium, zinc, and tellurium are required. The high-purity cadmium and zinc can be acquired domestically. Commercial-grade tellurium (~99.7% pure) is domestically produced in Texas; however, the commercial-grade tellurium is processed in Canada or Belgium into high-purity form.

The high-purity cadmium, zinc, and tellurium are processed into a boule and sliced into substrates. The areal dimensions, crystal orientation, and thickness of the substrates are highly dependent on application. There are two domestic manufacturing facilities. The larger of the two is in Pennsylvania , and it manufactures substrates for the commercial market. The second manufacturer is located in California and manufactures substrates for defense applications only; these substrates are not the correct crystal orientation or of sufficient size to be used in the latest generation IR devices. A single foreign supplier satisfies that demand.

The CZT market is small and global production is approximately 300 kg annually. Over half of the CZT produced is used for the production of medical devices.

How are these risks being managed?

Tellurium is the weak link in the CZT production supply chain; however, a sufficient quantity of high-purity tellurium is produced in Canada to satisfy demand for CZT defense products.

Is CZT recycled, reused, or recovered?

Manufacturing scrap is partly recovered and returned to the production line, but no recycling of produced products is completed domestically.

Cadmium and zinc are both recycled from other uses, but tellurium is not.

Are there substitutes for CZT?

There are several substitutes for CZT, but typically at a loss of performance. Silicon and germanium can both be used as the semiconductor in a radiation detector.

Silicon is currently the standard in use for baggage inspection equipment; CTZ use is not as common. Germanium and gallium arsenide can be substituted in some night vision equipment and weapons guidance systems.

Sources

Conversation with Rick Smith of Endicott Interconnect Technologies, Inc.

U.S. Geological Survey, Mineral Commodity Summaries, 2012– Copper

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STOCKPILE INVENTORY
0 metric tons

PREDICTED SHORTAGE
0 metric tons

GALLIUM

Photo Courtesy of U.S. Army PEO Solder

What is gallium?

Gallium (Ga, Z=31) is a soft, silvery metal that liquefies at slightly above room temperature (melting point, 85°F). It is primarily formed into gallium arsenide (GaAs) and gallium nitride (GaN) for electronic components.

Where is gallium found?

Gallium occurs in trace amounts in aluminum and zinc ores, and it can be separated during the smelting process. Currently, no domestic production is reported.

In 2011, China, Germany, Kazakhstan, and the Ukraine were the leading producers. The refining of gallium ore into a high purity form is primarily completed in China, Japan, and the United States.

What are the common uses of gallium?

- Integrated circuits (cell phones, especially smart phones, wireless internet)
- Optoelectronical devices (laser diodes, LEDs, photo-detectors, and solar cells)
- Specialty alloys (minor use, ~1%)

What are the important defense applications of gallium?

- Radar (air and missile defense, fast target tracking radar)
- Infrared imaging (short wave infrared tracking, night vision)
- Communications (tactical radios, satellite communications, cell phones)

What are some of the energy-related uses of gallium?

- Solar cells (GaAs)

World Mine Production (MT)		
	2010	2011
World Total	182	216

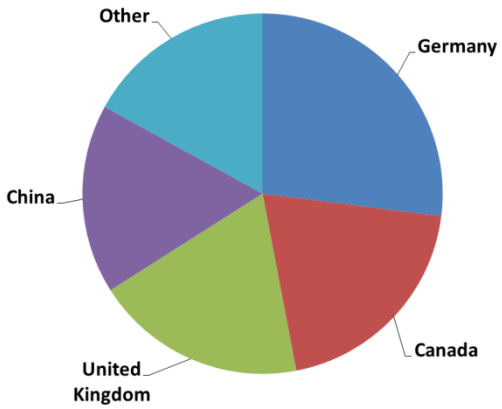
What are the risks associated with the supply of gallium?

The United States is effectively fully dependent on importing gallium. Gallium is neither domestically mined nor recycled; however, industrial scrap produced from manufacturing gallium wafers is recovered and reprocessed back into high-purity material, thus minimizing waste.

Gallium is imported as raw material (unwrought metal, waste, and scrap) primarily from Germany, Canada, China, and the Ukraine. The raw material is domestically processed into high-purity material and manufactured into wafers and substrates. GaAs and GaN wafers and substrates are not only manufactured domestically, but are imported from Japan, Germany, Taiwan, and China as well.

The demand for gallium is increasing primarily due to the growing popularity of several consumer products. GaAs and GaN wafers are used in producing integrated circuits for cell phone and wireless devices. Gallium is used in producing LEDs used in televisions, computer monitors, and low-energy light bulbs. The demand for gallium for military use is also increasing, supported by a need for more capable tactical communication devices, improved radar sensitivity, and infrared sensors.

Primary Sources of U.S. Ga Imports
U.S. Import Dependence = 99% (2011)

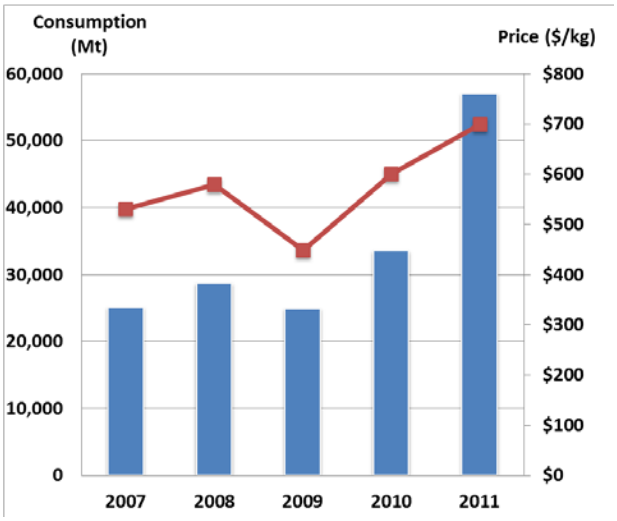


How are these risks being managed?

Gallium can be substituted for other materials in many consumer products, like LEDs and solar cells; however, in many defense-related applications, alternatives are not as effective due to gallium's unique properties.

The supply of gallium to the United States is highly diversified with multiple countries across the globe being able to supply raw metal, wafers, and substrates.

U.S. Apparent Consumption and Metal Price



Stockpile Inventory
0 metric tons

Predicted Shortage
1.4 metric tons

Is gallium recycled, reused, or recovered?

Manufacturing scrap is recovered and returned to the production line, but no recycling of produced products is completed domestically.

Sources

European Commission, Critical raw materials for the EU

FLIR, Short-Wave IR Components, informational sheet.

http://en.wikipedia.org/wiki/Gallium

U.S. Geological Survey, Mineral Commodity Summaries, 2012– Gallium

Prepared by Adam Carroll, 865-576-7505, carrollaj@ornl.gov

GERMANIUM

Photo Courtesy of image-of-elements.com

What is germanium?

Germanium (Ge, Z=32) is a hard, brittle, silvery-gray metalloid with unique properties making it desirable for producing telecommunication fiber optics, polymerization catalysts for certain plastics, lenses for infrared applications, and substrates for electronic circuitry.

Where is germanium found?

Germanium is principally recovered as a by-product of zinc mining. Domestically, germanium is recovered from a single zinc mine located in Alaska. Producing germanium as a primary product has been attempted without success. Globally, China accounts for two-thirds of germanium production; U.S. production is less than 3%.

What are the common uses of germanium?

- Polymerization catalyst for polyethylene terephthalates (PET)
- Telecommunication fiber optics
- Lenses for mid- and long- wavelength infrared (IR) devices

What are the important defense applications of germanium?

- Infrared devices (missile guidance systems, infrared vision systems)
- Solar cells for space applications (satellites)
- Radiation detectors

What are some of the energy-related uses of germanium?

- Solar cells (high efficiency, primarily used in space applications)

World Mine Production (MT)		
	2010	2011
United States	3,000	3,000
China	80,000	80,000
Russia	5,000	5,000
Other countries	30,000	30,000
World Total	118,000	118,000

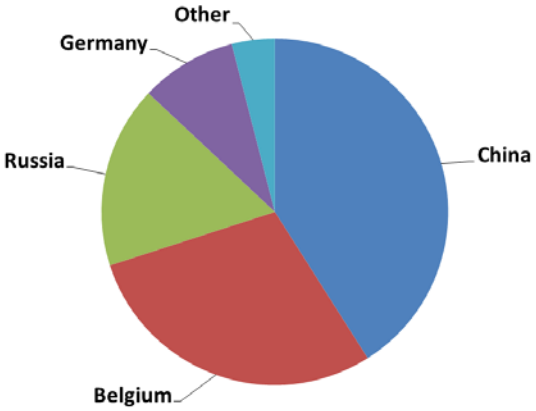
What are the risks associated with the supply of germanium?

Domestic germanium production is supplied as a by-product of zinc mining. Currently, the Red Dog Operation in Alaska is the sole domestic zinc mine recovering smelter residues for germanium extraction. These residues are shipped from Alaska to Trail, British Columbia, for processing to separate the germanium .

U.S. production accounts for only 8% of the total domestic consumption. Germanium is primarily imported from Europe and China, however, the germanium imported from Europe is largely mined in China and only processed in Europe. China produces two-thirds of the global germanium supply.

The military's demand for germanium likely surpasses half of all domestic consumption of germanium, which far exceeds domestic production. Half of the domestic germanium consumption is in manufacturing infrared optics which is primarily consumed by the military. The military also consumes a significant quantity of germanium for solar cells for space applications.

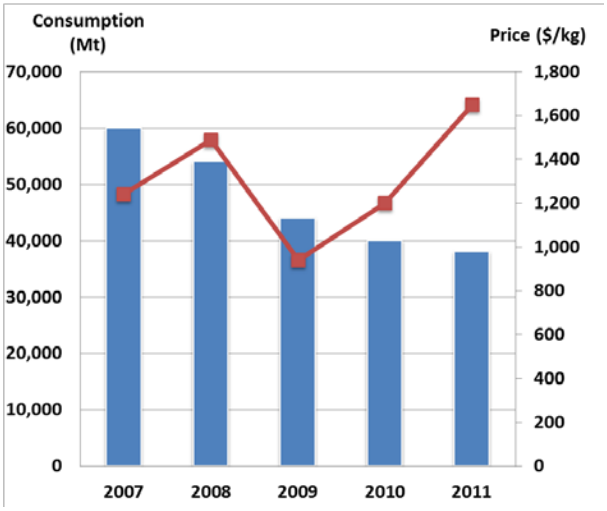
Primary Sources of U.S. Ge Imports
U.S. Import Dependence = 90% (2011)



How are these risks being managed?

Germanium can be substituted in certain applications. For space-qualified solar cells, gallium arsenide can be used as a substrate instead of germanium; however, gallium arsenide has less desirable physical properties and the supply of gallium is fully reliant on imports. For infrared applications, zinc selenide can be used, but with a loss of performance.

U.S. Apparent Consumption and Metal Price



Stockpile Inventory
16 metric tons

Predicted Shortage
100 kilograms

A second zinc mine with a history of germanium production, located in Metaline Falls, Washington, was placed on "temporary care-and-maintenance" status due to the drop in zinc prices. As global demand for zinc products improves, the domestic production of germanium should also improve.

Is germanium recycled, reused, or recovered?

Manufacturing scrap is recovered and returned to the production line, but no recycling of produced products is completed domestically.

Sources

Fiber at Home Council, www.ftthcouncil.org

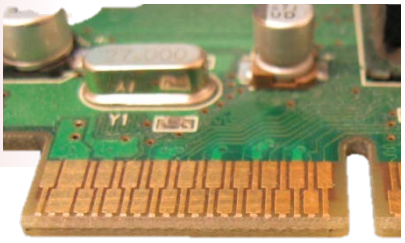
http://en.wikipedia.org/wiki/Germanium

Jorgenson, J. D., *Germanium Recycling in the United States in 2000*, U.S. Geological Survey Circular 1196-V, Washington, D.C..

U.S. Geological Survey, Mineral Commodity Summaries, 2012– Germanium

Prepared by Adam Carroll, 865-576-7505, carrollaj@ornl.gov

GOLD



What is gold?

Gold (Au, Z= 79) is a soft, shiny metal that is easily formed and shaped into products. Pure gold has a bright yellow color, which it maintains without oxidizing in air or water.

Where is gold found?

Approximately three-quarters of domestic gold production is from mines in Nevada. The remainder is largely from the southwestern states and Alaska.

The United States is the third largest producer of gold, following China, and Australia. In all, there are more than a dozen nations that produce at least 50 metric tons (mt) of gold annually.

What are the common uses of gold?

Approximately 54% of gold is consumed in jewelry and art; 7% in electronic and electrical devices; and 39% in dental and other uses. Of note, investment gold is not considered consumed.

- Jewelry
- Art (gold thread, glass, sculpture)
- Electronics (electrical connectors)
- Dental (crowns, fillings)
- Coins

What are the important defense applications of gold?

- Electrical connectors
- Electromagnetic radiation reflector in satellites
- Gold film to protect from electronic warfare equipment (EA-6B Prowler)
- Thermal protection

WORLD MINE PRODUCTION (MT)		
	2009	2010
United States	231	237
Australia	261	270
Canada	91	110
China	345	355
Indonesia	120	100
Peru	164	150
Russia	192	200
South Africa	189	190
Other countries	970	1,090
World Total	2,560	2,700

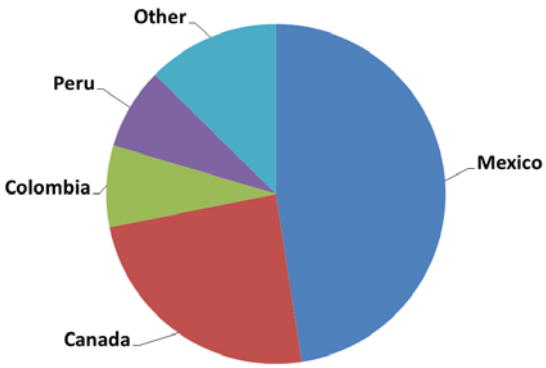
What are some of the energy-related uses of gold?

- Electrical connectors

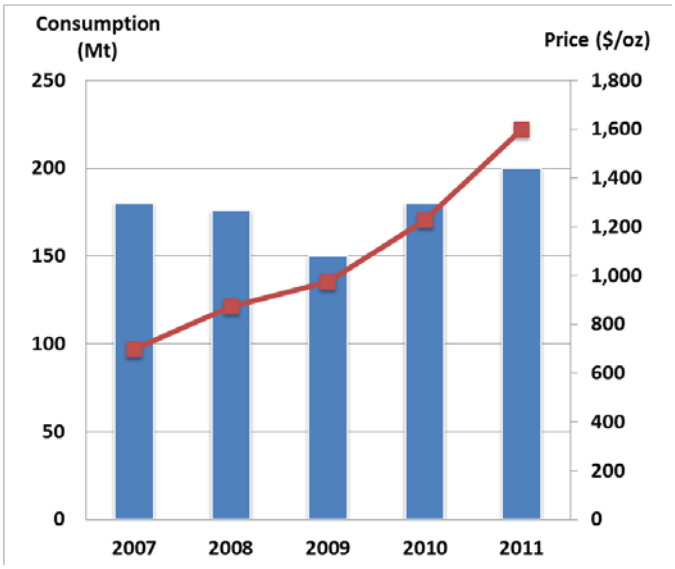
What are the risks associated with the supply of gold?

There is no risk to the supply of gold for use for defense purposes. The U.S. is the third largest gold producer and, with the exception of 2010 and 2011, is a net exporter of gold. Beyond production and consumption the U.S. holds a stockpile of 8,140 metric tons of gold.

Primary Sources of U.S. Au Imports
U.S. Import Dependence = 36% (2011)



U.S. Apparent Consumption and Metal Price



Stockpile Inventory
8,140 metric tons

Predicted Shortage
0 metric tons

With annual domestic consumption averaging 168 metric tons over the last five years, the U.S. Department of the Treasury's stockpile is sufficient to fully satisfy demand for nearly 50 years.

How are these risks being managed?

The 8,140 metric ton stockpile gold is sufficient to protect the domestic availability of gold. Further efforts are not required.

Is gold recycled, reused, or recovered?

Gold is recycled and recovered primary from jewelry, art, and electronics. The high value of gold has encouraged the recycling of scrap gold by the general population. The amount of gold recycled back into the market has more than doubled since 2005.

Sources

http://en.wikipedia.org/wiki/Gold

U.S. Geological Survey, Mineral Commodity Summaries, 20112– Gold

Prepared by Adam Carroll, 865-576-7505, carrollaj@ornl.gov

INDIUM

Photo Courtesy of U.S. Army PEO Soldier

What is indium?

Indium (In, Z=49) is a rare, very soft, silvery-white metal that is primarily formed into indium tin oxide (ITO). ITO is used for electrically conductive purposes, and it is highly transparent in the infrared spectrum.

Where is indium found?

Indium is a rare element at ~0.05 ppm in the earth's crust. Indium is most commonly recovered from the zinc-sulfide ore. Vein stockwork deposits of tin and tungsten host the highest known concentrations of indium.

What are the common uses of indium?

- LCD displays (TV, computer screens, portable electronic devices)
- Organic light-emitting diodes (LEDs)
- Fiber-optics (laser diodes)
- Solder and alloys

What are the important defense applications of indium?

- Infrared imaging (InSb, InGaAs)
- Communications (InP)

What are some of the energy-related uses of indium?

- Solar cells
- Nuclear control rods
- Alkaline batteries

WORLD MINE PRODUCTION (MT)

	2010	2011
United States	0	0
Belgium	30	30
Canada	67	64
China	340	340
Japan	70	70
Republic of Korea	70	100
Other Countries	32	36
World Total	609	640

What are the risks associated with the supply of indium?

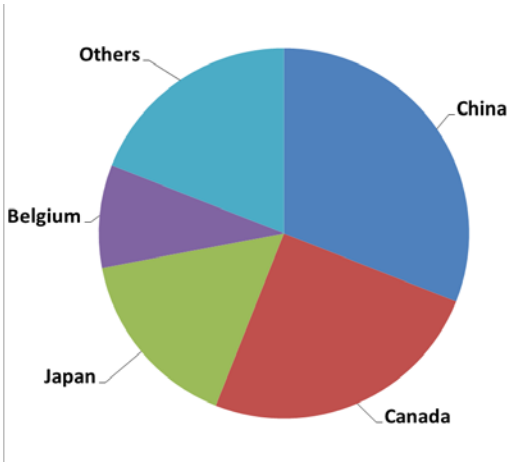
The United States is fully dependent on indium imports to satisfy demand. Domestically, two companies are capable of processing low-grade indium into high-purity metal and indium products; however, most indium is imported in its desired form.

The global demand for indium is expected to increase by 15% over the next three years, driven by demand for consumer electronics. Last year, 85% of all indium was consumed in making ITO, primarily used in manufacturing LCD products. Domestic LCD production is negligible compared with that of Asia.

How are these risks being managed?

The supply of indium is diverse; approximately half of the material is imported from Asia and the other half is imported from Europe, Canada, and South America.

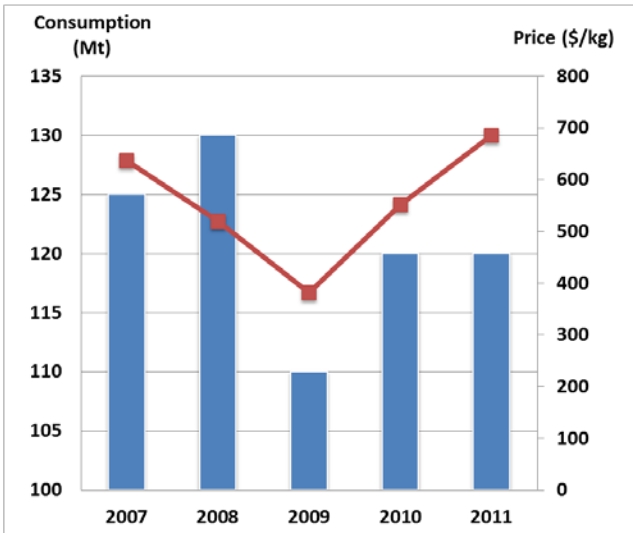
Primary Sources of U.S. In Imports
U.S. Import Dependence = 100% (2011)



Due to recent high ITO prices, several potential substitutes are being developed; however, use of any of these potential substitutes will be available, at the earliest, in 2014. Substitutes for some of indium's minimal uses are available. Gallium arsenide can substitute for indium phosphide in solar cells and in many semiconductor applications. Hafnium can replace indium in nuclear reactor control rod alloys.

Defense use of indium is minimal when compared with total domestic consumption.

U.S. Apparent Consumption and Metal Price



Stockpile Inventory
0 metric tons

Predicted Shortage
69 metric tons

Is indium recycled, reused, or recovered?

Indium is most commonly recovered from ITO. Sputtering, the process in which ITO is deposited as a thin-film coating onto a substrate, is highly inefficient. ITO scrap recovery is concentrated in China, Japan, and the Republic of Korea; the countries where ITO sputtering is taking place.

Sources

Alfantazi, A.M. Moskalyk, R.R. *Processing of indium: a review*, Minerals Engineering, 16 (2003) 687-694.

Greling, P.T. *InP-based microelectronics pilot line for commercial and military applications*, Hughes Research Laboratories.

http://en.wikipedia.org/wiki/Indium

U.S. Geological Survey, Mineral Commodity Summaries, 2012– Indium

Prepared by Adam Carroll, 865-576-7505, carrollaj@ornl.gov

LEAD

What is lead?

Lead (Pb, Z=82) is a heavy metal with a low melting point (327°C), making it easy to cast into form and use as a solder. Lead has a bluish-white color but commonly has an oxide layer giving it a dull gray look.

Where is lead found?

Lead is primarily mined domestically in Alaska and Missouri. Combined, these two states yield more than 90% of domestic production. Other producing states include Idaho, Montana, and Washington.

China is the largest producer of lead accounting for about 49% of global production. China is followed by Australia, and the United States, producing 12% and 8%, respectively.

World Mine Production (Thousand MT)		
	2010	2011
United States	369	345
Australia	625	560
China	1,850	2,200
Mexico	158	225
Peru	262	240
Other countries	880	930
World Total	4,140	4,500

What are the common uses of lead?

The lead-acid battery industry is the principal lead consumer, accounting for about 86% of all U.S. lead consumption in 2011.

- Batteries (lead-acid used in automobiles, uninterruptible power supplies, industrial-type batteries)
- Cable sheeting
- Solder
- Shielding (X-ray machines)

What are the important defense applications of lead?

- Lead-acid batteries (vehicles, generators)
- Ammunition
- Solder
- Cable Sheeting
- Shielding (X-ray machines)

What are some of the energy-related uses of lead?

- Radiation shielding (research facilities)

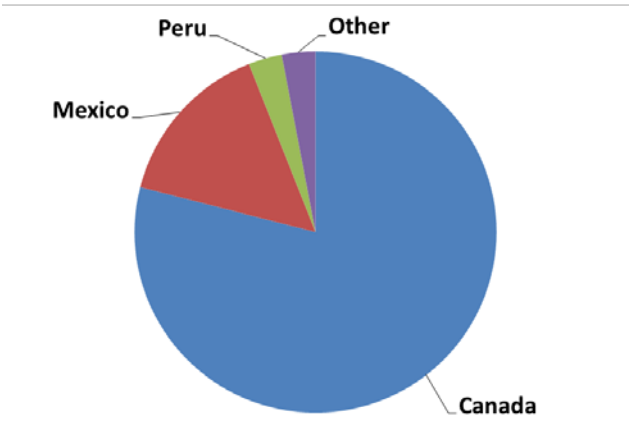
What are the risks associated with the supply of lead?

In 2011, the United States was the third largest producer of primary lead as well as the produced 1.2 million tons of secondary lead; this is equivalent to 80% of reported domestic consumption. Due to high levels of domestic recycling and mining, the United States is a net exporter of lead.

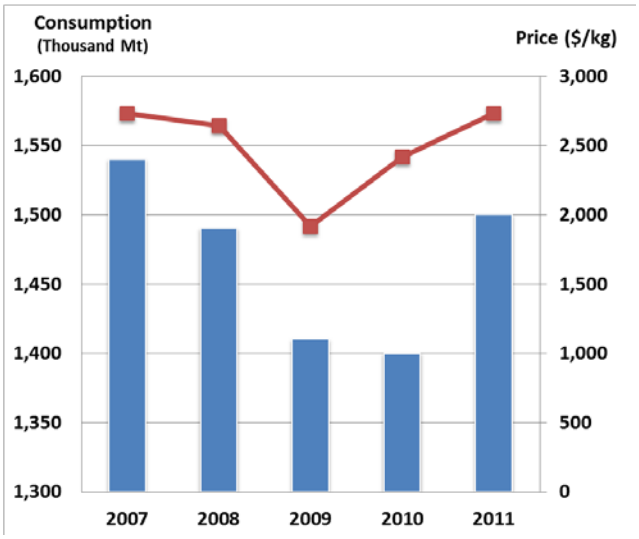
How are these risks being managed?

There are multiple mining operations producing lead, plus multiple recycling locations. Secondary lead is largely recovered from lead-acid batteries.

Primary Sources of U.S. Pb Imports
U.S. Import Dependence = 0% (2011)



U.S. Apparent Consumption and Metal Price



Stockpile Inventory
0 metric tons

Predicted Shortage
0 metric tons

Currently, the demand for this type of battery is still increasing, meaning the supply of secondary lead from this source will continue.

Consumption of lead can be reduced by substituting plastic in cable coverings, using lead-free solders, and replacing lead-acid batteries with nickel-hydride or lithium batteries.

Is lead recycled, reused, or recovered?

Lead is recycled primarily from lead-acid batteries and then mostly returned back to that use.

Sources

http://en.wikipedia.org/wiki/Lead

U.S. Geological Survey, Mineral Commodity Summaries, 2012– Lead

Prepared by Adam Carroll, 865-576-7505, carrollaj@ornl.gov

SELENIUM

Photo Courtesy of images-of-elements.com

What is selenium?

Selenium (Se, Z=34) is a purplish-gray nonmetal semiconductor with an unusual property: its conductivity is proportional to the intensity of light shined onto it. Also, selenium can produce electricity directly from sunlight, making it useful in solar cells.

Where is selenium found?

Selenium is recovered from refining copper ore; both selenium and tellurium become concentrated in the slimes. One copper refinery in Texas processes the slime to recover selenium. Other copper refineries export the slime for processing.

What are the common uses of selenium?

Selenium is largely consumed in metallurgy and the manufacturing of glass.

- Glass
- Electrolytic manganese (selenium dioxide)
- Additive to cast iron, copper, lead, and steel alloys to improve machinability
- Lead-acid batteries (small quantity in support grids)
- Rubber (vulcanization catalysts)
- Surge protectors (voltage suppressor)
- Pharmaceutical (dandruff shampoo, antifungal agent)

What are the important defense applications of selenium?

- Lead-acid batteries (0.02% selenium by weight in low-antimony lead batteries)

World Mine Production (MT)		
	2010	2011
United States	W*	W*
Belgium	200	200
Canada	79	95
Chile	90	90
Germany	650	650
Japan	753	630
Russia	140	140
Other Countries	210	200
World Total	2,120**	2,000**

** Withheld data to avoid disclosing proprietary information*
*** Excludes U.S. production*

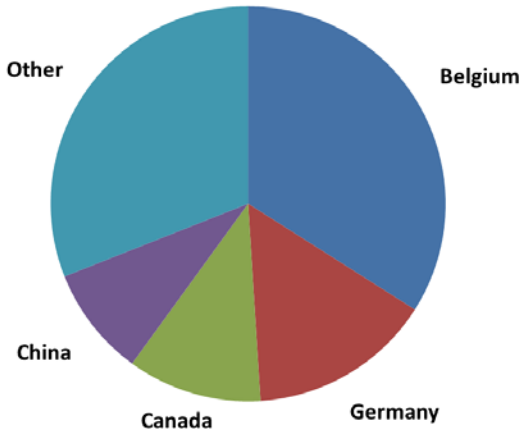
What are some of the energy-related uses of selenium?

- Solar cells (copper indium gallium diselenide, CIGS)

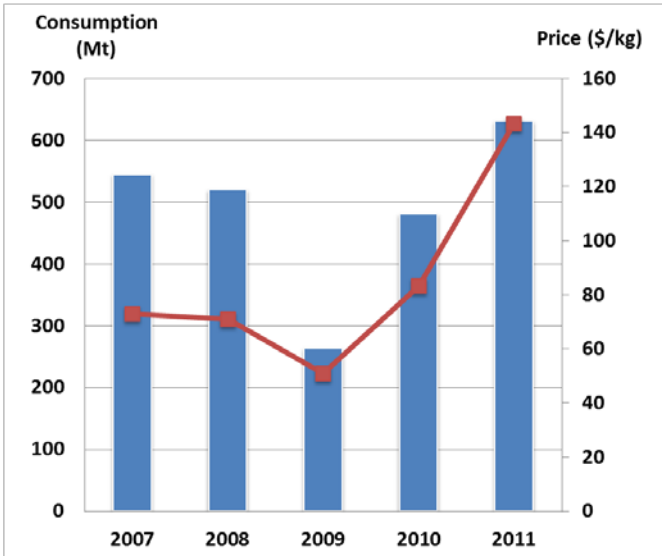
What are the risks associated with the supply of selenium?

The United States has sufficient capacity to fully satisfy domestic demand. The excess production is exported primarily to Germany, China, Republic of Korea, and Australia.

Primary Sources of U.S. Se Imports
U.S. Import Dependence = 0% (2011)



U.S. Apparent Consumption and Metal Price



Stockpile Inventory
0 metric tons

Predicted Shortage
0 metric tons

Is selenium recycled, reused, or recovered?

Selenium can be substituted in many of its applications. High-purity silicon can be used in low- and medium-voltage rectifiers and solar photovoltaic cells. Cerium oxide can be used as a colorant or decolorant in glass. Bismuth, lead, and tellurium can be used as an additive to improve free-machining alloys and lead-free brasses. Sulfur dioxide can be used as a replacement for selenium dioxide in the production of electrolytic manganese metal.

Sources

http://en.wikipedia.org/wiki/selenium

U.S. Geological Survey, Mineral Commodity Summaries, 2012– Selenium

Prepared by Adam Carroll, 865-576-7505, carrollaj@ornl.gov

SILICON

Photo Courtesy of images-of-elements.com

What is silicon?

Silicon (Si, Z=14) is a bluish-gray metalloid that composes over 25% of the earth's crust, by weight. Silicon rarely occurs as a native element but is commonly found combined with oxygen to form silicon dioxide (silica).

Where is silicon found?

Silicon is highly prevalent in the earth's crust and is primarily mined as silica in quarries. Domestically, three companies produce silicon materials, ferrosilicon, and metallurgical-grade silicon metal.

Silicon is produced in over a dozen nations. China is the single largest producer accounting for approximately two-thirds of global supply.

What are the common uses of silicon?

Silica is the most consumed form of silicon, it is used in manufacturing ceramic bricks, Portland cement, gravel, and concrete. Silicon is commonly alloyed with iron to make ferrosilicon and added to aluminum to improve casting properties. Only about 5% of total silicon metal demand is for semiconductor-grade metal.

- Semiconductors
- Cast aluminum
- Iron and steel production (ferrosilicon)
- Chemicals (silanes, silicones)
- Cutting tools (silicon carbide)

What are the important defense applications of silicon?

- Semiconductors (computers, communications, electronics)
- Steel (ferrosilicon consumed in manufacturing)

World Mine Production (MT) Ferrosilicon

	2010	2011
United States	176	350
Brazil	224	230
Canada	52	52
China	4,920	5,400
Norway	303	320
Russia	643	670
South Africa	137	130
Other Countries	840	850
World Total	7,290	8,000

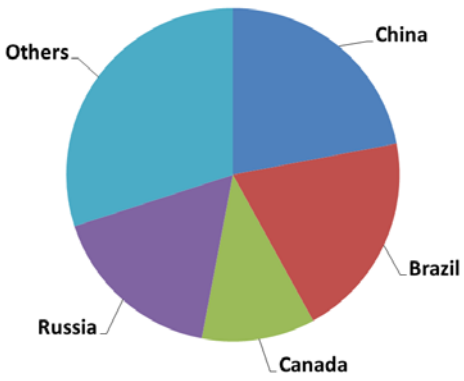
What are some of the energy-related uses of silicon?

- Solar cells
- Semiconductors (electronics)

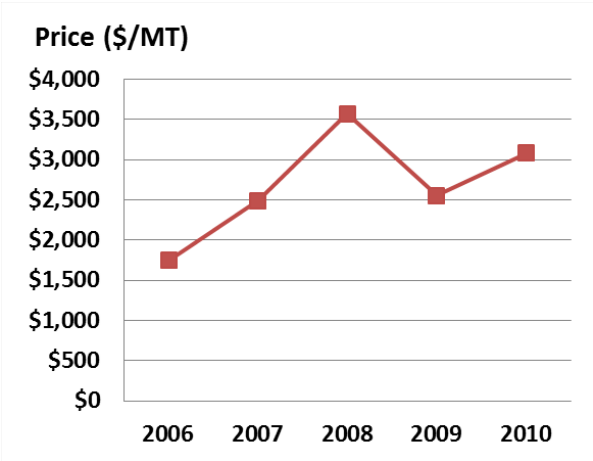
What are the risks associated with the supply of silicon?

The United States is a net importer of ferrosilicon and silicon metal. Domestic production of silicon metal occurs at two facilities: one in West Virginia, the other in New York. Ferrosilicon is produced in various grades by two companies at four plants.

Primary Sources of U.S. Total Si Imports
U.S. Import Dependence = 50% (2011)



U.S. Price of Si Metal



Stockpile Inventory
0 metric tons

Predicted Shortage
0 metric tons

How are these risks being managed?

There is little risk to the supply of silicon. Domestic production accounts for approximately half of total domestic consumption and exceeds defense consumption.

In addition to domestic sources, there is significant production of both silicon metal and ferrosilicon in Canada.

Sources

http://en.wikipedia.org/wiki/Silicon

U.S. Geological Survey, Mineral Commodity Summaries, 2012– Silicon

Prepared by Adam Carroll, 865-576-7505, carrollaj@ornl.gov

SILVER

Photo Courtesy of images-of-elements.com

What is silver?

Silver (Ag, Z=47) is a very ductile and malleable metal with the highest thermal and electrical conductivity of all metals, and it can be polished to a mirror quality shine making it excellent for jewelry and fine utensils.

Where is silver found?

Silver is domestically produced as a by-product at 35 mines, with production in Alaska exceeding all other states. Silver is commonly mined with other precious and base metals.

What are the common uses of silver?

- Coins, jewelry, and fine utensils
- Electronics (circuit boards, thermal solder)
- Clothing (silver nanoparticles inhibit bacteria and fungi growth)
- Photography (photo film, x-ray film)

What are the important defense applications of silver?

- RFID tags (miniature antenna)
- Electronics
- Mirrors and optics

What are some of the energy-related uses of silver?

- Fission control rods

What are the risks associated with the supply of silver?

The United States is reliant on imports to satisfy domestic consumption. The majority of silver is imported from Mexico (56%) and Canada (25%) with the remainder coming from South America.

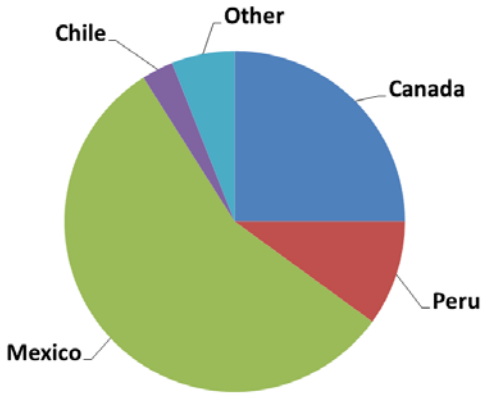
Domestic demand for silver for photography is reducing as digital imaging is expanding to dominate the photography and medical industries.

How are these risks being managed?

Risk to the military supply of silver and essential defense related companies is very low. Silver is extensively mined in several different states and it is heavily recycled due to its high value.

World Mine Production (MT)		
	2010	2011
United States	1,270	1,160
Australia	1,860	1,900
Bolivia	1,260	1.350
Canada	600	700
Chile	1,280	1,400
China	3,500	4,000
Mexico	4,410	4,500
Peru	3,640	4,000
Poland	1,180	1,200
Russia	1,150	1,400
Other Countries	2,950	2,200
World Total	23,100	23,800

Primary Sources of U.S. Metal Ag Imports
U.S. Import Dependence = 64%* (2011)
(*includes recycling)



Stockpile Inventory
0 metric tons

Predicted Shortage
80 metric tons

Is silver recycled, reused, or recovered?

Approximately 22% of apparent consumption is recycled from old and new scrap.

Are there substitutes for silver?

Silver substitutes exist for nearly all applications. Stainless steel can be used to manufacture utensils. Aluminum and rhodium may be used to replace silver used in mirrors and optics.

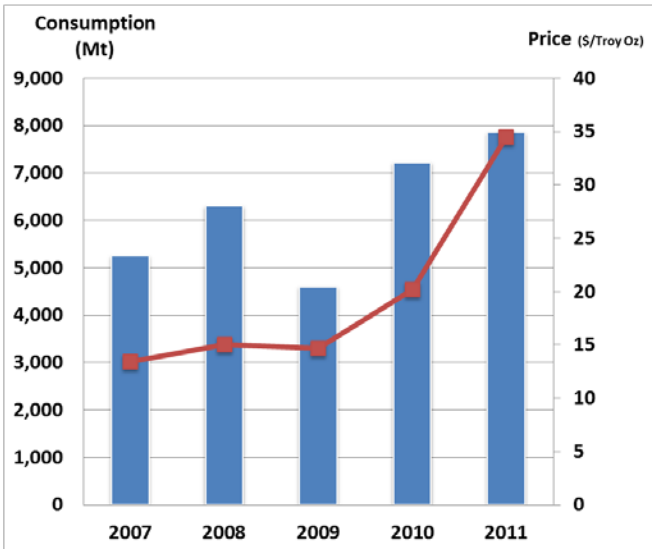
Sources

http://en.wikipedia.org/wiki/Silver

U.S. Geological Survey, Mineral Commodity Summaries, 2012– Silver

Prepared by Adam Carroll, 865-576-7505, carrollaj@ornl.gov

U.S. Apparent Consumption and Metal Price



TELLURIUM

Photo Courtesy of U.S. Army PEO Soldier

What is tellurium?

Tellurium is a brittle silver-white metalloid which appears similar to tin and is mildly toxic to people. Tellurium is primarily alloyed with steel and copper to improve machining and alloyed with bismuth for thermoelectric devices.

Where is tellurium found?

Tellurium is produced primarily from refined copper anode slimes and lead refinery skimmings. Domestically tellurium is produced from a copper refinery in Texas. Worldwide, there are multiple producers across several continents. China is likely the largest producer, but their production quantity is unknown.

What are the common uses of tellurium?

- Alloying additive to steel, copper, lead, and cast iron
- Vulcanizing agent (rubber)
- Pigment (glass and ceramics)
- Thermoelectric devices (bismuth telluride)

What are the important defense applications of tellurium?

- CdZnTe substrates (mid- and long- wave infrared devices)
- Metal alloys
- Thermoelectric devices (sensitive equipment cooling, temperature control applications, power generation)

What are some of the energy-related uses of tellurium?

- Solar cells (CdTe)

WORLD MINE PRODUCTION (MT)		
	2010	2011
United States	W*	W*
Canada	16	20
China	N/A	N/A
Japan	38	40
Peru	30	30
Russia	34	35
Other countries	N/A	N/A
World Total	N/A	N/A

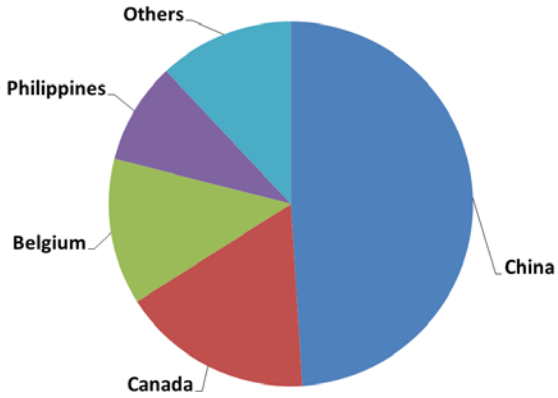
** Withheld data to avoid disclosing proprietary information*

What are the risks associated with the supply of tellurium?

The United States is a significant producer of tellurium, but is still dependent on imports to fully satisfy demand. China supplies nearly half of U.S. imports of tellurium.

There is little or no tellurium scrap to recycle or recover secondary tellurium. Currently, there is no domestic secondary recovery effort, but a very small quantity is recovered from scrapped selenium-tellurium photoreceptors in Europe.

Primary Sources of U.S. Te Imports
U.S. Import Dependence N/A

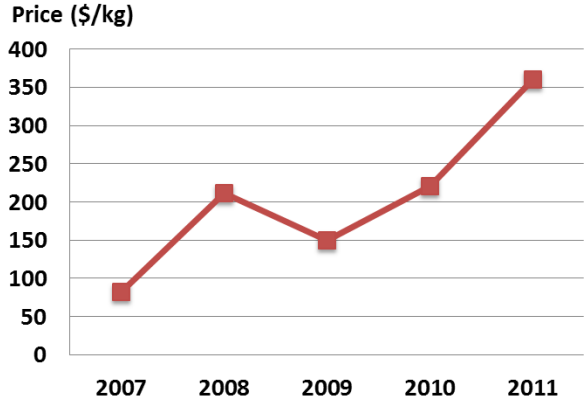


How are these risks being managed?

China is likely the single largest producer of tellurium. However, there is a domestic refiner with the capacity to satisfy at least demand for defense. Also, several other countries produce significant quantities of tellurium reducing the risk to supply.

There are several substitutes for tellurium in most applications, but usually with a loss of performance. Bismuth, calcium, lead, phosphorus, selenium, and sulfur can be used in place of tellurium in many free-machining steels. Sulfur and/or selenium can act as vulcanization agents in place of tellurides. There is no substitute for telluride in thermoelectric devices.

U.S. Price of Te Metal



Stockpile Inventory
0 metric tons

Predicted Shortage
1 metric ton

Is tellurium recycled, reused, or recovered?

No secondary tellurium is domestically produced.

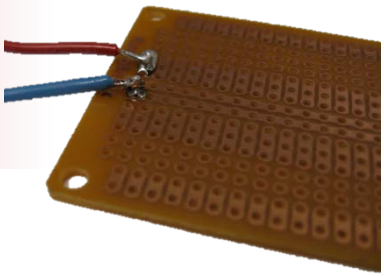
Sources

http://en.wikipedia.org/wiki/Tellurium

U.S. Geological Survey, Mineral Commodity Summaries, 2012– Tellurium

Prepared by Adam Carroll, 865-576-7505, carrollaj@ornl.gov

Tin



What is tin?

Tin (Sn, Z=50) is a silvery, corrosion-resistant metal, commonly plated onto steel and other metals to inhibit rust. It is also alloyed with lead to form solder and cable sheathing.

Where is tin found?

U.S. sources of tin are primarily located in Alaska; however, those resources are insignificant when compared with those of western Africa, southeastern Asia, South America, and Australia. Tin is not domestically recovered.

What are the common uses of tin?

Tin is largely used for tinplating, solder, chemicals, and alloys.

- Bearings (Babbitt metal)
- Containers (tin plated steel)
- Solder (lead-tin alloy, lead-free)
- Bronze and brass
- Chemicals (PVC plastic stabilizer, wood preservative, anti-biofouling agent)
- LCD TVs, touch screens, portable electronics (indium tin oxide)

What are the important defense applications of tin?

- Solder
- Bearings
- Electronics (indium tin oxide)
- Containers

What are some of the energy-related uses of tin?

- Solder
- Solar cells

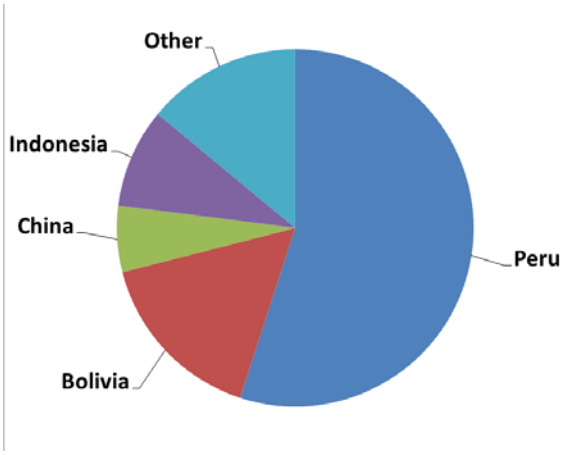
World Mine Production (MT)		
	2010	2011
United States	0	0
Australia	7,000	8,000
Bolivia	20,200	20,700
Brazil	11,000	12,000
China	120,000	110,000
Congo	6,700	5,700
Indonesia	56,000	51,000
Malaysia	1,770	2,000
Peru	33,800	34,600
Russia	1,100	1,000
Vietnam	5,500	6,000
Other Countries	2,000	2,000
World Total	265,000	253,000

What are the risks associated with the supply of tin?

Most tin used in the United States is imported from South America (71%) and Asia (15%). Domestically, tin has not been mined or smelted for nearly two decades. However, the United States is the largest producer of secondary tin, which accounts for more than one-quarter of total U.S. consumption (29%).

The global demand for tin is expected to increase in the near term due to increasing use of “lead-free” solder which utilizes a higher percent of tin. The U.S. demand for tin has been decreasing over the

Primary Sources of U.S. Metal Sn Imports
U.S. Import Dependence = 76%* (2011)
(Includes Recycling)



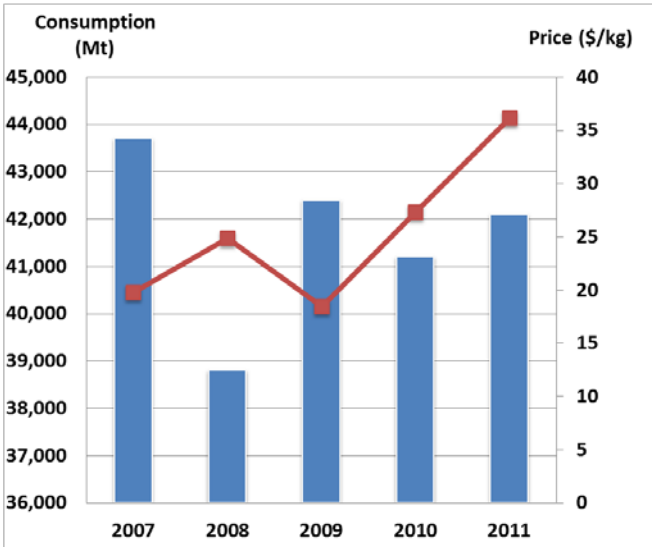
last several years as manufacturing of electronic devices (solder) has shifted from the United States.

How are these risks being managed?

As already mentioned, more than one-quarter of the U.S. consumption comes from domestic recycling. There are two primary tin recovering companies and multiple smaller scale facilities.

Tin is imported from multiple countries on two continents: South America (Peru, Bolivia, and Brazil) and Asia. Multiple sources minimizes the risk of a supply issue.

U.S. Apparent Consumption and Metal Price



Stockpile Inventory
3,956 metric tons

Predicted Shortage
14,944 metric tons

A strategic stockpile of about 4,000 mt is stored in Hammond, Indiana. The stockpile can be utilized under orders of the President to mitigate a supply issue and ensure adequate military supply.

Tin substitutes exist for nearly all applications. Aluminum, glass, paper, plastic, or tin-free steel can be substituted for tin-plated containers. Epoxy resins can replace some solders. Aluminum alloys, copper-base alloys, and plastic can replace tin for bearing materials. Compounds of lead and sodium can be used for some tin chemicals.

Is tin recycled, reused, or recovered?

Approximately 29% of apparent consumption is recycled from old and new scrap.

Sources

http://en.wikipedia.org/wiki/Tin

U.S. Geological Survey, Mineral Commodity Summaries, 2012– Tin

Prepared by Adam Carroll, 865-576-7505, carrollaj@ornl.gov

ZINC

Photo Courtesy of images-of-elements.com

What is zinc?

Zinc (Zn, Z=30) is a silvery-white metal with a relatively low melting point. It can be alloyed with copper to form bronze and brass.

Where is zinc found?

Zinc is typically found with other base metals including copper and lead. U.S. production of zinc occurs in Alaska, Idaho, Missouri, and Tennessee at 13 mines. Alaskan production accounts for greater than 85% of total domestic production and far exceeds production in the other three states.

What are the common uses of zinc?

Over half of all zinc is consumed in galvanizing steel.

- Galvanized steel (chain-link fence, metal roofing, automotive structures, etc.)
- Bronze and brass
- Antifouling paint (zinc oxide)
- Solder (lead-free solder)

What are the important defense applications of zinc?

- Solder
- "Zinc air" batteries

What are some of the energy-related uses of zinc?

- Solder
- Solar cells

What are the risks associated with the supply of zinc?

The United States is 73% reliant on the importation of zinc to satisfy consumption. The majority of zinc imported is from Canada (67%). Zinc is also imported from Peru (12%), Mexico (12%), and others (9%).

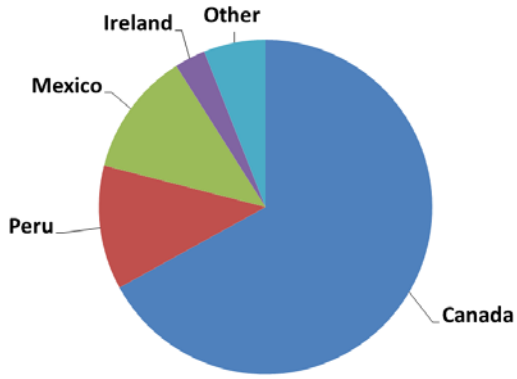
The global demand for zinc is expected to increase driven by the recovering global economy, with the majority of the increase from galvanized steel, zinc-based alloys, bronze, and brass.

World Mine Production (Thousand MT)		
	2010	2011
United States	748	760
Australia	1,480	1,400
Bolivia	411	430
Canada	649	660
China	3,700	3,900
India	700	790
Ireland	342	350
Kazakhstan	500	500
Mexico	518	630
Peru	1,470	1,400
Other Countries	1,490	1,600
World Total	12,000	12,400

How are these risks being managed?

The United States exports zinc ore and concentrates primarily to Canada for processing into zinc slabs; the slabs are then imported back into the United States for consumption. In addition to Canada, zinc is also imported from Mexico, Peru, and Ireland. With multiple sources, the risk to supply is reduced.

Primary Sources of U.S. Metal Zn Imports
U.S. Import Dependence = 73%* (2011)
(*includes recycling; slab zinc)

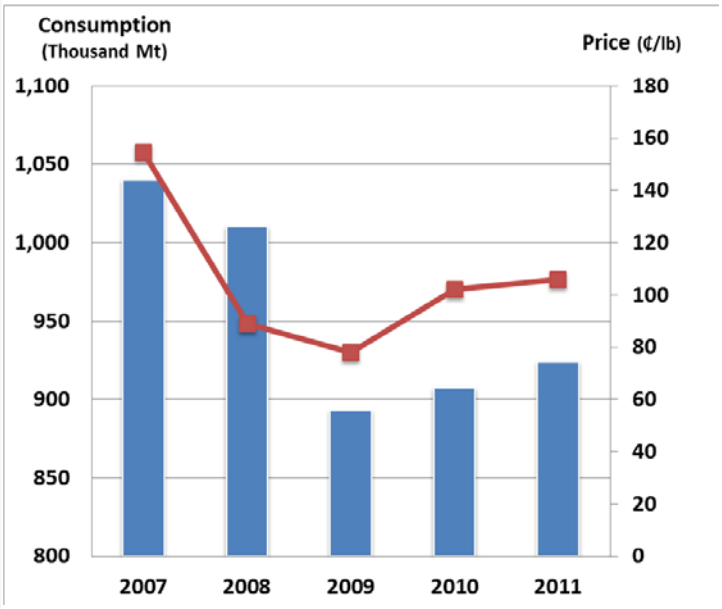


A strategic stockpile of 7,512 mt can be utilized under orders of the President to mitigate a supply issue and ensure adequate military supply.

Are there substitutes for zinc?

Zinc substitutes exist for nearly all applications. Aluminum, plastic, and non-zinc based plated steel can be utilized instead of galvanized steel.

U.S. Apparent Consumption and Metal Price



Stockpile Inventory
7,512 metric tons

Predicted Shortage
7,512 metric tons

Aluminum, magnesium, and plastics are possible substitutes for die-casting of zinc alloys. Aluminum and certain plastics can be used in place of brass. Tin- and lead-based solders can be manufactured without zinc.

Is zinc recycled, reused, or recovered?

Approximately 15% of apparent consumption is recycled from old and new scrap.

Sources

http://en.wikipedia.org/wiki/Zinc

U.S. Geological Survey, Mineral Commodity Summaries, 2012– Zinc

Prepared by Adam Carroll, 865-576-7505, carrollaj@ornl.gov

Al_2O_3 Fused Alumina Abrasives

Photo Courtesy of Simon Eugster
www.wikipedia.com

What is alumina?

Aluminum oxide, also known as alumina or corundum, is used extensively as an abrasive in a wide variety of industrial applications. Corundum can be found in nature, but is often impure and not available in large quantities. Natural corundum is found in metamorphic and igneous rocks such as syenite, nepheline, and pegmatite. Most of the fused alumina abrasive produced is by processing of bauxite ore with the Bayer process. The synthetic corundum is of high quality and cost competitive with natural sources. Three grades of fused alumina currently exist.

Brown alumina is produced from bauxite that is not of metallurgical grade. It is characterized by its high hardness, good toughness, and sharp shape in particles. This makes it suitable for grinding metals of high-tensile strength such as carbon steel, general purpose alloy steel, malleable cast-iron, and hard bronze.

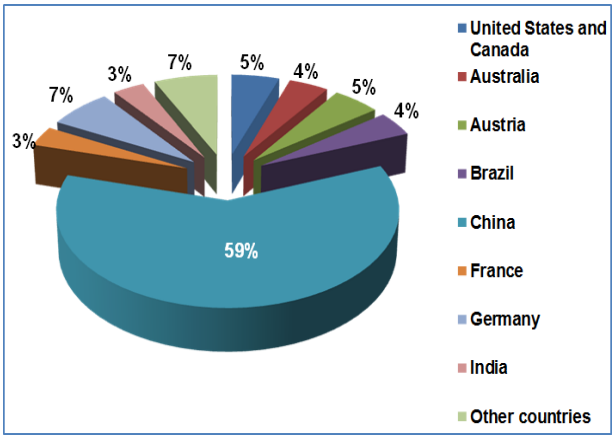
White fused aluminum oxide is made from high-grade alumina powder. It has higher hardness and slightly lower toughness than brown fused aluminum oxide. Characterized by its high purity, strong grinding ability, abrasive tools made of it are suitable for grinding and polishing of cutting tools, precision-castings, spraying and coasting, medium body for chemical industry applications, special ceramics, and high-grade refractory materials.

Pink fused aluminum oxide contains chromium oxide, which gives the material its pink color. The incorporation of the Cr_2O_3 into the Al_2O_3 crystal lattice produces a slight increase in toughness and a reduced friability compared with white fused alumina. Grinding wheels made of pink aluminum oxide have the features of outstanding durability and producing fine surface finish. Suitable for precision grinding applications with metrology instruments, engine crankshafts, instrument parts, threads, and samplers.

Where is alumina found?

China is the major producer of fused alumina, while the U.S. production is small.

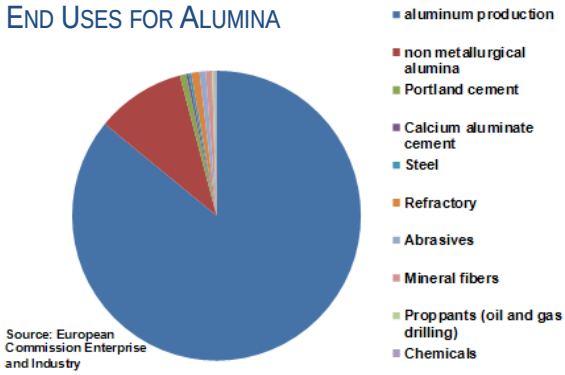
2010 World Mine Production Capacity for Fused Aluminum Oxide (1,190,000 Mt)



What are the common uses of alumina?

Corundum is very hard and is used as an abrasive in the manufacture of sandpaper, polishing compounds, and cutting tools. For abrasive applications, alumina can be used in industrial applications such as grinding operations, pressure blasting, and mass finishing. Abrasive alumina can cut, clean, or polish materials such as metals, wood, glass, ceramics, marble, granite, and other stones.

End Uses for Alumina



It can also be used to clean very large surfaces (e.g., rust removal on a bridge or ship) or small and precise components (e.g., electronic parts or medical devices).

What are the important defense applications of alumina?

Abrasive materials are vital for the finishing of military equipment and for its maintenance (i.e., rust removal).

What are some of the energy-related uses of alumina?

Fused alumina is important to the aircraft and automotive industries as well as almost all categories of energy production (e.g., wind energy).

What are the risks associated with the supply of alumina?

In 2010, the net import reliance for fused alumina was 100%, with most of the imports for fused alumina being from China.

Are there substitutes for alumina?

Natural and manufactured abrasives, such as garnet, emery, or metallic abrasives, can be substituted for fused aluminum oxide and silicon carbide can also be used in various applications.

Is alumina recycled, reused, or recovered?

Up to 30% of fused aluminum oxide may be recycled.

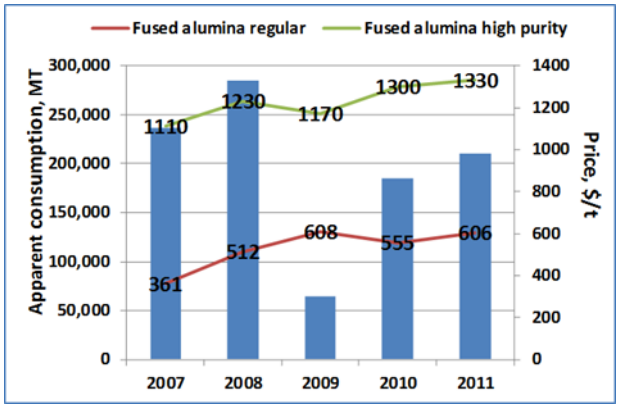
Stockpile Inventory

0 metric tons

Predicted Shortage

238,500 metric tons in base case
14,170 metric tons in alternate case

U.S. Apparent Consumption (MT) and Material Price



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Prepared by Catherine Mattus, 865-574-6793, mattusch@ornl.gov

ALUMINUM

Photo Courtesy of U.S. Navy

What is aluminum?

Aluminum is a silvery white metal. It is the third most abundant element (after oxygen and silicon) and makes up about 8% of the earth's weight percentage. It is not found in its elemental state but rather in over 270 different minerals. Of its many isotopes, only ^{26}Al and ^{27}Al occur naturally.

Where is aluminum found?

Feldspars, the most common group of minerals in the earth's crust, are aluminosilicates, but almost all metallic aluminum is produced from the ore bauxite. Large deposits of bauxite occur in Australia, Brazil, Guinea, and Jamaica and the primary mining areas for the ore are in Australia, Brazil, China, India, Guinea, Indonesia, Jamaica, Russia, and Surinam.

What are the common uses of aluminum?

Aluminum is the most widely used non-ferrous metal. During, end use of aluminum products were as follows in the United States and Canada:

- Transportation – 34%
- Containers and packaging – 27%
- Building and construction – 12%
- Electrical – 8%
- Machinery and equipment – 8%
- Consumer durables – 7%
- Other markets – 4%

What are the important defense applications of aluminum?

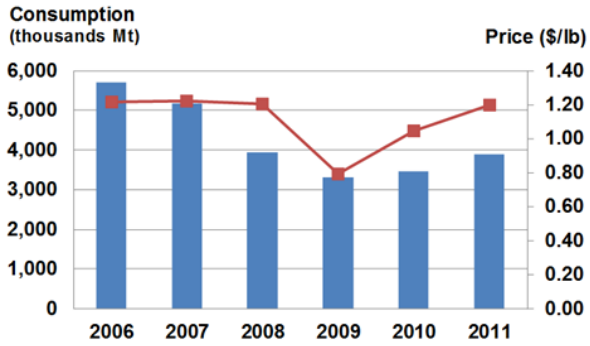
- Structural airframe material for aircraft construction (80 wt% in F-16, 54.7wt% in F-117, 31 to 49 wt% in F-18, 15 wt% in F-22, 39% in V-22, and 17.2 mt in F-35)
- Military and combat vehicles

WORLD SMELTER PRODUCTION (THOUSAND MT)

	2010	2011
United States	1,726	1,990
Australia	1,930	1,930
Bahrain	870	870
Brazil	1,540	1,410
Canada	2,960	2,970
China	16,200	18,000
Germany	394	450
Iceland	780	790
India	1,450	1,700
Mozambique	557	560
Norway	800	800
Qatar	190	390
Russia	3,950	4,000
South Africa	807	800
United Arab Emirates	1,400	1,800
Venezuela	335	380
Other countries	4,900	5,230
World Total	40,800	44,100

- Ship building (More than one million pounds of high-grade aluminum alloys are used in each littoral combat ship.)
- Torpedoes and mines
- Powdered aluminum in solid rocket fuels and thermite
- Guns and launchers

U.S. Apparent Consumption and Metal Price



What are some of the energy-related uses of aluminum?

- Electrical transmission lines for power distribution
- Air conditioning, refrigeration, heat exchange systems
- Transportation systems (light vehicles, rail cars, aircraft)
- Aluminum-ion batteries

What are the risks associated with the supply of aluminum?

Domestic aluminum requirements cannot be met by domestic bauxite resources. In 2011, the net import reliance for aluminum was 38% with major imports from Canada, Russia, China, and Mexico. The world reserves for bauxite are sufficient to meet the world demand for many years.

Non-bauxitic aluminum resources are abundant and could meet domestic aluminum demand. However, processes for using these resources have not been proven economically competitive with those now used for bauxite. The world reserves for bauxite are sufficient to meet world demand for metal well into the future.

Is aluminum recycled, reused, or recovered?

Recycling aluminum requires only 5% of the energy used to produce aluminum from ore. In the United States in 2011, 3.0 million tons of aluminum was recovered from scrap. Aluminum recovered from old scrap (discarded aluminum products) was equivalent to about 36% of the annual apparent consumption. In Europe, aluminum experiences high rates of recycling, ranging from 42% of beverage cans, 85% of construction materials, and 95% of transport vehicles.

Stockpile Inventory

0 metric tons

Predicted Shortage

34,000 metric tons

Are there substitutes for aluminum?

Composites can substitute for aluminum in aircraft fuselages, and wings. Glass, paper, plastics, and steel can substitute for aluminum in packaging. Magnesium, titanium, and steel can substitute for aluminum in ground transportation and structural uses. Composites, steel, vinyl, and wood can substitute for aluminum in construction. Copper can replace aluminum in electrical applications.

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ALUMINUM-BERYLLIUM

Photo Courtesy of U.S. Air Force

What is aluminum-beryllium?

Aluminum-beryllium (AlBe) is a family of low density, high elastic modulus alloys with 10%-75% beryllium. They combine the high specific stiffness of beryllium with the ductility and ease of fabrication of aluminum. Densities of these alloys range from 2.0 to 2.58 g/cc. They were initially created to fulfill the requirements of advanced aerospace designs.

Where is aluminum-beryllium found?

Higher grades of aluminum-beryllium alloys (containing larger percentages of beryllium) are fabricated by the manufacturers of pure beryllium. Only four manufacturers produce these: the lead manufacturer is in the United States, the second is Canadian with a facility in the United States, the third is in Kazakhstan, and the fourth is in China.

What are the common uses of aluminum-beryllium?

- Equipment shelves and support structures, due to its low density, high stiffness, and good vibration damping characteristics
- Computer disc drive armatures
- Heat sinks and radiators
- High-performance sports equipment
- Brakes
- Fabrication of magnesium and magnesium-aluminum alloys (5% Be alloy)

What are the important defense applications of aluminum-beryllium?

- Aviation and space applications (advanced electro-optical targeting and infrared countermeasure devices in fighter aircraft, missiles, and radar systems [40% to 100% beryllium content])
- Electronic components in sensor and guidance equipment for flight and satellite systems
- Optical substrate for head mirrors, night vision systems, and fire control optics
- Structural and components material for satellite such as Air Force's XSS-11 experimental polar-orbiting satellite
- Tracking and targeting optics (i.e., LANTIRN, Sniper, Arrowhead systems, or VLT, M1A2 and M-60 tanks; also, mirrors for NASA's current Hubble Space Telescope and its future James Webb Space Telescope)
- Propellants
- Space launch vehicles

What are some of the energy-related uses of aluminum-beryllium?

- High-performance engine pistons
- High-performance gas-turbine engines

What are the risks associated with the supply of aluminum-beryllium?

Military applications usually require very pure aluminum-beryllium alloys only available in the United States; however, other countries are manufacturing less pure beryllium which can be used in aluminum-beryllium alloys applications that

have less stringent requirements. Two domestic manufacturers offer aluminum-beryllium of high purity (i.e., AlBeMet® and Beralcast®) for use in defense applications.

Aluminum-beryllium alloy is expensive. Cast aluminum (39% beryllium alloy) for an aerospace component: is priced at €200 – €500 per kilogram; its is therefore used only when its properties are crucial.

Is aluminum-beryllium recycled, reused, or recovered?

Pure beryllium metal and high beryllium content alloy components are used in technological applications with extremely long lifetimes, and they therefore return to the recycle stream very slowly. Those used in space or in sensitive military applications do not return at all. Beryllium that is returned can be easily recycled. In 2004, the USGS estimated that 10% of beryllium was recycled in the United States; in 2009, Materion estimated the world recycling rate as being 22 to 25%.

Are there substitutes for aluminum-beryllium?

In some applications, some matrix metal or organic composites, high-strength-grade aluminum, pyrolytic graphite, silicon carbide, steel, or titanium may be substituted for aluminum-beryllium alloys.

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Stockpile Inventory
0 metric tons

Predicted Shortage
Combined with beryllium metal data.

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BAUXITE

PRIMARILY AL(OH)$_3$

Photo Courtesy of images-of-elements.com

What is bauxite?

Aluminum is the third most abundant element in the earth's crust, constituting about 8% of its total mass. Aluminum is extracted from bauxite, a rock composed mainly of aluminum oxide and aluminum hydroxide minerals. These might include gibbsite $Al(OH)_3$, boehmite γ-AlO(OH), and diaspore α-AlO(OH). The rock usually includes other materials such as iron hydroxides, clay, silt, and free silica. It most often occurs as a residual soil material in tropical and subtropical areas. It is the primary source of aluminum.

Bauxites are typically classified according to their intended commercial application: abrasive, cement, chemical, metallurgical, and refractory.

Where is bauxite found?

The following table contains U.S. Geological Survey (USGS) data for the world's mine production and reserve; however, the British Geological Survey provides data for reserves that is much higher, with 7.4 billion tons (BT) in Guinea, 6.2 BT in Australia, 2.1 BT in Vietnam, 2 Bt in Jamaica, and 1.9 BT in Brazil. The USGS indicates that the world resources for bauxite are estimated to total 55 to 75 billion tons (Africa,32%; Oceania, 23%; South America and the Caribbean, 21%; Asia,18%; and elsewhere (6%).

What are the common uses of bauxite?

Bauxite is the most common ore of aluminum. Between 5 and 15% of bauxite is of non-metallurgical grade and is calcined as brown fused alumina for abrasive applications. The remainder is used for the production of alumina by the Bayer refining process. About 90% of the alumina produced in the world is transformed into aluminum metal by electrolysis, the rest is used in the production of non-metallurgical products, such as abrasives, chemicals, and refractories.

WORLD MINE PRODUCTION (MT)		
	2010	2011
United States	NA	NA
Australia	68,400	67,000
Brazil	28,100	31,000
China	44,000	46,000
Guinea	17,400	18,000
India	18,000	20,000
Jamaica	8,540	10,200
Kazakhstan	5,310	5,400
Russia	5,480	5,800
Suriname	4,000	5,000
Venezuela	2,500	4,500
Other countries	7,650	8,480

What are the important defense applications of bauxite?

Aluminum is needed to reduce the weight of military equipment especially airplanes, UAVs, and satellites. Alumina is needed for finishing manufactured equipment.

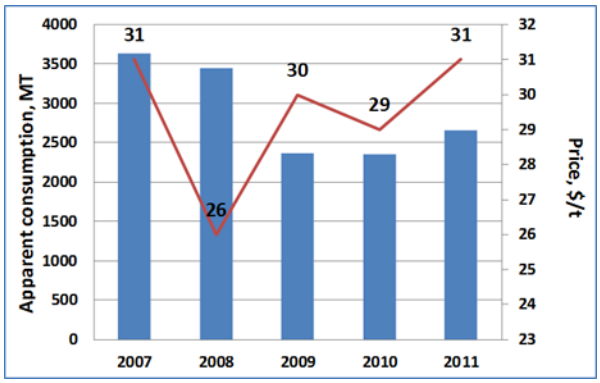
What are some of the energy-related uses of bauxite?

Aluminum is used to lightweight transportation vehicles (e.g., planes, trains, cars) in order to reduce fuel consumption.

What are the risks associated with the supply of bauxite?

In 2010 the net import reliance for bauxite and alumina was 100%, with major importers being Jamaica, Brazil, Guinea, and Australia. The domestic resources of bauxite are inadequate to meet current and long-term U.S. demand. The world reserves of bauxite are very large and present in various continents. Alternative sources of aluminum might someday include kaolin clay, oil shales, the mineral anorthosite, and even coal waste. However, as long as bauxite reserves remain plentiful and production costs are low, the technologies to process these alternative sources into alumina or metallic aluminum will likely not progress beyond the experimental stage. Although it would require new plants using different technology, alumina from these non-bauxitic materials could satisfy the demand for aluminum and alumina.

U.S. Apparent Consumption of bauxite and alumina (in aluminum equivalent) and bauxite Price



Is bauxite recycled, reused, or recovered?

As an ore, bauxite is transformed and cannot be recycled; however, it is possible to produce synthetic bauxite from the recycling of the salt slag used in secondary aluminum production

Are there substitutes for bauxite?

Synthetic mullite, produced from kyanite and sillimanite, can be substituted for bauxite-based refractories. Silicon carbide and alumina-zirconia can substitute for bauxite-based abrasives. Currently there is no substitute for bauxite in the production of aluminum.

Stockpile Inventory

0 metric tons

Predicted Shortage

108,500 metric tons for base case
4,540 metric tons for alternate case

Sources

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Beryl Ore

Photo Courtesy of Gery Parent
www.wikipedia.com

What is beryl ore?

Beryl is a beryllium aluminum silicate mineral $Be_3Al_2(SiO_3)_6$ most often found in granites and granite pegmatites. It can also be found in metamorphic rocks or in limestone and marbles. Beryl is the primary ore of beryllium. Some beryls can be of gem quality such as emerald and aquamarine (green). Beryllium's distribution in the earth's crust is 4 to 6 mg/kg (44th most abundant), and its abundance in sea water is 5.6 ppt.

Where is beryl ore found?

Beryl is found in Europe in Norway, Austria, Germany, Sweden, Ireland, and Russia, as well as in Brazil, Colombia, Madagascar, Mozambique, South Africa, the United States, and Zambia. U.S. beryl locations are in California, Colorado, Connecticut, Idaho, Maine, New Hampshire, North Carolina, South Dakota, and Utah.

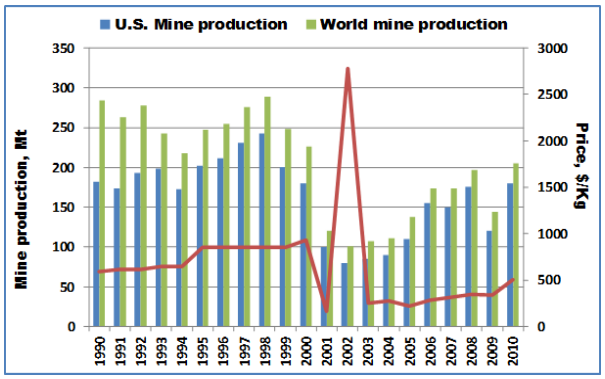
Bertrandite ore mined in Utah makes up nearly all of U.S. production, which represents about two-thirds of the world supply. Russia, Kazakhstan, and China produce most of the rest from beryl ores. Beryllium has been recovered from small deposits in many countries throughout the world, but the production of these mines is sporadic.

The reserves of beryllium in the world have been estimated to be more than 80,000 tons with 65% in the United States. The United States are the largest producer and consumer of beryllium in the world.

What are the common uses of beryl ore?

Three primary beryllium forms are produced from beryl/bertrandite ores. About 70-75% of world beryllium consumption is in high-strength and high-conductivity alloys such as copper-beryllium, aluminum-beryllium, and nickel-beryllium. The second major use is as beryllia ceramic (BeO) with approximately 15% of the world consumption.

U.S. and World Mine Production of Beryl Ore and Beryllium Price



Data are based on a beryllium metal equivalent of 4 percent beryllium in beryl and/or bertrandite ores, calculated as equivalent to beryl ore containing 11 percent BeO

Finally, nuclear and structural applications are last , representing approximately 10%.

- Aviation and space applications
- Satellite and aerospace components
- X-ray tube windows
- Satellite mirrors and space telescopes
- Computer chip heat sinks
- Electronic ignition systems of automobiles
- Automobile suspension
- Non-sparking explosive handling tools
- Undersea oil wellheads and gathering systems
- Electric motors, generators, and alternators
- Fiber optics and lasers
- Air-bag connectors and contacts

What are the important defense applications of beryl ore?

- Windshield frames and other structures in high-speed aircraft and space vehicles
- Aircraft and space shuttle brakes
- Inertial guidance systems and gyroscopes
- Nuclear weapons components

What are some of the energy-related uses of beryl ore?

- Shielding
- Nuclear and fusion power generation
- Neutron moderator or reflector in nuclear reactors

What are the risks associated with the supply of beryl ore?

In 2011, the net import reliance for beryllium was 21% with imports from Kazakhstan, Kenya, Germany, and Ireland. The world's largest company producing beryllium is the U.S. company, Materion. This company has a mine in Utah containing bertrandite, a mineral containing less beryllium than beryl, with reserves sufficient to last about 100 years.

How are these risks being managed?

Mining companies are searching for new sites around the globe. Recently investigations in Afghanistan have shown large reserves of beryllium amongst other metals.

Is beryl ore recycled, reused, or recovered?

Since it is an ore, it is transformed and cannot be recycled.

Are there substitutes for beryl ore?

Other minerals containing beryllium may be used, but new extracting processes for beryllium may have to be found.

STOCKPILE INVENTORY
1 metric ton

PREDICTED SHORTAGE
3,140 metric tons

Most common minerals containing beryllium:

- Beryl $3BeO \cdot Al_2O_3 \cdot 6SiO_2$
- Bertrandite $4BeO \cdot 2SiO_2 \cdot H_2O$
- Chrysoberyl $BeO \cdot Al2O_3$
- Phenacite $2BeO \cdot SiO_2$

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BERYLLIUM

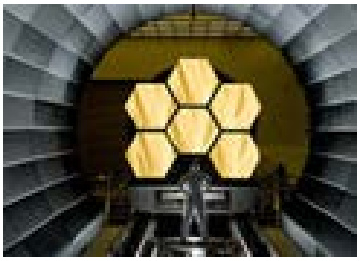


Photo Courtesy of NASA

What is beryllium?

Beryllium (Be, Z=4) is the 44th most abundant element in the earth's crust. Beryllium is a silvery-white, hard and brittle, extremely light metal, which is highly toxic. The mechanical and thermal properties relating to its low density are superior to those of all other materials, making it very useful for structural and electronic applications.

Where is beryllium found?

Beryllium is a relatively rare element at < 6 ppm in the earth's crust. Beryllium is mainly extracted from the mineral beryl, which is obtained from feldspar deposits. Brazil is believed to have the largest beryl mineral reserves in the world.

The United States has significant beryllium resources present as bertrandite and other minerals found in non-pegmatite deposits. World beryllium reserves are not sufficiently defined to permit reporting of consistent data from all sources.

What are the common uses of beryllium?

Beryllium ores are used to make specialty ceramics for electrical, electronic, and high-technology applications. Beryllium-containing metal alloys are used in automobiles, sports equipment, and electrical connectors.

- Battery contacts and electronic connectors
- Windows for X-ray tubes
- Aerospace castings
- High-definition and cable television
- Underwater fiber-optic cable systems
- High-density circuits for high-speed computers and automotive ignition systems
- Pacemakers and other medical devices

WORLD MINE PRODUCTION (MT)		
	2010	2011
United States	180	210
China	22	22
Mozambique	2	2
Other countries	1	1
World Total	205	240

What are the important defense applications of beryllium?

- Airborne forward-looking infrared systems
- Guidance systems on existing strategic missiles
- Surveillance, communications, and other satellites
- Missile defense systems
- Aircraft brakes
- Nuclear warheads

What are some of the energy-related uses of beryllium?

- Neutron reflectors in reactors

What are the risks associated with the supply of beryllium?

Although the United States is not dependent upon imports for its supply of beryllium, military applications require very high quality material that is generally not available from foreign sources. The U.S. Department of Defense's *(DoD) Annual Industrial Capabilities Report to Congress* (February 2005) concluded that even if the beryllium from

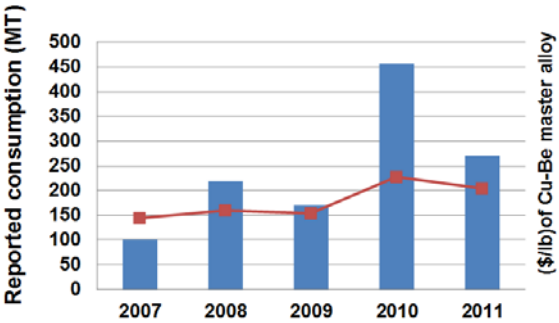
other sources such as Kazakhstan turned out to be pure enough for high-performance strategic applications, the risks were too great.

In addition, the report from the December 2008 Meeting of the DoD's Strategic Materials Protection Board, *Initial Analysis of National Security Issues Associated with Strategic Materials,* concluded high purity beryllium is the only critical material based upon the criteria that defense applications dominate the market; it is essential for important defense systems and unique in the function it performs.

How are these risks being managed?

In an effort to ensure current and future availability of high-quality domestic beryllium to meet critical defense and commercial needs, in 2005 under the Defense Production Act, Title III, DoD invested in a public-private partnership with Materion, the leading U.S. beryllium producer, to build a new primary beryllium facility in Ohio. Construction of the new beryllium facility was completed, but its start-up was extended to January 2012. Nevertheless, Materion still plans to produce at least 50,000 lbs. pebble in 2012.

U.S. Apparent Consumption (MT) and Metal Price



Is beryllium recycled, reused, or recovered?

About 10% of apparent consumption is recycled as primary scrap from manufacturing processes.

Are there substitutes for beryllium?

In some applications, certain metal matrix or organic composites, high-strength grades of aluminum, pyrolytic graphite, silicon carbide, steel, or titanium may be substituted for beryllium metal or beryllium composites. Copper alloys containing nickel and silicon, tin, titanium, or other alloying elements or phosphor bronze alloys (copper-tin-phosphorus) may be substituted for beryllium-copper alloys, but these substitutions can result in substantially reduced performance. Aluminum nitride or boron nitride may be substituted for beryllium oxide in some applications.

Stockpile Inventory

114 metric tons
(hot-pressed powder, vacuum cast ingot)

Predicted Shortage

50 metric tons for base case
100 metric tons for alternate case

Sources

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BERYLLIUM-COPPER

Photo Courtesy of NASA

What is beryllium-copper?

Beryllium alloys are the most common form of beryllium product, accounting for an estimated 75% of the total U.S. beryllium consumption. Beryllium-copper (BeCu) alloys are the most commonly used beryllium products. These alloys are divided into high-strength (typically containing 1.6-2% Be) and high-conductivity (containing around 0.3%- 0.7% Be) types.

Where is beryllium-copper found?

Beryllium-copper master alloy is manufactured by an arc-furnace method in which beryllium oxide is reduced by carbon in the presence of molten copper at 1,800 to 2,000°C. The resulting master alloy usually contains 4.00 to 4.25% beryllium by weight. Other copper-beryllium alloys are produced by melting the master alloy together with virgin copper, copper scrap, and possibly other metals.

What are the common uses of beryllium-copper?

The wrought high-strength alloys contain 1.6 to 2.0% beryllium and approximately 0.3% cobalt. The cast, high-strength alloys have beryllium concentrations up to 2.7%. The high-conductivity alloys contain 0.2 to 0.7% beryllium and higher amounts of nickel and cobalt.

- Electronic connector and relays
- Electrical equipment (e.g., switch and relay blades)
- Automotive electronics
- Springs, switches, and relays in automotive and robot industries
- Airbag collision sensor
- Electric motors, generators, and alternators
- Instrumentation and control systems
- Resistance welding systems
- Molds or casts to make metal, glass, and plastic items
- Housings for magnetic sensing devices,
- Fire suppression systems
- High-strength non-sparking tools
- Plastic injection molding dies

What are the important defense applications of beryllium-copper?

- Bushings and bearings in aircraft and heavy machinery
- Aircraft landing gear
- Electrical and electronic connectors
- Radars
- Fiber optics and lasers
- Electronics (i.e., communication systems, computers, connectors and relays)

What are some of the energy-related uses of beryllium-copper?

- Oil exploration equipment
- Automotive electronics (including the ignition control systems of many modern automobiles used to increase gas mileage)

What are the risks associated with the supply of beryllium-copper?

The United States imported 663 metric tons (mt) of beryllium copper master alloy in 2008 and 205 mt in 2009 (55% from Kazakhstan, 40% from Japan, and 4% from Germany). BeCu in the form of plates, sheets, and strips were also imported, 485 mt in 2008 and 165 mt in 2009 (99% from Japan).

These imports were caused by the absence of beryllium metal production in the United States between 2000 and 2011. Materion, the main worldwide producer, had their pebble plant closed while reconstructing a new one with the help of the U.S. Department of Defense under the Defense Production Act, Title III.

Because the production of Be-Cu does not require the highest purity beryllium, other sources for supply are available. The Canadian company, IBC Advanced Alloys, Inc., manufactures Be-Cu master alloy in Pennsylvania. They have a business agreement with the Kazakh Company ULBA which provides the beryllium metal. The Japanese company, NGK Metals Corporation, is one of the largest producers of BeCu alloy. They have a major plant in Japan and two smaller units, one in the United States (in Tennessee) and the other in France. At least two Chinese companies also produce master alloy.

How are these risks being managed?

The capability for U.S. production of pure beryllium necessary for making Be-Cu alloy was reinstalled with the help of the U.S. Department of Defense.

Is beryllium-copper recycled, reused, or recovered?

Primary BeCu alloy and by-products generated during BeCu production are recovered in a dedicated plant from Materion. Most of the BeCu alloy in scrap is lost to copper during recycling.

Are there substitutes for beryllium-copper?

NAVAIR has funded a SBIR project to design and develop an improved beryllium-free, high-strength copper alloy. QuesTek Innovations LLC developed Cupium® and is testing the product with Lockheed-Martin. Materion has developed new alloys with no beryllium that can be used in place of BeCu.

Stockpile Inventory

0 metric tons

Predicted Shortage

157 metric tons for base case
55 metric tons for alternate case

Sources

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BORON

Photo Courtesy of U.S. Army

What is boron?

Boron (B, Z=5) is a relatively rare element representing only 0.001% of the earth's crust. It is a metalloid with properties that are in-between or a mixture of those of metals and nonmetals. Ordinary elemental boron is a brown-black, amorphous powder. Pure boron can be made into extremely hard yellow monoclinic crystals with semiconductor properties much like silicon. Boron has two naturally occurring and stable isotopes, ^{11}B (80.1%) and ^{10}B (19.9%). Boron does not appear on Earth in elemental form but is found combined in borax, boric acid, or borates. Boric acid is sometimes found in volcanic spring waters. Four borates—colemanite, kernite, tincal, and ulexite—make up 90% of the borates used by industry worldwide.

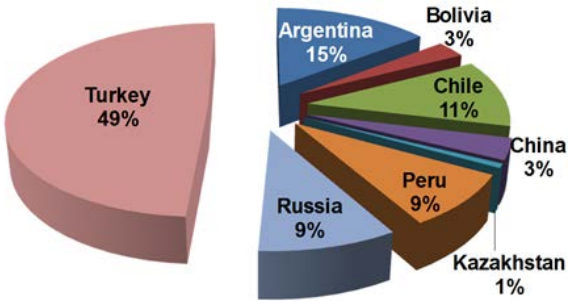
Where is boron found?

In the United States, borax is found in large amounts in California, in Searles Lake brines, and in the Mojave Desert. Most of the boron products consumed in the United States were manufactured domestically.

What are the common uses of boron?

- Borosilicate glass (~80%) and enamels, and glazes (~3%)
- Agriculture/domestic uses (~4%) such as pest controls, soil supplements, agricultural chemicals and fertilizers, antiseptics, and wood preservatives
- Detergent and bleaching agents (~4%)
- Super hard materials (Boron nitride and CNB are alternatives to diamond for coated tools.)
- Abrasives (boron carbide, cubic boron nitride, aluminum boride)
- Component of composite materials (boron fibers) in advanced aerospace structures and for making sports equipment like golf clubs and fishing rods

2011 WORLD PRODUCTION (4,300.000 MT)



- Dopant for semiconductors like silicon, silicon carbide, and germanium (Magnesium diboride is an important superconducting material.)
- Industrial catalyst for many organic reactions, such as polymerization reactions
- Major role in the electroplating of nickel, lead, and tin

What are the important defense applications of boron?

- Triethylborane ignites (Pratt & Whitney J58 turbojet/ramjet, F-1 engines on the NASA Saturn V Rocket)
- Inner plates of ballistic vests and for tank armor (carbon boride)
- Permanent $Nd_2Fe_{14}B$ magnets
- Some use as rocket fuels (boron hydrides)

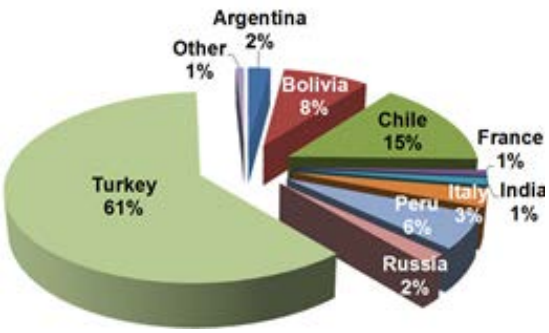
What are some of the energy-related uses of boron?

- In nuclear reactors for reactivity control and in emergency shutdown systems (^{10}B)
- Radiation shielding in nuclear reactors, gas tube neutron radiation detectors for monitoring radiation levels in the Earth's atmosphere and in space
- Insulating fiberglass

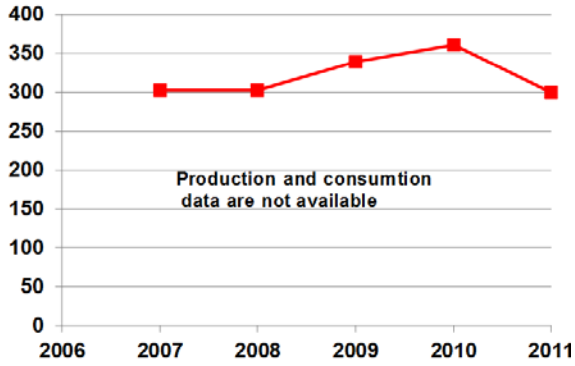
What are the risks associated with the supply of boron?

There is a worldwide increasing demand for boric acid, mostly for insulation industry. Chinese boron producers have been unable to meet rapidly growing demand for high quality borates. This has led to imports of sodium tetraborate (borax) growing by a hundredfold between 2000 and 2005, and boric acid imports increasing by 28% per year over the same period. However, at current levels of consumption, world resources are adequate for the foreseeable future.

2010 U.S. IMPORTS (49,500 MT)



U.S. APPARENT CONSUMPTION (MT) AND METAL PRICE (U.S. $ PER MT)



Is boron recycled, reused, or recovered?

The recycling is insignificant at less than 1% as estimated by the United Nations Environmental Programme

STOCKPILE INVENTORY
0 metric tons

PREDICTED SHORTAGE
0 metric tons

Are there substitutes for boron?

The substitution for boron compounds is possible for detergents (sodium percarbonate, chlorine), enamel (phosphate or lithium glass), insulation (cellulose, foam, mineral wools), and soaps (sodium and potassium salts of fatty acids).

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CARBON FIBERS

Photo Courtesy of U.S. Navy

What are carbon fibers?

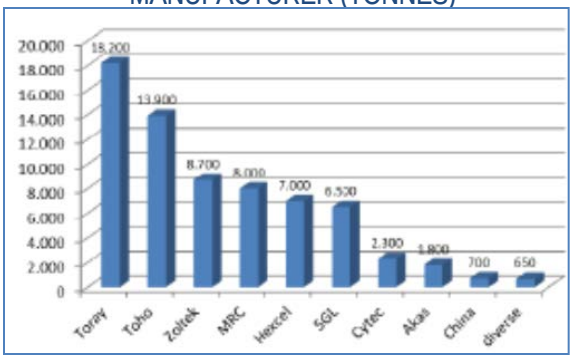
A carbon fiber (CF) is a long, thin strand of material about 5 – 10 µm in diameter and composed of a long chain of bonded carbon atoms. The fibers are extremely stiff, strong, and light. Several thousand carbon fibers are twisted together to form a yarn, which may be used by itself or woven into a fabric. Carbon fibers are produced by the polyacrylonitrile (PAN) or pitch methods. PAN-based carbon fiber is in the largest production and use. Carbon fibers are classified by the tensile modulus of the fiber which can vary from below 240 million kPa to 500 million - 1.0 billion kPa.

Carbon fibers are usually combined with polymer, metal, ceramic, and carbon matrices to form a carbon composite material (CCM).

Where is carbon fiber produced?

Carbon fiber manufacturing is very concentrated with six companies producing nearly 93% of the world's supply. Japanese manufacturers produce about 70% of the world's consumption but have plants located in both the United States and Europe. The United States is the second world producer of CF. Asian countries such as China and India are beginning to enter the CF market.

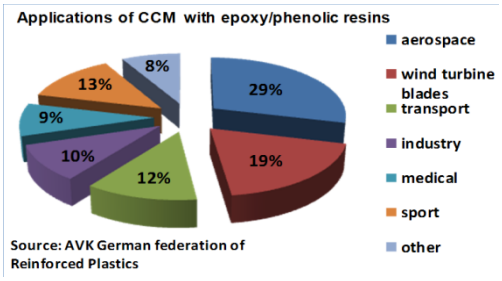
2010 CARBON FIBER CAPACITIES BY MANUFACTURER (TONNES)

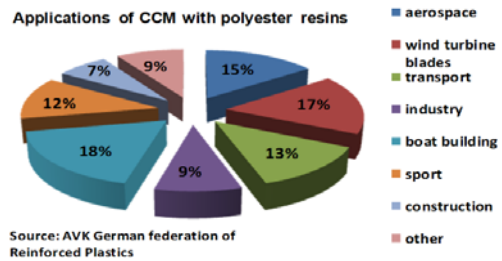


Source: AVK

What are the common uses of carbon fiber?

CF Applications by Industry





What are the important defense applications of carbon fibers?

Carbon fibers and composite materials are used increasingly in newer generations of military equipment and in all branches of the military, for:

- Missiles
- Bomb covers
- Unmanned aerial vehicles
- Aerospace antenna and support structures
- Internal parts for engines (Pratt & Whitney's F-135 and F-119) used in F-35 and F-22 fighter aircraft
- Aircraft structure in parts such as wings, doors, rudder, flaps, nose, forward fuselage, vertical and horizontal tail, wingbox, fairings, speed brake and empennage— 10% CCM used in F-18, ~ 25% in F-22, 26% in Harrier II (AV-8B), ~ 30% in Typhoon and ~ 42% in F-35.
- U.S. Navy's M-80 Stiletto (the largest Navy vessel made primarily with CCM)

- Rotor blades in helicopters (i.e., as in the Block III Apache)
- Weapons
- Land vehicles

What are some of the energy-related uses of carbon fibers?

- Wind energy
- Energy efficient transportation — aircrafts, trains, automotive
- Offshore oil and gas
- Pressure vessels
- Power transmission

What are the risks associated with the supply of carbon fibers?

Forecasts predict that the use of carbon fiber is going to increase rapidly due to the development of renewable energy resources, particularly for wind energy. The automotive sector is using CF for their high price vehicle market due to the high cost of the material. However, if the cost could drop to a reasonable price such as $ 5-7/lb, considerable amounts of CF would be needed and could create a shortfall or higher prices.

Total Global CF Demand (MT)

Industry	2009	2010	2011	2015	2019
Aerospace	5,800	6,410	7,010	13,090	18,100
Consumer	6,420	7,000	7,660	9,410	11,120
Energy and Industrial	21,210	25,870	29,620	66,760	105,060
Total carbon fiber demand	33,430	39,280	44,290	89,260	134,280

Source: www.compositeworld.com/articles/carbon-fiber-market-cautious-optimism

Are carbon fibers recycled, reused, or recovered?

There are two plants, one in the U.K. and one in Japan, that are recycling CF by pyrolysis. Several other plants are planned, including three in the United States. Even though the recycled fibers maintain 90 to 95% of their original properties, their short size do not qualify them for all uses. It is anticipated that the recycled fibers could be directed toward consumer electronics and automotive industries.

Stockpile Inventory
0

Predicted Shortage
Not Available

Are there substitutes for carbon fibers?

Carbon fibers are substituting for other materials because of their unique properties. Substitutes for carbon fibers would likely reverse the current trend and result in loss of performance.

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Prepared by Catherine Mattus, 865-574-6793, mattusch@ornl.gov

Glass Fibers

Photo Courtesy of U.S. Army

What are glass fibers?

Glass fiber is composed of numerous, very fine glass fibers and is generally produced using melt spinning technique. Glass fiber is commonly used as an insulating material, but it can also be used as a reinforcing agent in glass-reinforced plastic (GRP).

Glass fibers can be tailored for various applications:

- Type E (electrical), the most commonly used as electrical insulation tape, textiles, and reinforcement
- Type C (chemical), with superior acid resistance
- Type T for thermal insulation
- Type S-1 (high strength) for use in the wind turbine industry, long fiber reinforcement for thermoplastics (LFT), vehicle armor systems, breathing apparatus bottles, and compressed natural gas (CNG) tanks
- Type S-2 (high strength) used in rocket motor housing, combat vehicle hulls, and composite inserts for ballistic protection (i.e., vests, armor door protection systems)
- Type HS2/HS4 military strength fiber glass is designed to provide effective blast mitigation against improvised explosive devices and other ballistic threats

Where is glass fiber found?

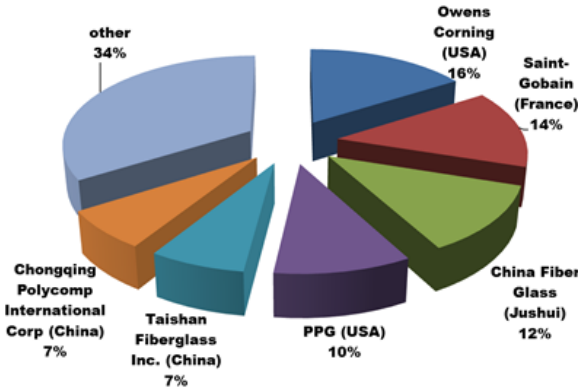
Approximately 78% of the total global glass fiber capacity is provided by the top six glass fiber companies. Over 90% of the glass fiber market is held by E-glass, and about 65% of all composites produced use glass fiber and polyester or vinyl ester resin.

What are the common uses of glass fiber?

The $7 billion global market is distributed as follows:

- Construction (residential, commercial, water transportation and storage) – 32%

2007 Global World Glass Fiber Production



- Transportation (cars, trucks, buses, trains, marine) – 28%
- Industrial (factories, mining, offshore platforms) – 21%
- Consumer (appliances, electronics, recreation) – 11%
- Wind energy – 8%

What are the important defense applications of glass fibers?

- Personal protection (body armor inserts, helmets, shields, anti-mine shoes, gloves)
- Armored vehicles (ballistic panels for floor, door, bodywork, roof, interior)
- Armored aerial vehicles (floor, seat, cockpit for helicopters and aircraft)
- Armored marine vehicles (submarines, shipboard [bridge, compartment])
- Ballistic panels for structural parts (vulnerable buildings, bridges, shelters)
- Fiber optics
- Mine sweeper hulls

- Radomes
- Rocket nozzles

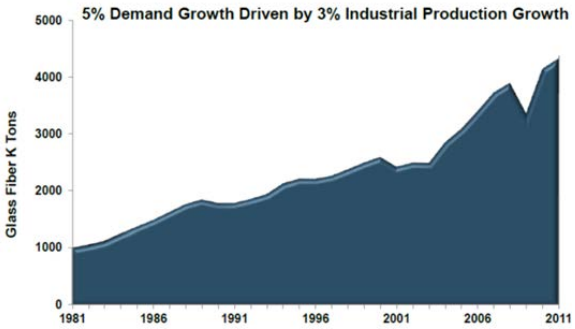
What are some of the energy-related uses of glass fibers?

- Oil industry structures
- Insulating buildings
- Lightweighting vehicles
- Relining large diameter pipes for water and wastewater systems
- Electric power transmission and distribution
- Fabrication of wind turbines blades

What are the risks associated with the supply of glass fibers?

The glass fiber market has rapidly increased by 7.2 percent annually from 2000 to 2010. In 2011 the global glass fiber output was supposed to reach 4.88 million tons while the demand was expected to be 4.86 million tons, almost achieving balance. It is anticipated that in 2012, glass fiber will be in short supply in the world. Prior to 2007 the global glass fiber production occurred mainly in Europe and America, but today China has become both the world's the largest glass fiber producer and consumer. China's apparent consumption of glass fiber was 800,000 tons in 2005 and 3.36 million tons in 2010. About 35% of China's production is for exportation.

2007 Global World Glass Fiber Production (30 years averaging 5% Compound Annual Growth Rate)



Stockpile Inventory

0

Predicted Shortage

Not available

Are glass fibers recycled, reused, or recovered?

At least two commercial facilities in the United States are recycling glass fiber composite. Glass fiber is a listed, recycled commodity.

Are there substitutes for glass fibers?

Carbon, basalt, quartz, ceramic, poly p-phenylene-2,6-benzobisoxazole (PBO), boron, and natural fibers (i.e., abaca, coconut, flax, hemp, jute, kenaf and sisal) are the most common substitutes, which vary depending on the application.

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Prepared by Catherine Mattus, 865-574-6793, mattusch@ornl.gov

GRAPHITE

Photo Courtesy of U.S. Navy

What is graphite?

Graphite is one of four forms of crystalline carbon. Graphite is gray to black in color, opaque, and usually has a metallic luster.

There are three types of natural graphite:

- Amorphous (very small crystal size) is the lowest quality and most abundant type. It results from thermal metamorphism of coal.
- Flake or crystalline is less common and of higher quality than amorphous.
- Vein or lump is the most rare, most valuable, and highest quality type of natural graphite.

Graphite has a melting point of 3,927°C, and is highly refractory. It has a low specific gravity and is the most electrically and thermally conductive of the nonmetals; it is chemically inert.

Where is graphite found?

- *Amorphous:* Large deposits are found in China, Mexico, and the United States.
- *Flake*: The foremost deposits are found in China, Canada, Brazil, and Madagascar.
- *Lump:* It is only commercially mined in Sri Lanka.

No natural graphite was reportedly mined in the United States in 2010, but 118,000 tons of synthetic graphite was produced in 2009.

What are the common uses of graphite?

U.S. apparent consumption of natural and synthetic graphite was estimated to be 21,700 tons and 112,000 tons, respectively. The major uses of natural graphite in 2010 were estimated as follows:

- Foundry operations (amorphous) and steelmaking (amorphous and lump) – 32%

WORLD MINE PRODUCTION (THOUSANDS METRIC TONNES)

	2010	2011
United States	—	—
Brazil	76	76
Canada	25	25
China	600	600
India	140	140
North Korea	30	30
Romania	20	20
Other	34	34
World total	925	925

- Refractory applications (48% of flake graphite used in 2009) and crucibles – 31%
- Brake linings (amorphous graphite) – 8%
- Lubricants – 3%
- Batteries and pencils – 3%
- Other applications (e.g., brushes for electric motors, seals, gaskets, and fuel cells) – 23%

The main market for high-purity synthetic graphite is as a carbon raiser additive in iron and steel, but it is also used for catalyst supports; low-current, long-life batteries; porosity-enhancing inert fillers; powder metallurgy; solid carbon shapes; static and dynamic seals; steel; and valve and stem packing.

What are the important defense applications of graphite?

- Batteries
- Lubricant
- Body armor

- Engine turbine components
- Composite components such as reinforced carbon-carbon or graphite epoxy laminate coating for aircraft manufacturing

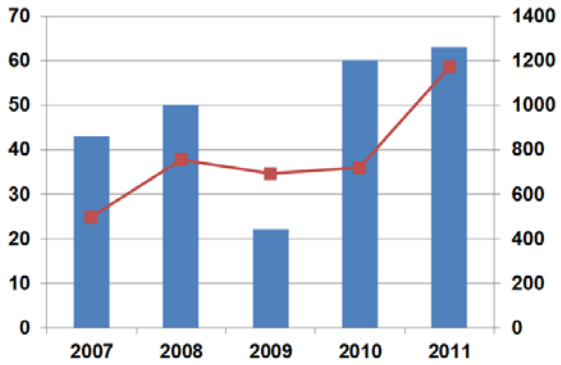
What are some of the energy-related uses of graphite?

- Neutron moderator in nuclear reactors
- Batteries (primary and rechargeable alkaline, lead acid, Zn-air, Li-ion)
- Fuel cells
- Oil drilling

What are the risks associated with the supply of graphite?

In 2010, the net import reliance for natural graphite was 100%, with major suppliers being China (46%), Mexico (23%), Canada (21%) and Brazil(6%). China was the largest producer in the world. The world reserves are in China (85%), India (8%), Mexico (5%), Brazil, and Madagascar (1%). Fuel cells are a potential high-growth, large-volume graphite (natural and synthetic) end use but they represent a very small part of consumption at the present time. End use for this application may increase in the long term.

U.S. Apparent Consumption (MT) and Metal Price (U.S. $ per lb)



Is graphite recycled, reused, or recovered?

The market for recycled refractory graphite material is growing with material being recycled into products such as brake linings, for use in steelmaking industry, and for thermal insulation.

Stockpile Inventory
0 metric tons

Predicted Shortage
0 metric tons

Recovery in steelmaking from kish graphite is feasible but not practiced at the present time. Information on the quantity and value of recycled graphite is not available.

Are there substitutes for graphite?

Manufactured graphite powder, scrap from discarded machined shapes, and calcined petroleum coke compete for use in iron and steel production.

Finely ground coke with olivine is a potential competitor in foundry facing applications. Molybdenum disulfide competes as a dry lubricant but is more sensitive to oxidizing conditions.

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LITHIUM

Photo Courtesy of U.S. Army PEO Soldier

What is lithium?

Lithium is a very reactive, alkali metal. It is silvery shining, tough, and has the lowest density of all metals and is able to strong alloys. Lithium is the lightest of all solid elements. It is silvery white, soft, and reacts immediately with air and water. It is the 27th most abundant element and is found at 60ppm in the earth's crust. Lithium has two natural isotopes ^{6}Li (7.4%) and ^{7}Li (92.6%).

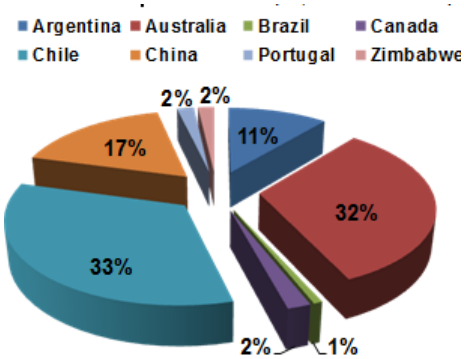
Where is lithium found?

The most important minerals containing lithium are pegmatites such as spodumene ($LiAlSi_2O_6$), petalite ($LiAlSi_4O_{10}$), and lepidolite ($K_2Li_3Al_4Si_7O_{21}(OH,F)_3$). The largest producers are Australia, China, Zimbabwe, and Canada. Lithium-rich brines from salt lakes are the preferred method of lithium recovery with deposits located in the Andes of Chile and Argentina, in the Himalayas of China, and in the U.S. in California and Nevada. The only lithium producing plant in North America is located in Clayton Valley, Nevada. Hectorite clays have unproven production, but are a potential future source.

What are the common uses of lithium?

- In enamels, glass, and ceramics, to lower process melting points, and as a glazing agent, in ceramic (frits) and glass manufacturing
- Batteries and accumulators for disposable batteries; rechargeable lithium-ion batteries used in mobile phones, computers, and optical modulators, and in dry cells and storage batteries
- Lubricant greases used for working in extreme temperature and change conditions
- In metallurgy to lower the melting point of the cryolite bath in primary aluminum production and as an alloy where it can be combined with aluminum, cadmium, copper, or manganese to make high performance aircraft parts
- Chemical uses, such as a reduction agent in the synthesis of many organic compounds, as desiccants, in air conditioning and dehumidification systems, as a catalyst in the production of synthetic rubber, plastics, and pharmaceutical products
- In focal lenses for telescopes (e.g., Mt. Palomar telescope).

U.S. 2010 WORLD PRODUCTION (26,300 MT)



What are the important defense applications of lithium?

- Rocket propellants and oxygen candles to supply submarines and space capsules with oxygen
- Air purification in confined areas, such as on spacecraft or submarines
- Lithium-ion batteries for powering computers in missiles, UAVs, long endurance autonomous systems, tactical vehicles, and Special Forces operations (Used in aircraft such as in the Global Hawk and the JSF/F-35. DoD has funded a DPA Title III project for the production of lithium batteries for long life applications.)

- Al-Li alloys used for aircrafts parts like main wing box, center fuselage, leading and trailing edges, access covers, seat tracks, and wing skins
- Al-Li alloys used as substitute for conventional Al alloys in helicopters, rockets, and satellite systems (for liquid oxygen and hydrogen fuel tanks in aerospace vehicles)
- Nuclear applications (Lithium deuteride was used for the hydrogen bomb, and is now used as a fusion material in modern nuclear weapons.)
- Lubricant greases
- Power generator in the MK-50 Torpedo

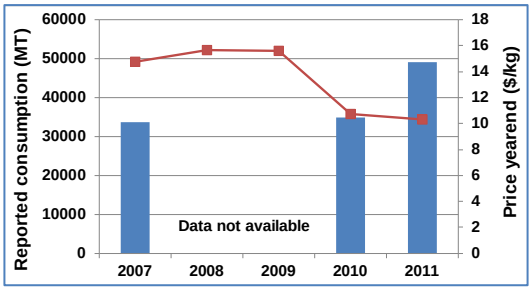
What are some of the energy-related uses of lithium?

- Rechargeable lithium-ion and lithium-polymer batteries used to power instruments and to store energy
- To produce tritium in the ITER nuclear fusion reactor
- To absorb neutrons in nuclear fusion
- As an alpha particle source

What are the risks associated with the supply of lithium?

- In 2010, the net import reliance for lithium was 43% with major import sources Chile, Argentina, and China.
- Lithium consumption increased at a rate of 6% per year between 2000 and 2008, and civil use may increase the demand in future years.

U.S. Apparent Consumption (MT) and Metal Price (U.S. $ per lb)



Stockpile Inventory

0 metric tons

Predicted Shortage

0 metric tons

- Major producers of brines cannot easily increase capacity (risk collapse of water table) while hard rock mining is still relatively expensive and time intensive to start up.

Are there substitutes for lithium?

Sodium and potassium salts in glass and aluminum production, calcium and aluminum soaps as lubricants, composite materials, mercury can be substituted in batteries or Ni-Cd batteries could be used.

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MAGNESIUM

Photo Courtesy of U.S. Navy

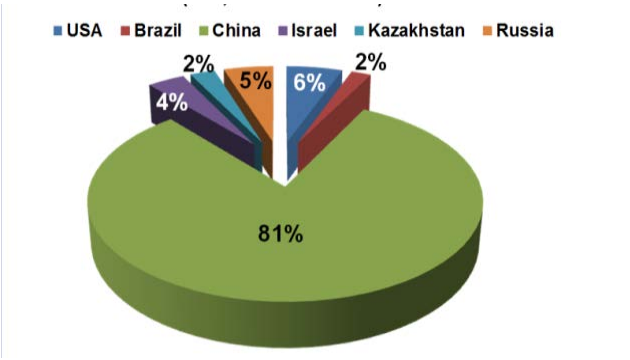
What is magnesium?

Magnesium (Mg, Z= 12) is the eighth most abundant element in the Earth's crust, representing about 2% of its total mass. It belongs to the alkaline Earth metal series. The minerals of commercial importance are dolomite, magnesite, brucite, carnallite, talc, and olivine. Today, magnesium can be extracted from the minerals dolomite ($CaCO_3 \cdot MgCO_3$) and carnallite ($KCl \cdot MgCl_2 \cdot 6H_2O$), but it is most often obtained from seawater or well and lake brines. The metal is silvery white. Two principal production processes are in use today: electrolysis of molten magnesium chloride (the most used) and thermal reduction of magnesium oxide for the magnesium bearing minerals.

Where is magnesium found?

Magnesium compounds can be recovered from a wide variety of minerals, brines, or seawater that are globally widespread.

2010 WORLD PRODUCTION OF PRIMARY MG (809,100 MT)



What are the common uses of magnesium?

In 2012, the United States produced 272,000 mt and consumed 582,000 mt of magnesium compounds. They are used mainly as refractory material in furnace linings for producing iron and steel, nonferrous metals, glass, and cement. Magnesium compounds also are used in agricultural, chemical, and construction industries.

Principal industrial uses of magnesium metal include the following:

- Alloying with aluminum - (43% of the primary metal use). Alloying varies between 1% and 10% Mg. The 5,000 series (marine alloys) contains up to 5.5% Mg, while the 7,000 series (aerospace alloys) contains up to 3.5 % Mg. Mg-Al alloys are used in airplanes, missiles and rockets, cameras, horseshoes, baseball catchers' masks, and snowshoes .
- Structural uses - in automotive die casting for cylinder head covers, clutch housings, steering columns, wheels, instrument panels and valve covers, and in other numerous applications.
- Desulfurization of iron and steel - (11% of U.S. consumption of primary metal). Magnesium is also used for the production of ductile iron castings used in automotive components and pipe.
- Electrochemical and other uses - cathodic protection (1.3%); iron and steel desulfurization (10.7%); reducing agent for titanium, zirconium; hafnium, uranium and beryllium production (1.6%). and other 3.6%)
- Cardiovascular implants/stents made of bioresorbable magnesium alloys

What are the important defense applications of magnesium?

- Helicopter transmission housings
- HMMWV "run flat" wheels
- Armored vehicles
- Radar equipment
- Portable ground equipment
- Stingray torpedoes
- Anti-tank ammunition rounds

- Dry cell and reserve cell batteries, principally in military applications
- Ignition source for thermite
- Alloy component used for aircraft, car engine casings, and missile construction
- Flare and ordinance applications, notably decoy flares and illumination flares

What are some of the energy-related uses of magnesium?

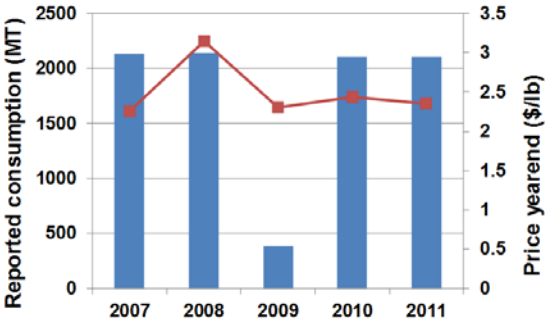
- Nuclear fuel element containers

What are the risks associated with the supply of magnesium?

In 2010, the net import reliance for magnesium metal was 34%. The United States. imported 35% magnesium products from Israel, 21% from Canada, 8% from United Kingdom, 4% from China and Mexico, and 29% from other countries.

Magnesium metal is derived from seawater, natural brines, dolomite, and other minerals. The reserves for this metal are sufficient to supply current and future requirements. Resources from which magnesium may be recovered are virtually unlimited and are globally widespread

U.S. Apparent Consumption (MT) and Metal Price (U.S. $ per lb)



Is magnesium recycled, reused, or recovered?

In 2011, about 21,000 tons of secondary production was recovered from old scrap. The UNEP indicates that worldwide, magnesium was recycled between 25 and 50%.

Stockpile Inventory
0 metric tons

Predicted Shortage
0 metric tons

Are there substitutes for magnesium?

Aluminum and zinc may substitute for magnesium in castings and wrought products. For iron and steel desulfurization, calcium carbide may be used instead of magnesium. For some refractory applications, chromite and silica can be substitute for magnesia.

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Silicon Carbide Abrasives

Photo Courtesy of Solaris2006
www.wikipedia.com

What is silicon carbide?

Silicon carbide (SiC) is a synthetic mineral most commonly produced in electrical resistance furnaces by the Acheson process. A mixture of carbon material (usually petroleum coke) and either silica or quartz sand is reacted at high temperatures (1,700 – 2,500°C) resulting in the formation of α-SiC. Silicon carbide occurs in nature as the extremely rare mineral moissanite

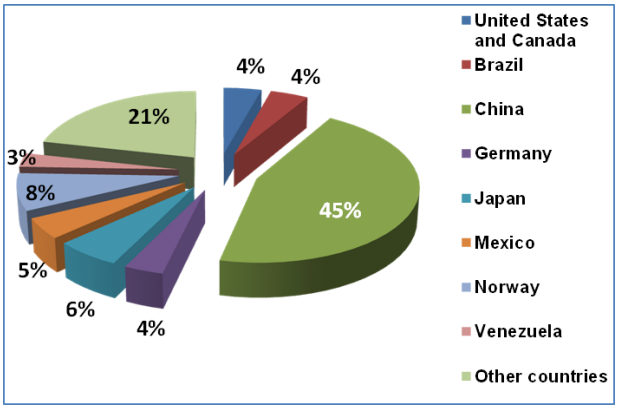
Virtually all the silicon carbide sold in the world is synthetic. SiC has an outstanding hardness, only surpassed by diamond, cubic boron nitride, and boron carbide.

Two types of silicon carbide are manufactured. The green silicon carbide (containing 99% or greater SiC) is generally used in grinding wheels for particular grinding properties or in industrial applications requiring a high purity SiC. The black silicon carbide is of lower purity (95-98% SiC).

Where is silicon carbide found?

China is by far the world's largest producer of silicon carbide, although a number of other countries produce significant quantities.

2010 World Production of SiC (1,009,610 mt)



USGS 2011 data

What are the common uses of silicon carbide?

- Machining or finishing cast iron, non-ferrous metals, stone, leather, rubber, and other materials
- Gear lapping and flat lapping of metals, ceramics, and glass
- Pressure blasting, lapping, grinding, and polishing of hard metal alloys and non-metallic materials that are hard and brittle such as jewels, optical glass, granite, or ceramics
- Polishing for soft materials such as copper, brass, aluminum, or magnesium
- Precision grinding, sharpening, forming and finishing applications in the automotive, aerospace, and machine tool sectors
- Surface-treatment and polishing applications in markets such as the furniture, lumber, cabinet, boat, automotive, welding, foundry, jewelry, and do-it-yourself markets
- Shaping of engine and transmission components, such as cam and crankshaft
- Slicing of silicon wafers
- Sharpening of circular saws and other woodworking tools

What are some of the defense applications of silicon carbide?

- Finishing and polishing of manufactured equipment
- Corrosion maintenance by preparing the surfaces before coating
- Clean and peen jet rotor blades and other precision parts.

- Clean welds, castings, manifolds, sub-assemblies, and parts before magna-fluxing or after heat-treating
- Clean carbon from exhaust stacks to prevent fire
- Abrasive water jet machining technology

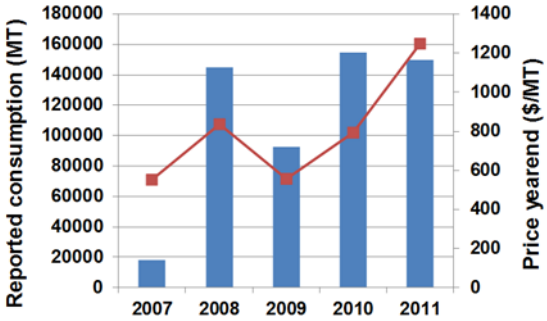
What are some of the energy-related uses of silicon carbide?

Silicon carbide is used for general maintenance at gas and electricity plants for cleaning turbine blades, pipe, valves, and meters. It is also used for the finishing of the manufactured new equipment.

What are the risks associated with the supply of silicon carbide?

In 2010, the net import reliance for silicon carbide was 77%. China is dominating the market and the U.S. imported 84% of SiC crude and 42% of SiC grain from China.

U.S. Apparent Consumption (MT) and Metal Price (U.S. $/kg)



Is silicon carbide recycled, reused, or recovered?

About 5% of silicon carbide is recycled

Are there substitutes for silicon carbide?

Natural and manufactured abrasives, such as garnet, fused alumina, emery, metallic abrasives, alumina-zirconia, or boron carbide can be substituted for silicon carbide in various applications.

Stockpile Inventory

0 metric tons

Predicted Shortage

72,900 million tons for the base case
6,750 million tons for the alternate case

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Prepared by Catherine Mattus, 865-574-6793, mattusch@ornl.gov

TITANIUM (SPONGE)

Photo Courtesy of U.S. Air Force

What is titanium?

Titanium (Ti, Z=22) is a hard, silvery-gray metallic element. It is the ninth most abundant element in the Earth's crust and the fourth most abundant metallic element. In nature, titanium is mostly found, and commercially exploitable, in the forms of rutile (TiO_2) and ilmenite ($FeTiO_3$). The largest quantities are found in Australia. About 95% of the titanium minerals mined is used to manufacture TiO_2 pigment, and about 5% is used to produce metal. To produce metal, the ore is first converted into titanium sponge, then the sponge is converted into ingot of pure or alloyed titanium. The titanium process is complicated, making it a high priced metal.

Where is titanium found?

Only six countries in the world produce titanium sponge. Ilmenite provides about 90% of the titanium used every year and major deposits are found in South Africa, Norway, Australia, Canada, Finland, and the United States (Florida and Virginia). The main reserves of rutile are found in South Africa, India, Sri Lanka, Australia, and Sierra Leone. The world estimated resources of TiO_2 are comprised of 1 billion tons in illmenite and 230 million tons in rutile.

What are the common uses of titanium?

In 2010, an estimated 75% of the 30,000 metric tons titanium metal was used in aerospace applications:

- Landing gears, springs, rotors (helicopter), fittings, and attachments
- Structural components for airplanes, satellites, and spacecraft
- gas turbine engines —engines account for about 42% of US titanium demand

The remaining 25% was used in:

- Chemical processing for heat exchangers, vessels, tanks, agitator, pipe, and tubing

WORLD SPONGE METAL PRODUCTION (MT)		
	2010	2011
United States	W	W
China	57,800	60,000
Japan	31,600	56,000
Kazakhstan	14,500	20,700
Russia	25,800	40,000
Ukraine	7,400	9,000
World Total	137,000	186,000

- Medical applications for joint replacement parts such as hip and knee joints
- Marine service for pleasure boat components, naval surface ship, and submarine cooling water systems, ferries, and fishing boats
- Sporting goods
- Desalinization plants

What are the important defense applications of titanium?

- *Air Force*— used in aircraft construction (~ 26% for the F-15 and over 39% in the F-22) in a variety of components, including critical structural parts, engines, fuselage, firewalls, landing gear, exhaust ducts (helicopters), and hydraulic systems
- Army—used for armor plated vehicles, light combat vehicles, light weight howitzers, ordinance, missile, and personal armor.
- Navy. Titanium is used in naval ships, deep-sea submersibles and submarines for ship propellers, heat exchangers, coolers, condensers, distillation units, piping systems, ballast, waste drain, sprinkling systems, compressors, fire main pumps, steam catapult components, urinal drains, and fastener

What are some of the energy-related uses of titanium?

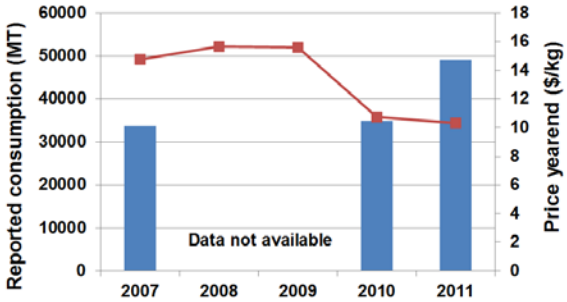
- Steam turbines and exchangers in power plants and refineries
- Offshore oil and gas exploration and production
- Petroleum processing
- Downhole oil and gas
- Geothermal well production
- Deep sour gas well applications
- Power generation

What are the risks associated with the supply of titanium?

In 2010, the net import reliance for titanium sponge was 64%. Imports were from Russia (36%), Japan (36%), Kazakhstan (25%), and other nations (3%).

Regarding its use in the new aerospace market (Airbus A350 and 380 and Boeing 777 and 787) titanium metal producers have or are increasing their plant capacity. China has the largest capacity (38%, or 103,500 metric tons per year), but the quality of sponge it produces is not sufficient for critical aerospace applications. High quality sponge is produced by Japan and the United States.

U.S. APPARENT CONSUMPTION (MT) AND METAL PRICE (U.S. $ PER LB)



Is titanium recycled, reused, or recovered?

About 95% scrap is recycled. New scrap metal recycled by the titanium industry totaled about 29,000 tons in 2010. Low titanium scrap is recycled to make ferrotitanium (microalloy additive to steel and stainless steel).

STOCKPILE INVENTORY

0 metric tons

PREDICTED SHORTAGE

4,240 metric tons for base case
9,460 metric tons for alternative case

Are there substitutes for titanium?

There are few good substitutes for titanium in aerospace uses. In high-strength applications, titanium competes with aluminum, composites, intermetallics, steel, and superalloys. Aluminum, nickel, specialty steels, and zirconium alloys may be substituted for titanium for applications that require corrosion resistance.

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RTI International Metals, Inc., Presentation given at Citigroup Global Markets, 2011 Small/Mid Cap Conference, November 15 - 16, 2011

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FLUORITE

Photo Courtesy of U.S. Navy photo by Mass Communication Specialist 1st Class James Kimber

What is fluorite?

Fluorite (CaF_2, fluorspar) is a naturally occurring mineral found in wide-range of colors. It is the source of most of the world's fluorine, making it the parent to virtually all fluorine-containing chemicals. When synthetically grown as perfectly packed crystalline material, CaF_2 is transparent and therefore very useful in optical applications.

Where is fluorite found?

Fluorite is a mineral found throughout the world at resources of approximately 500 mt, often as vein deposits, with the largest reserves in South Africa, Mexico, and China, respectively.

The United States has multiple small resources of fluorite, but present reserves stopped being mined in the mid-1990s. Current U.S. mining of fluorite is limited to a western Kentucky mine that reopened in 2010 and is expected to produce only 50 kilotons (kt, thousand metric tons) per year.

What are the common uses of fluorite?

Fluorite is used in both an acidic grade (>97% CaF_2) and in a sub-acidic grade (≤97% CaF_2). Sub-acidic fluorite is used as a flux in the steel and aluminum industries. Acidic-grade fluorite is a major production source of hydrofluoric acid, from which essentially all fluorine-bearing chemicals are derived. It requires ~2.2 tons of acid-grade fluorite to manufacture 1 ton of HF. HF is a very important chemical used in a wide range of industries/applications.

- Metal processing (Al and stainless steel)
- Steel and iron production (CaF_2 flux)
- Catalysts (detergent, high-octane gasoline)
- Semiconductor etching (silicon wafers)
- Hydrofluorocarbons/olefins (insulating foams and refrigerants)
- Electric power distribution (WF_6, SF_6)

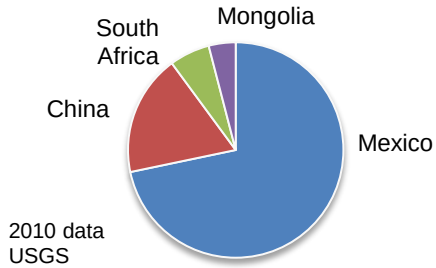
World Mine Production (kt)		
	2009	2010
Brazil	64	65
China	2,900	3,000
Kazakhstan	67	65
Kenya	16	30
Mexico	1,040	1,000
Mongolia	460	450
Morocco	75	80
Namibia	74	110
Russia	240	220
South Africa	204	130
Spain	140	120
Other Countries	180	170
World Total (rounded)	5,460	5,400

- Specialty chemicals (Teflon, Kalrez, Nafion)
- Manufacturing of opalescent glasses, enamels
- Pharmaceuticals and medical propellants

What are the important defense applications of fluorite?

- Uranium enrichment for nuclear weapons and reactors for propulsion
- Temperature control in complex defense system components
- High-quality camera and telescope lenses
- Seals and adhesives in missile and engine components

Primary Sources of U.S. Fluorite Imports
U.S. Import Dependence = 100% (2010)



What are some of the energy-related uses of fluorite?

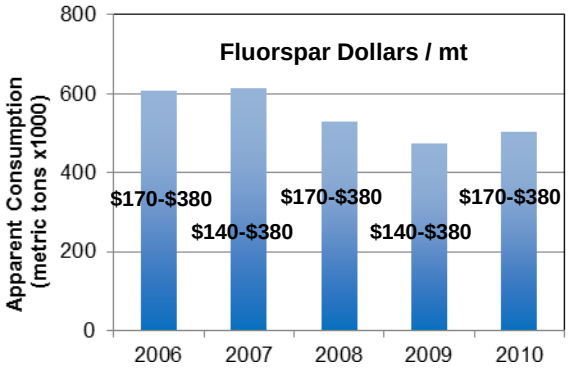
- Electric power distribution
- Nuclear power production and storage
- Energy efficient building insulation
- Energy efficient refrigeration
- Cleaner burning, high-octane gasoline

What are the risks associated with the supply of fluorite?

After the sell of the CaF_2 stockpile in 2007, the United States became 100% dependent on foreign imports for a supply of 539kt (2010) of fluorite. Since the primary consumption of fluorite is used to produce HF, it is important to also keep in mind that the United States imported an additional 135 kt of HF.

A 2009 Institute for Defense Analysis Report to Congress listed fluorite as the U.S. Department of Defense's (DoD) fourth largest, regular use, standard material. The report also stressed that under a peacetime supply disruption, the DoD would experience a shortage.

U.S. Apparent Consumption and Metal Price



Stockpile Inventory
0 metric tons

Predicted Shortage
235,947 metric tons

How are these risks being managed?

The United States reduced its dependence on China for acid-grade fluorite from almost half its imports in 2007 to only a sixth in 2009. The import dependence was primarily shifted to Mexico, a nation traditionally friendly to the United States.

Is fluorite recycled, reused, or recovered?

The mineral fluorite, CaF_2, is not typically recovered in its original form; however, HF which is recovered directly reduces the demand for fluorite.

HF is recycled in the aluminum industry, oil refineries, and from multiple applications (i.e. uranium enrichment, petroleum alkylation, and stainless steel pickling).

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www.roskell.com/reprots/fluorspar

Prepared by Melanie Moses DeBusk, 865-574-5977, mosesmj@ornl.gov

IRIDIUM

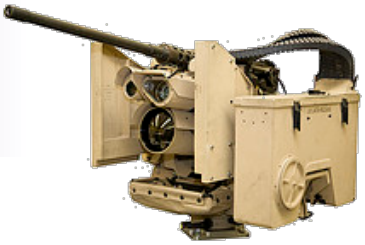


Photo Courtesy of U.S. Army PEO Soldier

What is iridium?

Iridium (Ir, Z=77), the second densest element, is a silvery-white that resembles platinum but with a slightly yellow tint. It is hard and brittle with a high boiling point that makes it difficult to use or even work. Iridium is the most corrosion-resistant metal. It has handling temperatures as high as 2,000ºC, but in a powder or dust form it is highly reactive and even flammable.

Where is iridium found?

Iridium is one of the rarest elements in the Earth's crust, making up only 0.001ppm of its crustal rock. It is routinely found at concentrations of ≥0.5ppm in meteorites. Iridium can be found naturally in both elemental form and in alloys. It is commonly found alloyed with osmium, raw nickel, or raw copper, and in nickel and copper deposits where it replaces some platinum in platinum sulfides, tellurides, antimonides, and arsenides. Highest concentrations of these forms of iridium are found in the following geological structures: igneous deposits, impact craters, and deposits reworked from these structures.

Annual world production of iridium is not routinely reported, and world reserves have not been estimated. The largest known primary reserve of iridium is located in South Africa with other significant deposits in Russia. Secondary deposits with platinum and other platinum group metals can be found in Canada and Columbia.

Commercial sources of iridium are primarily recovered from pyroxenite and the sulfide ore laurite in South Africa in addition to pentlandite recovered in Russian and Canadian nickel mining regions.

The United States has small iridium reserves. Production reports group it with other primary platinum group metals (PGMs). Two mines, Stillwater and East Boulder, in south-central Montana are the only PGM mines in the United States. Copper refining also recovers a small quantity of PGMs.

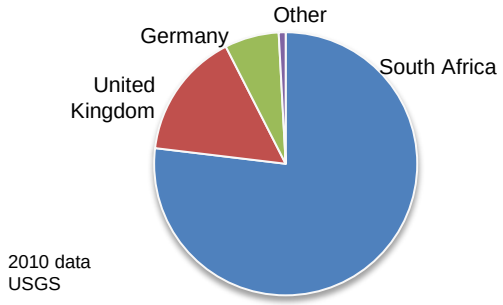
GROSS GLOBAL DEMAND (troy ounces)		
	2009	2010
Chemical	11,000	18,000
Electrical	7,000	201,000
Electrochemical	33,000	79,000
Other	30,000	40,000
Global Total	81,000	338,000

What are the common uses of iridium?

Iridium is used in catalysts, spark plug tips, as well as a number of other niche applications. Its use as a high temperature crucible has grown exponentially in recent years as the need for iridium crucibles for high purity single crystal growth has increased. Demand for synthetic sapphires, which are used to produce green and blue light emitting diodes (LEDs), are being considered responsible for the dramatic rise in iridium demand which quadrupled in 2010.

- Spark plug tips used in internal combustion engines
- High temperature crucibles
- Backlit LED screens
- Organic LEDs
- Platinum hardening agent
- Industrial γ-radiography
- Catalytic production of Acetone
- γ-radiation for cancer treatment

Primary Sources of U.S. Ir Imports
U.S. Import Dependence = 100% (2010)



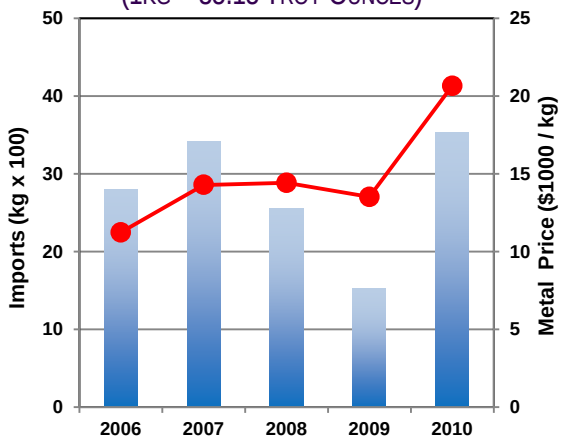
What are the important defense applications of iridium?

- Electro-explosive devices
- Iridium alloys used in aircraft engines
- Guided missile systems
- Satellites, GPS/cellular phones
- Computers, radar screens
- Military semiconductors

What are some of the energy-related uses of iridium?

- Iridium-titanium alloy for deep water pipes
- Energy efficient lighting: LEDs, OLEDs
- Spark plug tips

U.S. Imports and Metal Price
(1kg = 35.15 Troy Ounces)



Stockpile Inventory
568 troy ounces

Predicted Shortage
36,822 troy ounces

What are the risks associated with the supply of iridium?

Primary production of iridium comes from South African mines which have been plagued by strikes and other disruptions associated with the region. These challenges are hurdles for the production expansion needed to meet growing demand.

How are these risks being managed?

The increasing demand for iridium caused a ~150% jump in price in 2010. The soaring prices may incite producers to ramp up production in South Africa despite the volatility of the region. A laser spark plug is being developed in Japan that would offer a desirable alternative to iridium-tipped sparks plugs.

Is iridium recycled, reused, or recovered?

Catalysts are designed for reuse but often become deactivated over time. Iridium used in catalysts, spark plugs, and crucibles can be recovered.

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Prepared by Melanie Debusk, 865-574-5977, mosesmj@ornl.gov

OSMIUM

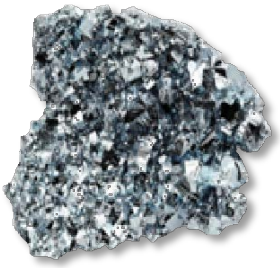


Photo Courtesy of Heinrick Pinoik

What is osmium?

Osmium, a hard, brittle, platinum group metal (PGM), is lustrous with a blue-gray tint. Its density is slightly greater than iridium making it the densest element.

Where is osmium found?

Osmium is considered the least abundant, stable element in the earth's crust. It is predominately found in platinum ore but can also be found alloyed with iridium, nickel, or copper. Osmium also replaces trace amounts of platinum in sulfides, tellurides, antimonides, and arsenides found in mined nickel and copper deposits.

Osmium is commercially mined as a by-product from South African platinum ore with smaller quantities mined in Russia and Canada. Due to the small quantities obtained, mining reports often group it with ruthenium and iridium and offer little information.

What are the common uses of osmium?

Like other PGMs, osmium is alloyed with other metals (i.e. iridium, platinum) to improve hardness and corrosion resistance. The rarity and cost have limited its application development.

- Catalyst (chemical synthesis)
- Stain for electron microscopy
- Surgical Implants (pulmonary valves)
- Electrical contacts (pacemakers)
- Instrument pivots
- Fingerprint and DNA staining

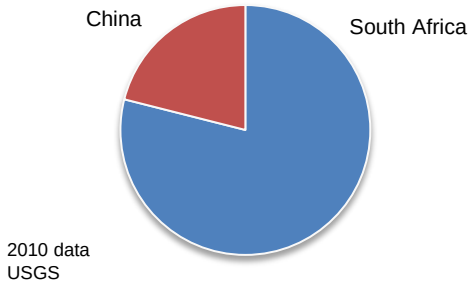
What are the important defense applications of osmium?

- Specialized electroplating finishes

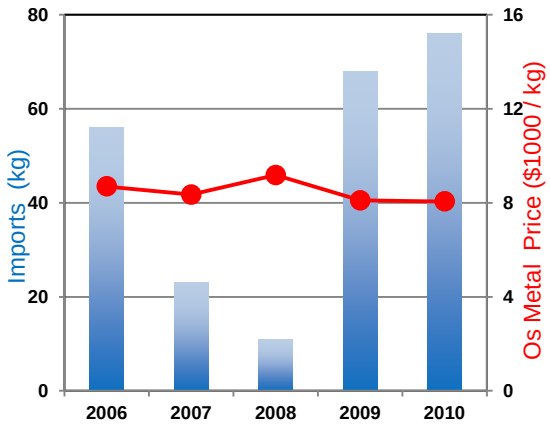
What are the risks associated with the supply of osmium?

Since South Africa has the largest global reserve of PGMs and mine production, the political and infrastructure uncertainties in the area can create supply issues. The limited applications of osmium may dampen the impact of short-term supply disruption.

Primary Sources of U.S. Os Imports
U.S. Import Dependence = 100% (2010)



U.S. Impots and Metal Price
(1kg = 35.15 Troy Ounces)



Stockpile Inventory
0 metric tons

Predicted Shortage
0 metric tons

Is osmium recycled, reused, or recovered?

Osmium is not mined or used in large enough qualities for this to be tracked.

Sources

http://en.wikipedia.org/wiki/Osmium

Patricia J. Loferski. U.S. Geological Survey, 2007-2010 Minerals Yearbook(s) *advanced release(s)*, October 2008-2011.

Patricia J. Loferski. U.S. Geological Survey, Minerals Commodity Summaries, January 2011.

Prepared by Melanie Debusk, 865-574-5977, mosesmj@ornl.gov

PALLADIUM

Photo Courtesy of images-of-elements.com

What is palladium?

Palladium (Pd, Z=46), like other platinum group metals (PGMs), is a rare, silvery-white metal found in the Earth's crust. When annealed, it is a soft, ductile metal that does not tarnish in air below 800ºC. The strength and hardness of palladium can be increased by cold-working. It has the lowest boiling point, (2,963ºC) and it is the least dense of all PGMs. It has a unique ability to absorb hydrogen at up to 900 times its own volume.

Where is palladium found?

Palladium makes up 0.015 ppm of the Earth's crust. The largest PGM reserves are located in South Africa. Palladium mined in South Africa, Russia, the United States, and Canada account for nearly three-quarters of the world mine production. The concentration of palladium in different deposits varies as result of different ore-grades and deposit types. Mining of lower-grade platinum ores in Russia and Canada benefit from the processing of the large quantities of nickel or copper ores with which they are found.

Domestic palladium mines are located in Montana near Nye and south of Big Timber; both are owned by the Stillwater Mining Co. (SMC). U.S. mine production of palladium is highest of all U.S. PGMs mined. Explorations for new domestic mines are underway in Minnesota and Alaska. Domestic copper refining also recovers a small quantity of PGMs.

What are the common uses of palladium?

More than half of global palladium consumption occurs in the autocatalyst industry. By volume the electronic industry and investments are the next major users of palladium. While still important ,its use by volume in the chemical, dental and jewelry industries are significantly smaller.

World Mine Production (kg)		
	2009	2010
United States	12,700	11,600
Canada	6,500	9,400
Russia	83,200	87,000
South Africa	75,000	73,000
Zimbabwe	5,680	6,600
Other Countries	9,230	9,800
World Total (rounded)	192,000	197,000

- Hydrogen purification
- Electronic conductive connectors
- Brazing and soldering filler metals
- Automotive catalysts
- Bulk chemical catalysts
- Multi-layer ceramic capacitors

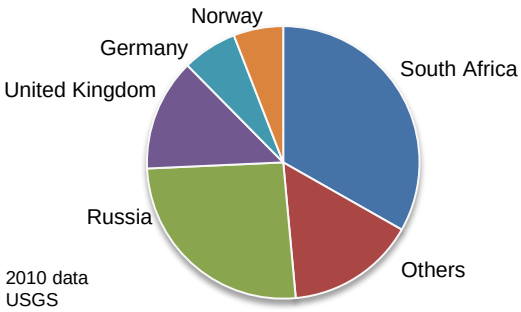
What are the important defense applications of palladium?

- Internal computer component connectors
- Aerospace brazing and soldering
- Electronic circuit boards

What are some of the energy-related uses of palladium?

- Semiconductor industry
- Engine emission treatment catalysts

Primary Sources of U.S. Pd Imports
U.S. Import Dependence = 58% (2010)



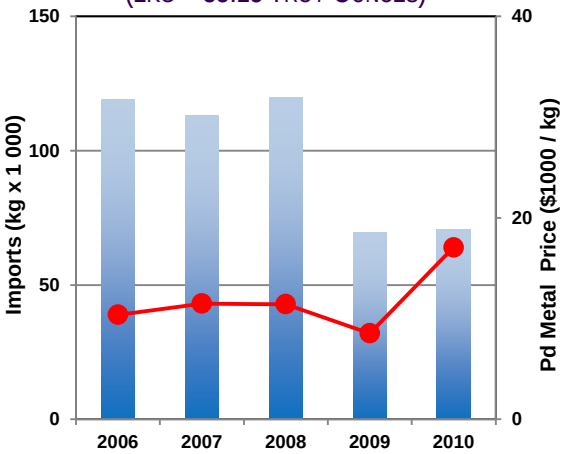
Stockpile Inventory
0 troy ounces

Predicted Shortage
0 troy ounces

What are the risks associated with the supply of palladium?

The U.S. imports from an array of global refineries, which creates a more stable, refined supply. However, South Africa has the largest global reserve of PGMs and mine production. Political and infrastructure uncertainties in the area can create supply issues.

U.S. Imports and Metal Price
(1kg = 35.15 Troy Ounces)



Is palladium recycled, reused, or recovered?

Palladium used in automotive catalysts is routinely recovered, while smaller amounts of that used in electronics and jewelry are recycled. A significant portion of palladium used in automotive catalysts is supplied by recovery. Stillwater Metals Co., located in Montana, is the major domestic recycle center for PGMs housing the only working smelter in the country. However, other companies use smelters located outside the US and refine domestically or abroad.

Sources

http://en.wikipedia.org/wiki/Palladium

Patricia J. Loferski. U.S. Geological Survey, 2010 Minerals Yearbook *advanced release*, October 2011.

Patricia J. Loferski. U.S. Geological Survey, Minerals Commodity Summaries, January 2011.

Jonathan Butler. Platinum 2011Interim Review, Johnson Matthey.

Prepared by Melanie Moses DeBusk, 865-574-5977, mosesmj@ornl.gov

PLATINUM

Photo Courtesy of Heinrick Pinoik

What is platinum?

Platinum, one of the rarest elements found in the Earth's crust, has a silvery-white color that never tarnishes. It is a dense, ductile metal that is malleable. Platinum, a noble metal, is corrosion-resistant with high-temperature stability and is non-oxidizable with stable electrical properties. It is part of a group of metals known as the platinum group metals (PGMs).

Where is platinum found?

Platinum makes up only 0.005 ppm of the Earth's crust. It has a higher abundance on the moon and in meteorites, which can increase its concentration at bolide impact sites on Earth. Platinum can be found chemically uncombined as native platinum and alloyed with other PGMs like iridium in alluvial deposits. It is also commonly found in nickel and copper deposits as sulfides, tellurides, antimonides, and arsenides.

The largest PGM reserves are located in South Africa with other significant sources located in Russia, the United States, and Canada. The concentration of platinum in different deposits varies even within the same mine. South African mines predominantly have higher-grade PGM, while PGM ores mined elsewhere are normally lower-grade and/or in small quantities reducing their commercial mining viability due to cost. Most lower-grade PGM ores are mined commercially because they are located near huge quantities of nickel or copper ores that are processed, thus lowering the cost.

Domestic platinum mines are located in Montana near Nye and south of Big Timber; both are owned by the Stillwater Mining Co. Explorations for new domestic mines are underway in Minnesota and Alaska. Domestic copper refining also recovers a small quantity of PGMs.

WORLD MINE PRODUCTION (kg)		
	2009	2010
United States	3,830	3,500
Canada	4,600	5,500
Columbia	1,500	1,500
Russia	21,000	24,000
South Africa	141,000	138,000
Zimbabwe	7,230	8,800
Other Countries	2,420	2,400
World Total	181,000	183,000

What are the common uses of platinum?

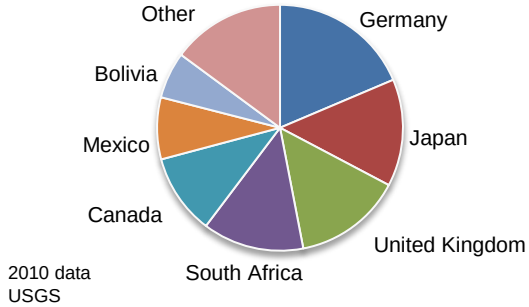
Platinum is used in a wide variety of applications. Based on the volume used, its top use is for vehicle emissions control devices (i.e. catalytic converters) with jewelry, chemical catalyst, and electronics rounding out the top four uses. Platinum's unique set of chemical and physical properties also lend itself to a host of other small yet very important applications.

- LCD/flat panel displays
- Silicones
- Catalysts (automotive, bulk chemical, petroleum refining)
- High temperature, corrosion resistant alloy

What are the important defense applications of platinum?

- Aircraft turbine blades and coatings
- Aircraft and engine seals and gaskets
- Alloys for high temperature applications

PRIMARY SOURCES OF U.S. Pt IMPORTS
U.S. IMPORT DEPENDENCE = 94% (2010)



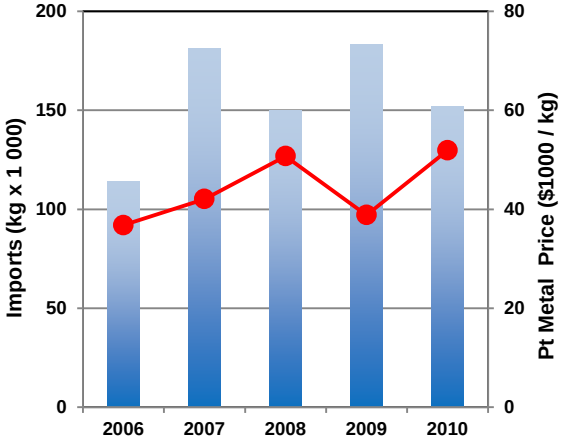
What are some of the energy-related uses of platinum?

- Sensors for control of air/fuel ratio
- Electrodes
- High-octane gasoline
- Reducing engine emissions
- Deep sea oil pipes

What are the risks associated with the supply of platinum?

The United States imports from an array of global refineries, creating a more stable refined supply. However, South Africa has the largest global reserve of PGMs and mine production. Political and infrastructure uncertainties in the area can create supply issues.

U.S. IMPORTS AND METAL PRICE
(1KG = 35.15 TROY OUNCES)



STOCKPILE INVENTORY
8,380 troy ounces

PREDICTED SHORTAGE
8,380 troy ounces

How are these risks being managed?

The high cost of platinum can affect its use in some applications where alternatives are available. This is most notable in the automotive sector where cheaper palladium is used in place of platinum with limited effect on efficiency.

Is platinum recycled, reused, or recovered?

Platinum from automotive catalysts, electronics, and jewelry are routinely recycled. The predominate form of U.S. platinum imports is scrap and waste. Stillwater Metals Co. located in Montana is the major domestic recycle center for PGMs. However, other US companies recover PGM using smelters operated in other countries. In 2010, more than 73% of the US platinum imports were from waste and scrap Pt. It is impossible to confirm if the platinum recovered from catalytic converters is that used to produce new converters because it is sent through the smelting and refining process with freshly mined Pt due to economics of the process that takes 5-6 months.

Sources

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Jonathan Butler. Platinum 2011Interim Review, Johnson Matthey.

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RHODIUM

Photo Courtesy U.S. Navy photo by Mass Communication Specialist 2nd Class Julia A. Casper

What is rhodium?

Rhodium (Rh, Z=45), a platinum group metal (PGM), is an inert, reflective, silvery-white metal found in the earth's crust. It is a hard metal with low electrical resistance and high corrosion resistance. The oxygen is released when the metal solidifies. One of the rarest precious metals, it has historically been the most expensive PGM, but dropped below platinum after the global market crash of 2008.

Where is rhodium found?

Rhodium makes up about 0.001 ppm of the Earth's crust. This rare PGM is only mined as a profitable by-product in the mining of other metals. Mined rhodium ores are found mixed with more profitably mined metals like palladium, silver, platinum, and gold.

The three principal sources include South Africa, the Ural Mountains (Russia), and North America. Like most PGMs the primary exporter of rhodium is South Africa. Rhodium is present in higher concentration within the PGM ores found in chromite type deposits like the UG2 Reef in South Africa.

Stillwater Mining Company in Montana is the United States only domestic source of rhodium. Rhodium is a by-product of Stillwater's palladium and platinum mining operations.

What are the common uses of rhodium?

The majority of annual global rhodium production is used for automotive emission control. It was estimated to be roughly 80% in 2011 and isn't expect to decline in the near future. The historically high price of rhodium has limited its use in many application. This may change in the future if the lower prices remain since rhodium offers unique properties. Other rhodium applications often involve alloying with Pt to improve platinum's hardness and corrosion resistant properties.

GLOBAL SUPPLY (TROY OUNCES)		
	2009	2010
South Africa	663,000	632,000
Russia	70,000	70,000
North America	15,000	10,000
Zimbabwe	19,000	19,000
Other	3,000	3,000
Global Total	770,000	734,000

- Three-way catalytic converter
- Platinum-rhodium alloys
  - Fiberglass
  - Flat panel glass for LCD
  - Thermocouples
  - Electrical contacts
- Chemical production catalyst (acetic acid, nitric acid, oxo-alcohol)

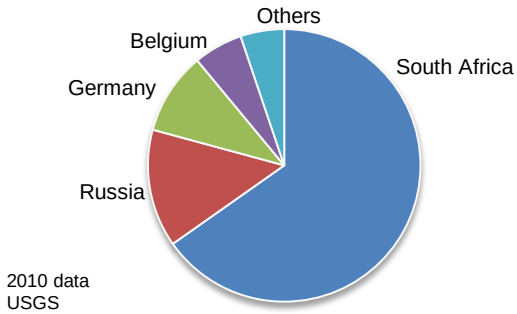
What are the important defense applications of rhodium?

- Aircraft components
- Electronic LCD screens
- Electronic circuit boards
- High temperature thermocouples

What are some of the energy-related uses of rhodium?

- Nuclear power facilities – neutron detectors
- Reduction NOx emission (Catalytic Converters)

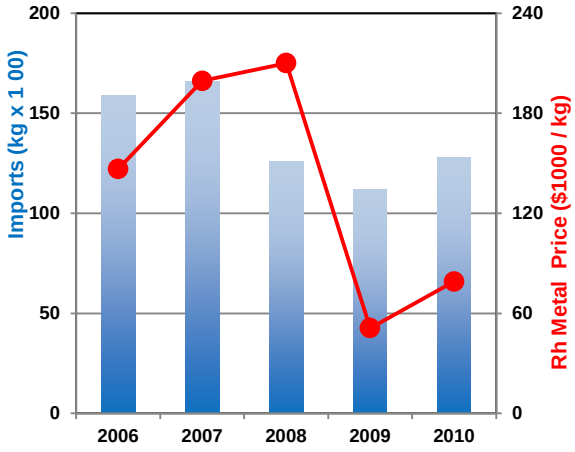
Primary Sources of U.S. Rh Imports
U.S. Import Dependence = 100% (2010)



What are the risks associated with the supply of rhodium?

The U.S. imports from an array of global refineries, creating a more stable, refined supply. However, South Africa has the largest global reserve of PGMs and mine production. More than half of the United States rhodium imports consistently come from South Africa, reaching 67% in 2009. Political and infrastructure uncertainties in the area can create supply issues.

U.S. Imports and Metal Price
(1kg = 35.15 Troy Ounces)



Stockpile Inventory
0 metric tons

Predicted Shortage
0 metric tons

Is rhodium recycled, reused, or recovered?

Rhodium is recovered globally from automotive catalysts. Recycled rhodium accounts for roughly 25-20% of autocatalyst consumption. While recycling of catalytic converts continues to increase, the quantity of rhodium recovered is dependent on that used at the time they were produced. When rhodium prices were extremely high, manufactures worked to reduce its loading on catalytic converters. Therefore, rhodium content in converters being recycled do not necessarily reflect quantities needed for current converter manufacturing.

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http://en.wikipedia.org/wiki/Rhodium

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Nick Morley and Dan Eatherley. Material SecurityTechnology Strategy Board - Ensuring resource availability for the UK economy. Resource Efficiency Knowledge Transfer Network, March 2008.

A1-Specialized Services & Supplies, Inc. Platinum Market Review, January 2012.

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RUTHENIUM

Photo Courtesy of images-of-elements.com

What is ruthenium?

Ruthenium (Ru, Z=44), a platinum group metal (PGM), is an inert, silvery-white metal found as part of platinum-ore in the Earth's crust. It is soluble in fused alkalis and is resistant to acid attack, but susceptible to halogen attack at high temperatures. The corrosion resistance and hardness properties of ruthenium can be transferred to other metals by alloying and electroplating.

Where is ruthenium found?

Ruthenium makes up about 0.001 ppm of the Earth's crust. It is found in pentlandite and pyroxenite deposits and is mined commercial with platinum ore and as a by-product of nickel and copper mining. Only about 12 tons of ruthenium are mined each year, but world reserves were estimated at 5,000 tons in 2003.

The largest PGM reserves are located in South Africa. Most commercially available ruthenium comes from the platinum ore mined in South Africa. The fraction of ruthenium in platinum ore is dependent on the type of geochemical formation. Typically, 11% of PGM mined in South Africa is ruthenium, compared to only 2% of PGM mined from Russia's Ural Mountains.

The small quantities recovered from North America's PGM, nickel, and copper mining are traditionally minimal and grouped with osmium and iridium, so statistical production numbers are not available.

What are the common uses of ruthenium?

The primary uses of metallic ruthenium exploit its wear resistance properties for use in electrical contacts and thick-film resistors. Ruthenium is also added to many PGM alloys to improve their corrosion resistance.

- Thick-film resistors

GROSS GLOBAL DEMAND (troy ounces)		
	2009	2010
Chemical	89,000	100,000
Electrical	336,000	679,000
Electrochemical	95,000	124,000
Other	54,000	42,000
Global Total	574,000	945,000

- Grubb's catalyst (alkene metathesis)
- Titanium alloy (corrosion resistance)
- Chlorine generation from sea water
- Oxygen sensors
- Cathodic protection of underground and submerged structures

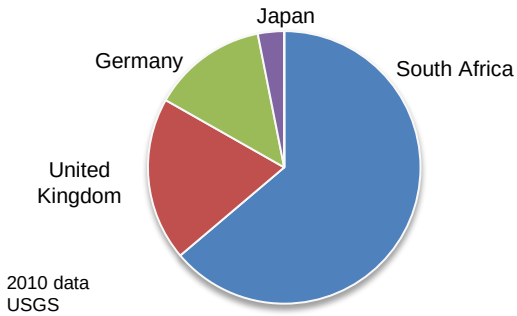
What are the important defense applications of ruthenium?

- Jet engine turbine blades
- Computer hard disk drives
- Wear-resistant electrical contacts
  - Missiles, radar, and communications
  - Computerized controls
  - Aircraft, ships, and ground vehicles

What are some of the energy-related uses of ruthenium?

- Dye-sensitized solar cells
- Cathodic protection anode
  - Power plant steam condensers
  - Off-shore oil rig platforms
  - Buried and submerged pipelines
  - Deep wells and oil storage tanks

PRIMARY SOURCES OF U.S. Ru IMPORTS
U.S. IMPORT DEPENDENCE = 100% (2010)



- Fuel cell electrode and catalyst
- Vehicle engine efficiency (oxygen sensors)

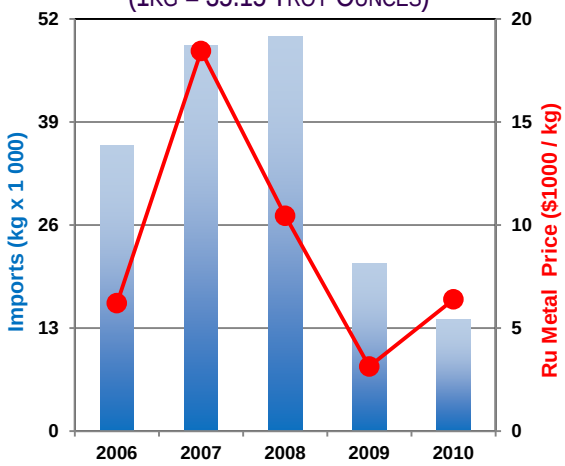
What are the risks associated with the supply of ruthenium?

The US imports from an array of global refineries which creates a more stable refined supply. However, South Africa has the largest global reserve of PGMs and mine production. Political and infrastructure uncertainties in the area can create supply issues.

How are these risks being managed?

While mining occurs primarily in South Africa, many of the mines and refining operations are run by more stable countries from which the US imports a third of its ruthenium. This may bring some more stability to import supply.

U.S. IMPORTS AND METAL PRICE
(1KG = 35.15 TROY OUNCES)



STOCKPILE INVENTORY
0 metric tons

PREDICTED SHORTAGE
0 metric tons

Is ruthenium recycled, reused, or recovered?

Ruthenium can be recovered from electrodes and monolith catalyst. However, due to the small quantities in use this is not done on a large-scale. Other PGMs (palladium, platinum and rhodium) are routinely recovered from catalytic converters.

Sources

http://en.wikipedia.org/wiki/Ruthenium

Patricia J. Loferski. US Geological Survey, 2010 Minerals Yearbook *advanced release*, October 2011.

Jonathan Butler. Platinum 2011Interim Review, Johnson Matthey.

Nick Morley and Dan Eatherley. Material SecurityTechnology Strategy Board - Ensuring resource availability for the UK economy. Resource Efficiency Knowledge Transfer Network, March 2008.

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BARIUM

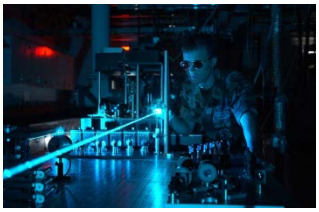


Photo Courtesy of U.S. Air Force

What is barium?

Barium (Ba, Z=56) is a silvery-white, soft metal that is found only in combination with other elements, most commonly with carbonate (witherite) and sulfate (barite and heavy spar). Its abundance in the earth's crust is ~628 mg/kg. It is also found in seawater in trace concentrations (13 µg/L). Barium metal is easily oxidized and is often used as a scavenger in vacuum tubes. Barium has many isotopes; 5 are stable, Ba-134 to 138, and 22 radioisotopes are known.

Where is barium found?

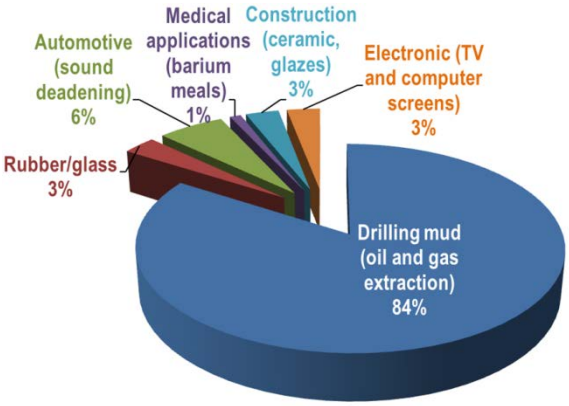
Four mines in Nevada and one in Georgia are mining barite in the US.

What are the common uses of barium?

Barium is a common constituent in many compounds and some alloys and is used in many industries.

- Dielectrics (capacitors, superconductors, piezoelectric devices)
- Medical (x-ray diagnostics and shielding)
- Pyrotechnics
- Scavenger in electronic tubes
- Medical x-ray examination

MAJOR APPLICATIONS FOR BARIUM



BARITE WORLD MINE PRODUCTION (THOUSAND MT)

	2010	2011
United States	662	640
China	4,000	4,000
India	1,100	1,100
Morocco	650	650
Turkey	250	250
Kazakhstan	200	200
Other Countries	988	960
World Total	7,850	7,800

- Rat poison
- Paints
- Plastics
- Automobile brakes
- Added to molten steel and metals in deoxidizing alloys to lower oxygen content
- Alloy used for spark plugs
- Some radioisotopes have applications in nuclear reactions and spectrometry

What are the important defense applications of barium?

- Dielectrics (capacitors, superconductors, piezoelectric devices)
- Optics
- In lead alloy grid of acid batteries

What are some of the energy-related uses of barium?

- Dielectrics
- Oil well drilling fluids
- Use in high-density concrete for radiation shielding

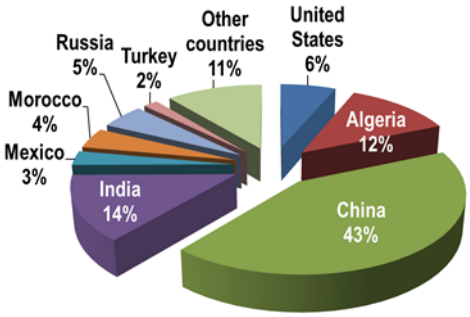
What are the risks associated with the supply of barium?

The United States is heavily reliant on importing barium (e.g., barite, metal, oxide, and other compounds— 95% China, 3% India, and 2% other countries. Barium domestic production is primarily for gas and oil drilling, which is expected to increase sharply in future years. The strong demand for barite resulted in a sharp price increase. China's domestic demand increases, reducing the availability for export.

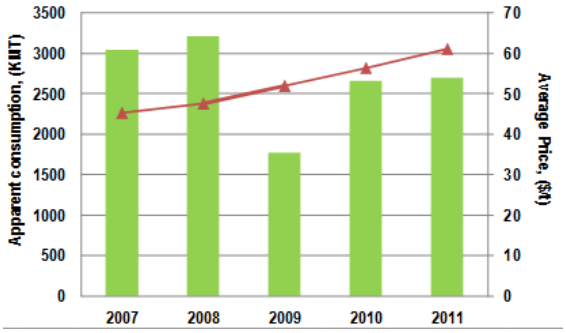
Domestically, crude barite is not typically processed into oxides and other compounds required for military applications. The military consumption of barium is primarily in dielectrics as capacitors in the form of barium titanate, piezoelectric devices (transducers), and nonlinear optics.

U.S. IMPORT DEPENDENCE = 78% (2011)

2011 BARITE WORLD MINE RESERVES (240,000 THOUSANDS MT TOTAL)



U.S. APPARENT CONSUMPTION AND METAL PRICE



STOCKPILE INVENTORY
0 metric tons

PREDICTED SHORTAGE
0 metric tons

Is barium recycled, reused, or recovered?

The United Nations Environment Programme estimates that the post-consumer end of life recycling is less than 1%.

Are there substitutes for barium?

Some substitutes exist for the drilling mud market, such as celestine, ilmenite, and iron ore, but they are rarely used.

Sources

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UNEP, *Recycling Rates of Metals—A Status Report,* 2011, http://www.unep.org/resourcepanel/metals_recycling/

European Commission, Annex V to the report Ad-Hoc Working Group on Defining Critical Raw Materials, http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/annex-v_en.pdf

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CERIUM

Photo courtesy of ORNL

What is cerium?

Cerium (Ce, Z=58) is a very reactive iron-gray colored metal and the most abundant of the lanthanide series, or rare earth elements (REEs). Cerium averages 63 mg/kg, making it the 26th most abundant element in the earth's crust. It is mostly used in one of its many oxide states, as the unalloyed metal is toxic and reactive. It has 4 stable natural isotopes and 26 radioisotopes.

Where is cerium found?

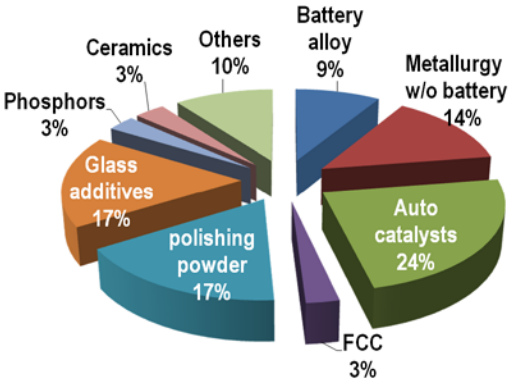
Most economical world resources are contained primarily in bastnasite (US and China) and secondly in monazite (Australia, Brazil, China, Malaysia, South Africa, Sri Lanka, Thailand, and the US). The Mountain Pass mine (bastnasite) contains 49.4% Ce_2O_3 in its REOs, while Mount Weld in Australia (Monazite) contains 46.74%. Large deposits of monazite in India and Brazil and allanite (in Western US) are also sources for cerium. The largest REEs deposit in the world is the Bayan Obo deposit in China, which has resources totaling at least 48 million metric tons of rare earth oxides (REOs) out of a world total of 95.27 million metric tons.

2010 WORLD SUPPLY OF CERIUM OXIDE ~ 38,400 MT

What are the common uses of cerium?

- Glass manufacture additive and polishing compound
- Phosphors in TV screens and fluorescent lamps
- Carbon-arc lighting
- Chemical oxidizing agent
- Self-cleaning ovens
- Incandescent gas mantle
- Ceramic capacitors, semiconductors, and other components for LCDs and electronics
- Dental ceramics, medicines
- Pigment for paints
- Wastewater treatment, agriculture

CERIUM OXIDE DISTRIBUTION PER APPLICATION



- Misch metal (a mix of lanthanum, cerium, neodymium and praseodymium) used as minor alloy for the casting of steel and iron and for gas lighter and ignition devices
- In various aluminum and iron alloys, in steel and cast iron

What are the important defense applications of cerium?

- Lens and silicon wafer polishing compounds
- Rocket propellant
- Getter in vacuum tubes
- Heat-resistant superalloys
- Optical lenses, optical filters, coatings
- High-strength steel landing gear struts
- Permanent magnets

What are some of the energy-related uses of cerium?

- UV filters in glass
- In catalytic converters and as diesel additive
- Diluent for plutonium in nuclear fuel
- Petroleum refining as fluid cracking catalyst
- Solar panel
- Solid oxide fuel cells

What are the risks associated with the supply of cerium?

The United States is only partially dependent upon imports for its supply of cerium. The importation of cerium compounds has been decreasing over the past 5 years, along with pure oxide. Cerium compounds and mixed rare earth compounds containing cerium continued to be produced and exported.

All the mine development projects in the western world contain cerium, which is an abundant light REE and for which demand should not pose any problem. In the US, Mountain Pass expects 49.1% Ce_2O_3 in its REOs production (42,402 mtpa expected) and Bear Lodge 47.11% for an expected production of 7,000 mtpa in 2015. Mount Weld in Australia contains 51.00% cerium (2,000 mtpa expected). Cerium production is likely to be in surplus over the next few years.

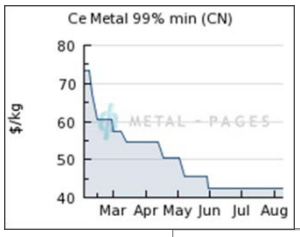
Primary Sources of U.S. REE Imports (2007-2010):

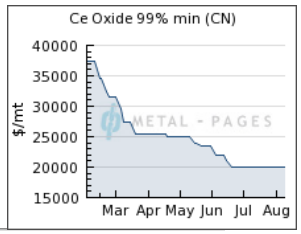
China, 79%; France, 6%; Estonia, 4%, Japan, 3% and others, 8%

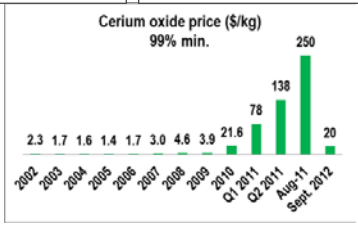
U.S. Import Dependence = 100% (2011)

Market Forecast For Cerium Oxide (Mt)			
Demand 2010	Supply 2010	Demand 2014	Supply 2014
43,900	38,400	52,800	66,300

2012 CERIUM PRICES







Stockpile Inventory

0 metric tons

Predicted Shortage

0 metric tons

Is cerium recycled, reused, or recovered?

The United Nations Environment Programme estimates that the post-consumer end of life recycling is less than 1%.

Are there substitutes for cerium?

Substitutes exist but are generally less effective.

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Lynas Corp., www.lynascorp.com/

Molycorp, Inc., http://www.molycorp.com/

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DYSPROSIUM

Photo courtesy of Wikipedia

What is dysprosium?

Dysprosium (Dy Z=66) is a soft metal with a bright silver luster. The metal is a by-product in the commercial production of yttrium. Dysprosium exists in the earth's crust at an average concentration of ~3.9 mg/kg. Its concentration in sea water is ~0.9 ng/L. Dysprosium has 7 natural isotopes and 29 radioisotopes.

Where is dysprosium found?

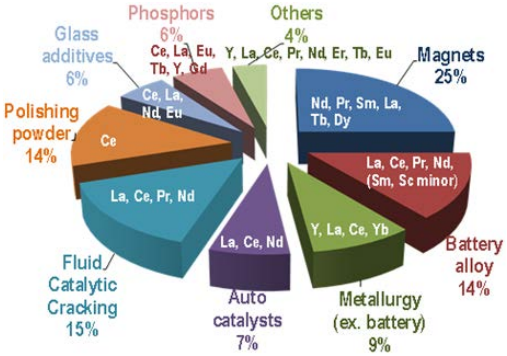
Large resources of dysprosium are available in xenotime and monazite. The content of Dy_2O_3 in xenotime represents ~8 to 9% of the REOs, and in the most abundant ore monazite, 0.2 to 0.9%. The Longnan-type ion-absorption ore contains 6 to 7% Dy_2O_3 in the total REOs, but the Xunwu-type only contains trace amounts. Minor amounts are found in bastnasite from Mountain Pass and the monazite of Mountain Weld contains ~0.124% Dy_2O_3 in the total REOs. The Lemhi Pass district in Idaho-Montana contains 1.49% Dy_2O_3 in the total REOs. Sub-economic amounts are present in various mines in Canada. The Russian loparite contains 0.6% Dy_2O_3 in the total REOs, while in Kyrgyzstan a synchysite contained 4.3%. However, the main source of dysprosium worldwide is the ion-absorption lateritic clay of the southern provinces of China. Currently producing niobium and tantalum mines in Brazil produce tailings which are high in dysprosium.

2010 WORLD SUPPLY OF DYSPROSIUM OXIDE
~2,300 MT

What are the common uses of dysprosium?

- Permanent magnets
- High-intensity lighting
- Fluorescence activator in phosphors
- Data storage applications such as CDs
- Chemical reaction testing
- Laser diodes and high-power, high-frequency applications
- Medical applications (Dy-165)
- Semiconductors and photo-optic applications

Distribution of rare earths by application



What are the important defense applications of dysprosium?

- NdFeB magnets (Dy can substitute as much as 6% Nd)
- Laser materials (ceramics and specialty glass)
- Component of Terfenol-D a component used in transducers, sonar sensors, positioning actuators, active noise and vibration cancellation, seismic waves and tool machining.
- Capacitors and chips in electronics

What are some of the energy-related uses of dysprosium?

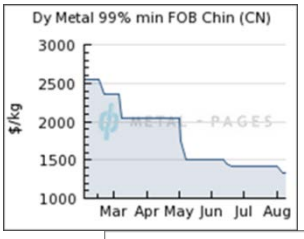
- Neutron-absorbing control rods in nuclear reactors and in dosimeters to measure neutron flux
- High-powered electric motors
- Lighter vehicles/improved performance
- High-precision liquid fuel injectors

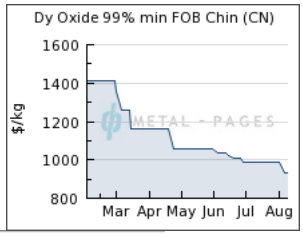
What are the risks associated with the supply of dysprosium?

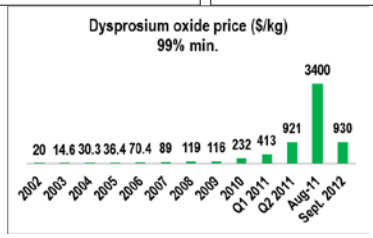
Dysprosium is obtained as a by-product of yttrium and the US is dependent on China for the supply of yttrium. During the 2007–2010 time frame, yttrium oxide compounds were imported from China (63%), Japan (9%), France (6%), UK (4%), and other (18%). The reserves for yttrium in the US are about half of those in China, but these deposits are not currently economical for development. The substitution of 6% neodymium in NdFeB magnets for improvement of drive motors in hybrid cars could require a large demand that could not be fulfilled with current production. Among the mine projects in development, at least five mines have concentrations of dysprosium above 1% of the total REEs content, among them Dubbo, Australia (2.016%—expected 2,580 mtpa in 2014); Nechalacho, Canada (2.71%—expected 9,296 mtpa in 2015); Strange Lake, Canada (4.104% —12,120 mtpa in 2015); Knanefjeld, Greenland (1.100%—expected 43,700 mtpa in 2015). Domestically, Mountain Pass does not contain heavy REEs, but Bear Lodge is expecting 0.405% with an expected production of 7,000 mtpa in 2015. Mount Weld mine (Australia) contains 0.200% dysprosium (22,000 mtpa).

Market Forecast For Dysprosium Oxide (Mt)			
Demand 2010	Supply 2010	Demand 2014	Supply 2014
1,600	2,300	2,500	1,100

2012 Price of Dysprosium







Stockpile Inventory

0 metric tons

Predicted Shortage

0 metric tons

U.S. Import Dependence = 100% (2011)

Is dysprosium recycled, reused, or recovered?

The United Nations Environment Programme estimates that the post-consumer end of life recycling is less than 1%.

Are there substitutes for dysprosium?

No direct substitutes exist for applications that require dysprosium.

Sources

USGS, mineral commodity http://minerals.usgs.gov/minerals/pubs/commodity/

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ERBIUM

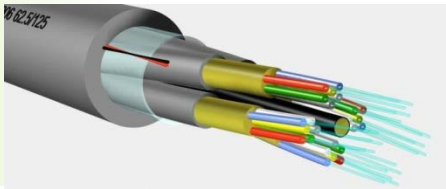


Photo Courtesy of Srleffler - Wikipedia

What is erbium?

Erbium (Er, Z=68) is a bright, silvery metal. It belongs to the heavy REEs that are less abundant in nature. Erbium is distributed in nature occurring in mixtures with other lanthanide elements. A common mineral is gadolinite. Its concentration in the earth's crust is ~2.3 mg/kg and ~0.9 ng/L in sea water. The metal is fairly stable in air and does not oxide as rapidly as some other metals. Erbium has 6 natural isotopes and 29 radioisotopes.

Where is erbium found?

Large resources of erbium are found in xenotime and monazite. In xenotime, Er_2O_3 makes up 5.6 to 6.4% of the total REOs; in monazite, which is more abundant than xenotime, the concentration of Er_2O_3 varies from trace amounts to 0.1 to 0.2% of the total REOs. In China, the Longnan-type ion-absorption lateritic clays contain ~6.7% Er_2O_3 from the total REOs, while the Xunwu-type only contains 0.88%. In the bastnasite ores of Bayan Obo (China), only traces of erbium are found, and the same situation exists for Mountain Pass. At Lemhi Pass district in Idaho-Montana, Er_2O_3 is present at 0.43% of the total REOs. Sub-economic resources are available in several deposits in Canada.

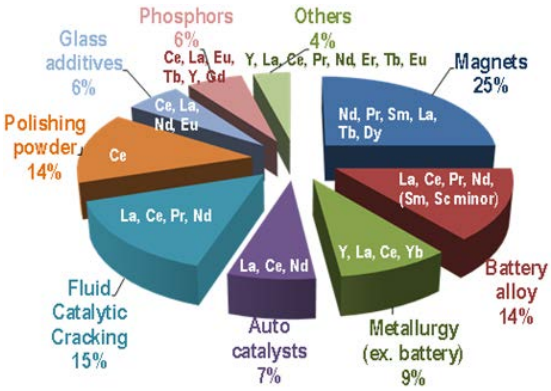
REOs World mine production (MT)		
	2010	2011
Brazil	550	550
China	130,000	130,000
India	2,800	3,000
Malaysia	30	30

2010 WORLD SUPPLY OF ERBIUM OXIDE NOT AVAILABLE

What are the common uses of erbium?

- Er:YAG laser in medical applications (dermatology, dentistry)
- Pink colorant in cubic zirconia, glass and porcelain enamel glazes
- Photographic filter
- In lasers for cutting and welding
- Alloy additive for vanadium
- Activator in phosphors
- Cryocoolers

Distribution of rare earths by application



What are the important defense applications of erbium?

- Eye-safe lenses
- Lasers
- Erbium-doped optical fiber amplifiers (EDFAs)
- Fiber optic cables

What are some of the energy-related uses of erbium?

- Neutron-absorbing control rods

What are the risks associated with the supply of erbium?

The United States is completely dependent upon imports for its supply of erbium, and mines with heavy REEs are less common than those with light REEs. Among the mine projects in development, at least four mines have concentrations of erbium above 1% of the total REEs content: Dubbo, Australia (1.163%—expected 2.,580 mtpa in 2014); Nechalacho, Canada (1.26%—expected 9,296 mtpa in 2015); Strange Lake, Canada (2.803%—12,120 mtpa in 2015); and Norra Karr, Sweden (3.345%—5,000 mtpa). Domestically, Mountain Pass does not contain heavy REEs, but Bear Lodge is expecting 0.055% erbium with an expected production of 7,000 mtpa in 2015. Mount Weld mine (Australia) contains 0.200% erbium (22,000 mtpa expected)

Primary Sources of U.S. REEs Imports (2007-2010):

China, 79%; France, 6%; Estonia, 4%, Japan, 3% and others, 8%

World mines reserves (MT of REOs)	
United States	13,000,000
Australia	1,600,000
Brazil	48,000
China	55,000,000
Commonwealth of Independent States	19,000,000
India	3,100,000
Malaysia	30,000
Other countries	22,000,000
World total (rounded)	110,000,000

PRICE (U.S. $ / kg)

	12/31/11	03/05/12	09/19/12
Erbium metal ≥ 99.9%	350.00	275.00	NA
Erbium oxide ≥99.5%	175.00	180.00	496.90

Is erbium recycled, reused, or recovered?

The United Nations Environment Programme estimates that the post-consumer end of life recycling is less than 1%.

Stockpile Inventory

0 metric tons

Predicted Shortage

0 metric tons

Are there substitutes for erbium?

In some applications, certain metal matrix or organic composites, high-strength grades of aluminum, pyrolytic graphite, silicon carbide, steel, or titanium may be substituted for erbium metal or erbium composites. Aluminum nitride or boron nitride may be substituted for erbium oxide in some applications.

Sources

USGS, mineral commodity http://minerals.usgs.gov/minerals/pubs/commodity/

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Öko-Institute e.V., *Study on Rare Earths and their Recycling,* Jan. 2011

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EUROPIUM

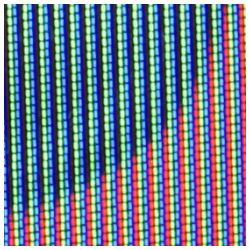


Photo courtesy of Wikipedia

What is europium?

Europium (Eu, Z=63), is a soft silvery metal. It ignites in air at ~150–180°C and is the most reactive of the REEs. The metal is soft and quite ductile. Europium is a fission product generated in nuclear reactors. Besides the natural Eu-151 isotope, 35 artificial radioisotopes are known. Europium is not found in nature as a free element but is found mixed with other REEs. Europium's concentration in the earth's crust is ~1.0 mg/kg and in seawater is ~1.5 ng/L. Europium has 2 natural isotopes and 35 radioisotopes.

Where is europium found?

Most economical world resources are contained in bastnasite (US and China), then in monazite (Australia, Brazil, China, Malaysia, South Africa, Sri Lanka, Thailand, and the US). The Bayan Obo iron ore deposit in China contains 0.2% Eu_2O_3 in its total REOs . Mountain Pass mine in California contains 0.100% Eu_2O_3 in its total REOs, and Mount Weld deposit in Australia, 0.400%. In Russia, europium is extracted from loparite. Many other mining projects for REEs worldwide are in various stages of development.

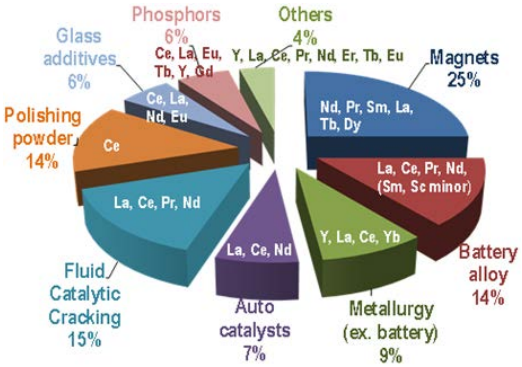
REOs World mine production (MT)		
	2010	2011
Brazil	550	550
China	130,000	130,000
India	2,800	3,000
Malaysia	30	30

2010 WORLD SUPPLY OF EUROPIUM OXIDE
~390 MT

What are the common uses of europium?

- Phosphors used in display screens, television, and trichromatic fluorescent lights
- NMR spectroscopy
- Activator for yttrium- based phosphors for TVs and computer screens
- Fluorescent light bulbs
- Some alloys
- Agent for fluorescent glass
- Ceramics and specialty glass
- Science and medical
- Anti-counterfeiting fluorescent phosphors in Euro banknotes

Distribution of rare earths by application



What are the important defense applications of europium?

- Red and blue phosphors for visual displays and light emitting diodes
- Dopant for plastic and glass to make lasers

What are some of the energy-related uses of europium?

- Energy-efficient lighting
- Color screen LCDs/PDPs
- Control rods in nuclear reactors (Eu-151)

What are the risks associated with the supply of europium?

The United States is completely dependent upon imports for its supply of europium. Europium is scarce, and its price and supply are unstable. In the various deposits in development in the world (except China), the content of europium in the ore is low, between 0.078 and 0.72% of the REOs. In the US, Mountain Pass contains 0.100% with 42,402 mtpa production expected and Bear Lodge 0.549% with 7,000 mtpa production expected in 2015. In Canada, the expected concentration of europium and mine production are as follows: Holdas Lake (0.72%—5,000 mtpa); Nechalacho (0.49%—9,296 mtpa in 2015); and Strange Lake (0.200%—12,120 mtpa in 2015). Mount Weld mine (Australia) contains 0.400% europium with an expected production of 22,000 mtpa.

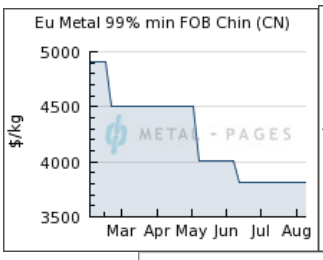
Primary Sources of U.S. REEs Imports (2007-2010):

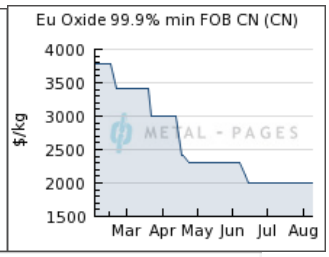
China, 79%; France, 6%; Estonia, 4%, Japan, 3% and others, 8%

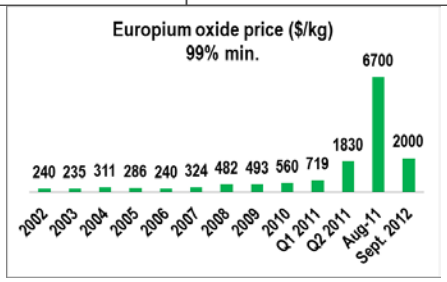
U.S. Import Dependence = 100% (2011)

Market Forecast For Europium Oxide (MT)			
Demand 2010	Supply 2010	Demand 2014	Supply 2014
400	390	540	375

Price of Europium (2012)







Stockpile Inventory

0 metric tons

Predicted Shortage

82 metric tons Basic case

Is europium recycled, reused, or recovered?

The United Nations Environment Programme estimates that the post-consumer end of life recycling is less than 1%.

Are there substitutes for europium?

Substitutions are not available for most applications, and those that are, remain generally less effective.

Sources

USGS, mineral commodity http://minerals.usgs.gov/minerals/pubs/commodity/

USGS, *The future of rare earth elements*, open file report 2011-1189

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GADOLINIUM

Photo Courtesy of U.S. DoD

What is gadolinium?

Gadolinium (Gd, Z=64), is a silvery white ductile metal which is classified as a light REE. It is relatively stable in dry air but tarnishes in moist air. Gadolinium has the highest thermal neutron capture cross-section of any known element. It is ferromagnetic at temperatures below 20°C and paramagnetic above this temperature. Its abundance in the earth's crust is ~4.0 mg/kg and 0.7 ng/L in seawater. Gadolinium has 6 natural isotopes and 29 radioisotope.

Where is gadolinium found?

Gadolinium is found always associated with other REEs. The primary source of gadolinium is from carbonatites and bastnasite (US and China) and secondly from monazite (Australia, Brazil, China, Malaysia, South Africa, Sri Lanka, Thailand, and the US). In Russia it is found in loparite. Mountain Pass mine in California contains 0.200% Gd_2O_3 from its total REOs and Mount Weld deposit in Australia 0.100%.

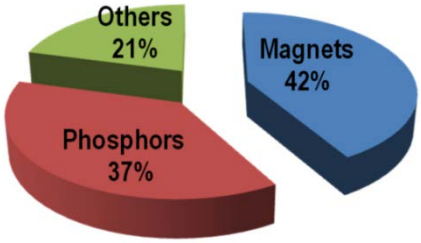
REOs World mine production (MT)		
	2010	2011
Brazil	550	550
China	130,000	130,000
India	2,800	3,000
Malaysia	30	30

2010 WORLD SUPPLY OF GADOLINIUM OXIDE
~2,800 MT

What are the common uses of gadolinium?

- Shielding in neutron radiography
- Medical services: MRIs contrast agent, X-ray
- NMR spectroscopy relaxation agent
- X-ray tubes
- High refractive index glass or garnets
- Added to chromium, iron or related alloys

DISTRIBUTION OF GADOLINIUM OXIDE PER USE



- Microwave applications (GdYG)
- Computer memory devices and CDs
- Optical lenses, optical filters, coatings
- Green phosphor for display
- Thermoelectric generating devices such as thermoionic emitter
- Deoxidation of molten titanium
- Catalytic applications
- Magnetic component that can sense hot and cold

What are the important defense applications of gadolinium?

- SmCo and NdFeB magnets
- Lasers
- Radar warning receiver, radar jammer
- Burnable poison for nuclear marine propulsion
- Green phosphors for display
- YGG used in various electronic components for communications and radar

What are some of the energy-related uses of gadolinium?

- In nuclear reactors as an emergency shutdown mechanism
- Most efficient element used to detect power plant radiation leaks
- Gd-157 used in nuclear control rods to control the fission process

What are the risks associated with the supply of gadolinium?

Although the United States is not dependent upon imports for its supply of gadolinium, military applications require very high-quality material which is generally not available from foreign sources. Gadolinium's concentration in the mines in development ranges from 0.200 to 3.435% of the REOs. Among them: Mountain Pass (0.200%—42,402 mtpa) and Mount Weld, Australia (1.00%—22,000 mtpa) should produce soon, while Bear Lodge is expected to contain 1.214% (7,000 mtpa in 2015). The Canadian's mine gadolinium content is Nechalacho—3.71%, 10,000 mtpa in 2015; Strange Lake—2.703%, 12,000 mtpa in 2015; and Holdas Lake—0.89% with 5,000 expected mtpa.

Primary Sources of U.S. REEs Imports (2007-2010):

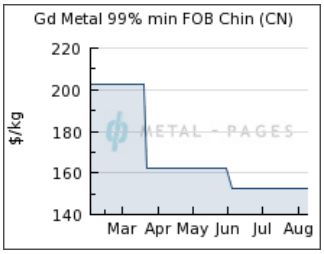
China, 79%; France, 6%; Estonia, 4%, Japan, 3% and others, 8%

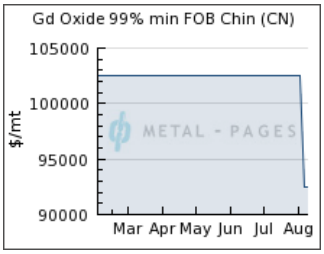
U.S. Import Dependence = 100% (2011)

Market Forecast For Gadolinium Oxide (MT)			
Demand 2010	Supply 2010	Demand 2014	Supply 2014
820	2,800	1,200	1,700

World mines reserves (MT of REOs)	
United States	13,000,000
Australia	1,600,000
Brazil	48,000
China	55,000,000
Commonwealth of Independent States	19,000,000
India	3,100,000
Malaysia	30,000
Other countries	22,000,000
World total (rounded)	110,000,000

2012 price of dysprosium





Stockpile inventory

0 metric tons

Predicted Shortage

0 metric tons

Is gadolinium recycled, reused, or recovered?

The United Nations Environment Programme estimates that the post-consumer end of life recycling is less than 1%.

Are there substitutes for gadolinium?

Substitutions are not available for most applications, and those that are, remain generally less effective.

Sources

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HOLMIUM

Photo courtesy of ORNL

What is holmium?

Holmium (Ho, Z=67) is a soft, malleable metal with a bright silver luster. It oxidizes rapidly in moist air and at elevated temperatures. It falls within the heavy lanthanide rare earths and has the strongest magnetic moment of any natural element. Holmium exists in the earth's crust at an average concentration of ~0.83 mg/kg, making it the 55th most abundant element. Holmium has one naturally occurring isotope.

Where is holmium found?

Large resources of holmium are available in xenotime and monazite. Xenotime contains 2.0 to 2.6% of Ho_2O_3 in its total REOs. Monazite, which is more abundant in the earth's crust than xenotime, has 0.05 to 0.12% Ho_2O_3 in its total REOs. The largest supplier of holmium is China, where the Longnan ion-absorption lateritic clay has 1.6% Ho_2O_3 in its total REOs, but the Xunwu deposit has only trace amounts. In Idaho-Montana, the Lemhi Pass district averages 0.19% Ho_2O_3 in its total REOs. In Russia, holmium is found in apatite, loparite, and eudialyte at contents of 0.05%, 0.7% and 2.9%, respectively, of Ho_2O_3 in the total REOs. Some sub-economic resources are present in Canada. Currently producing niobium and tantalum mines in Brazil produce tailings which are high in heavy rare earths including holmium.

REOs World mine production (MT)		
	2010	2011
Brazil	550	550
China	130,000	130,000
India	2,800	3,000
Malaysia	30	30

2010 WORLD SUPPLY OF HOLMIUM OXIDE IS ESTIMATED TO BE SMALL

What are the common uses of holmium?

- Strongest artificially generated magnetic fields
- Yellow or red colors in glass manufacturing
- Calibration in gamma ray spectrometers
- Medical and dental microwave equipment
- Cubic zirconia colorant
- Ho:YAG most widely used laser in medical surgical procedures

What are the important defense applications of holmium?

- Solid state lasers (YIG, YLF)
- Ho:YAG solid state lasers are used in military and space-based laser distance and ranging (LADAR) systems
- Ho:YAG is used in infrared countermeasure (IRCM) systems to confuse shoulder-launched, infrared "heat-seeking" missiles firing at jets and helicopters

What are some of the energy-related uses of holmium?

- Nuclear control rods

What are the risks associated with the supply of holmium?

The US is completely dependent upon imports for its supply of holmium.

PRIMARY SOURCES OF U.S. REES IMPORTS (2007-2010):

CHINA, 79%; FRANCE, 6%; ESTONIA, 4%, JAPAN, 3% AND OTHERS, 8%

U.S. IMPORT DEPENDENCE = 100% (2011)

Mountain Pass mine does not contain heavy REEs, and Bear Lodge's holmium content is 0.026% of REOs content with an expected production of 7,000 mtpa in 2015. Mount Weld (Australia) contains 0.100% holmium and has an expected production of 22,000 mtpa. Within the mines in various stages of development worldwide, the Canadian mines are Nechalacho— 0.480%, 10,000 mtpa in 2015; Strange Lake— 0.901%, 12,000 mtpa in 2015; and Holdas Lake— 0.090%, 5,000 mtpa.

Other projects other than in China are Dubbo, Australia—0.388% holmium, 2,580 mtpa in 2014; Knanefjeld— 0.200% holmium, 44,000 mtpa in 2015; Norra Karr, Sweden— 1.145% holmium, 5,000 mtpa; Zandkopsdrift, South Africa— 0.130% holmium, 20,000 mtpa in 2015; and Steenkampskraal, South Africa— 0.050% holmium, 2,500 mtpa.

World mines reserves (MT of REOs)	
United States	13,000,000
Australia	1,600,000
Brazil	48,000
China	55,000,000
Commonwealth of Independent States	19,000,000
India	3,100,000
Malaysia	30,000
Other countries	22,000,000
World total (rounded)	110,000,000

THERE IS NO PRICE AVAILABLE FOR HOLMIUM.

Is holmium recycled, reused, or recovered?

The United Nations Environment Programme estimates that the post-consumer end of life recycling is less than 1%.

Are there substitutes for holmium?

Substitutions are not available for most applications, and those that are, remain generally less effective

Stockpile inventory

0 metric tons

Predicted Shortage

0 metric tons

Sources

USGS, mineral commodity http://minerals.usgs.gov/minerals/pubs/commodity/

USGS, *The future of rare earth elements*, open file report 2011-1189

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LANTHANUM

Photo courtesy of U.S. DOE

What is lanthanum?

Lanthanum (La, Z=57) is a soft, silver white metal. It is rarely kept in elemental form due to the quickly proceeding oxidation reaction that occurs in air. Its oxide is much more stable and is the basis for most applications which use lanthanum. Lanthanum's concentration in the earth's crust is ~31 mg/kg, making it the 29th most abundant element between neodymium and yttrium. Lanthanum's concentration in seawater is ~ 29–45 ng/L. It has two natural isotopes.

Where is lanthanum found?

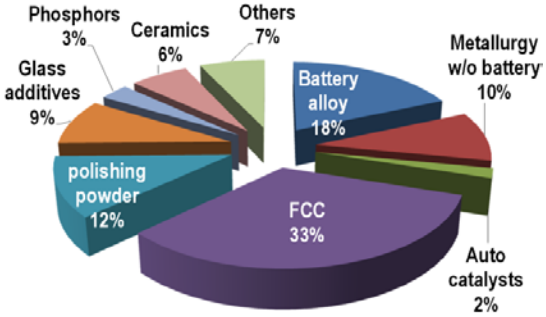
The primary source for lanthanum is in carbonatites and bastnasite (United States and China have the largest resources), a secondary source is from monazite (Australia, Brazil, China, India, Malaysia, South Africa, Sri Lanka, Thailand and the United States). Loparite in Russia is also a source. Allanite and many additional minerals can be sources. Current production occurs mostly in China, notably at the Bayan Obo rare earth and iron mine. Additional production has resumed in California at the Mountain Pass mine, where previously, only small amounts of stockpiled ore were processed. Production also started in Western Australia at the Mount Weld deposit. All non-xenotime–based REE deposits have a high percentage of lanthanum.

2010 WORLD SUPPLY OF LANTHANUM OXIDE
~30,500 MT

What are the common uses of lanthanum?

- Optical fibers, optical glasses and lenses
- Ceramic capacitors, semiconductors, and other components for LCD and electronics
- Glass manufacturing
- Doping agent for camera and telescope lenses
- Electronic vacuum
- Carbon lighting applications
- Polishing glass and gemstones
- Alloying with many different metals
- Pyrophoric alloys used in flint ignition devices for lighters and torches
- Misch metal (a mix of lanthanum, cerium, neodymium and praseodymium) used as minor alloy for the casting of steel and iron

DISTRIBUTION OF LANTHANUM OXIDE USE



What are the important defense applications of lanthanum?

- Metal alloys for nickel metal hydride batteries
- Fiber-optical communication systems
- Heat-resistant superalloys
- In samarium-cobalt magnets
- High-strength 300 M steel landing gear struts
- Infrared-absorbing glass for night vision goggles

What are some of the energy-related uses of lanthanum?

- Petroleum refining as fluid cracking catalyst
- Catalyst for oil refineries
- Ni-MH batteries
- Batteries (NiMH) for hybrid vehicles, computers and electronic devices
- Hydrogen fuel storage cells
- Phosphors in LEDs

What are the risks associated with the supply of lanthanum?

The US was completely dependent upon imports for its supply of lanthanum. Mountain Pass mine is starting production of REEs; it contains 33.20% of its REOs as lanthanum, and Mount Weld, 26.00%. In projects in development worldwide, Bear Lodge contains 31.214% of La (7,000 mtpa in 2015); in Canada, Nechalacho contains 15.83% La (10,000 mtpa in 2015); Strange Lake contains 13.213% La, 12,000 mtpa in 2015; Holdas Lake contains 20.33% La, 5,000 mtpa.

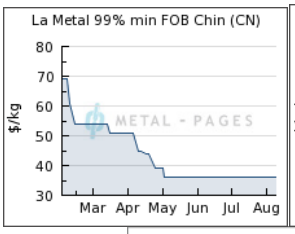
Primary Sources of U.S. REEs Imports (2007-2010):

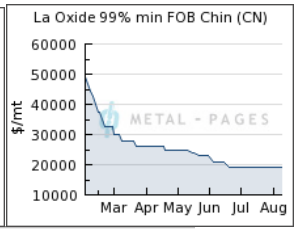
China, 79%; France, 6%; Estonia, 4%, Japan, 3% and others, 8%

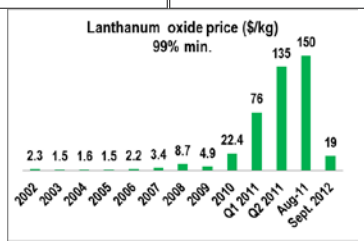
MARKET FORECAST FOR LANTHANUM OXIDE (MT)			
Demand 2010	Supply 2010	Demand 2014	Supply 2014
41,200	30,500	53,800	40,000

World mines reserves (MT of REOs)	
United States	13,000,000
Australia	1,600,000
Brazil	48,000
China	55,000,000
Commonwealth of Independent States	19,000,000
India	3,100,000
Malaysia	30,000
Other countries	22,000,000
World total (rounded)	110,000,000

Price of Lanthanum (2012)







Stockpile Inventory

0 metric tons

Predicted Shortage

0 metric tons

U.S. Import Dependence = 100% (2011)

Is lanthanum recycled, reused, or recovered?

The United Nations Environment Programme estimates that the post-consumer end of life recycling is less than 1%.

Are there substitutes for lanthanum?

Substitutions are not available for most applications, and those that are, remain generally less effective.

Sources

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LUTETIUM

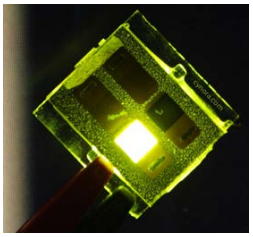

Photo courtesy of Tobias G./ Wikipedia

What is lutetium?

Lutetium (Lu, Z=71), is a silvery white metal that is relatively stable in air. It is found in very small amounts in almost all minerals containing yttrium. It is commercially extracted from monazite in which it is present at ~0.001%. It is one of the most difficult metals to prepare. The abundance of lutetium in the Earth crust is only about 0.31 mg/kg. It is one of the rarest and the most expensive of the rare earth metals with a price about US $10,000 per kilogram. It has very few commercial applications. It has two naturally occurring isotopes and several radioisotopes.

Where is lutetium found?

Resources in lutetium are in xenotime (~ 1.0 to 1.8% Lu_2O_3 in the total REOs) recovered as a by-product of mining zircon, titanium minerals, or tin minerals. Vein monazite has been mined in South Africa and the US, and as a by-product of tungsten mining in China. In Russia, loparite concentrates contain 0.15% Lu_2O_3 and eudialyte has a grade of 0.3% Lu_2O_3. The main source of the world's lutetium is in the ion-absorption lateritic clays in Southern China provinces. The Lu_2O_3 contents are 0.1 to 0.3% in the Xunwu ore and 0.4 to 0.5% in the Longnan ore's total REO grade. Mountain Pass mine in California and Mount Weld deposit in Australia do not contain lutetium.

REOs World mine production (MT)		
	2010	2011
Brazil	550	550
China	130,000	130,000
India	2,800	3,000
Malaysia	30	30

2010 WORLD SUPPLY OF LUTETIUM OXIDE IS ESTIMATED TO BE SMALL

What are the common uses of lutetium?

- Catalysts in hydrogenation and polymerization processes
- High-refractive-index optical lenses (LuAG) used in immersion lithography for manufacturing high-tech integrated circuits.
- Computer memory devices
- Dating meteorites
- X-ray phosphors
- High-refractive-index glass
- Single crystal scintillator used mainly for positron emission tomography (PET)
- Tm:LuYAG laser is used in metrology to measure wind speed and direction, pollution, and moisture

What are the important defense applications of lutetium?

- Specialty silicon nitride ceramic bearings

What are some of the energy-related uses of lutetium?

- Catalyst in refining petroleum
- Catalyst in organic LEDs
- Organic light emitting diode (OLEDs)

What are the risks associated with the supply of lutetium?

The US is completely dependent upon imports for its supply of lutetium. Lutetium is very rare and is not present in Mountain Pass and Mount Weld mines.

A few mine projects in development contain lutetium. They are in Canada, Nechalacho (0.140% of REOs, 10,000 mtpa in 2015); Strange Lake (0.400% Lu, 12,000 mtpa in 2015); and Holdas Lake (0.300% Lu, 5,000 mtpa); in South Africa, Zandkopsdrift (0.030% Lu, 20,000 mtpa in 2015) and Steenkampskraal (0.10% Lu, 2,500 mtpa); and in Australia, Dubbo(0.155% Lu, 2,580 mtpa in 2014).

Stockpile Inventory
0 metric tons

Predicted Shortage
0 metric tons

Primary Sources of U.S. REEs Imports (2007-2010):
China, 79%; France, 6%; Estonia, 4%, Japan, 3% and others, 8%

U.S. Import Dependence = 100% (2011)

World mines reserves (MT of REOs)	
United States	13,000,000
Australia	1,600,000
Brazil	48,000
China	55,000,000
Commonwealth of Independent States	19,000,000
India	3,100,000
Malaysia	30,000
Other countries	22,000,000
World total (rounded)	110,000,000

THERE IS NO PRICE AVAILABLE FOR LUTETIUM

Is lutetium recycled, reused, or recovered?

The United Nations Environment Programme estimates that the post-consumer end of life recycling is less than 1%.

Are there substitutes for lutetium?

Substitutions are not available for most applications, and those that are, remain generally less effective.

Sources

USGS, mineral commodity http://minerals.usgs.gov/minerals/pubs/commodity/

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NEODYMIUM

Photo courtesy of U.S. Navy

What is neodymium?

Neodymium (Nd, Z=60) is a soft, bright silvery metal. It is one of the most reactive REEs and quickly oxidizes in air. Neodymium averages ~ 27 mg/kg in the earth crust. The primary source of neodymium is from carbonatites and bastnasite, and a secondary source is in monazite. It is found in minerals such as cerite and allanite. The pure metal has limited application. Its mixture with praseodymium is called didymium. Neodymium has 7 natural isotopes and 23 radioisotopes.

Where is neodymium found?

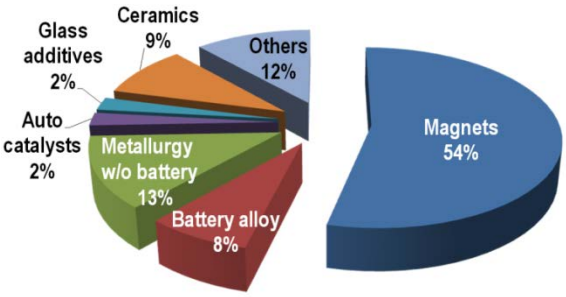
Bastnasite deposits in China and the US have the largest percentage of the world's rare-earth economic resources. Current production occurs mostly in China, notably at the Bayan Obo rare earth and iron mine. Additional production has resumed in California at the Mountain Pass mine, where previously, only small amounts of stockpiled ore were processed. Production also started late in Western Australia at the Mount Weld deposit. All non-xenotime-based REE deposits have a high percentage of neodymium. Many other projects worldwide are in various stages of development.

2010 WORLD SUPPLY OF NEODYMIUM OXIDE ~24,400 MT

What are the common uses of neodymium?

- Glass production
- Cryo-coolers
- Samarian-neodymium dating
- Glare reduction for rear-view mirrors
- Incandescent light bulbs
- Cathode ray tubes
- Misch metal (a mix of lanthanum, cerium, neodymium and praseodymium) used as minor alloy for the casting of steel and iron, magnesium, aluminum, zirconium, and titanium alloys
- Ceramic capacitors, semiconductors, and other components for LCD and electronics

DISTRIBUTION OF NEODYMIUM OXIDE USE



- NdFeB magnets used in smartphones, computer hard drives, and many consumer electronics
- MRI machines
- Welding goggles

What are the important defense applications of neodymium?

- NdFeB magnets such as those used for propulsion in the DDG-51
- Doping agent in yttrium-aluminum-garnet (Nd:YAG) lasers

What are some of the energy-related uses of neodymium?

- Electric motors for hybrid and electric vehicles
- High-powered electric motors
- Reducing fuel consumption
- Wind turbine generators
- Magnets in transportation

What are the risks associated with the supply of neodymium?

Neodymium demand exceeds available supply, and this trend is expected to continue in the foreseeable future despite new mines planned to start producing in the coming years. In the US, Mountain Pass mine contains 12.000% of its REOs content in Nd and the production is expected to be ~ 40,000 mtpa.

Bear Lodge, scheduled to produce in 2015, has 11.85% Nd and is expected to supply 7,000 mtpa. Mount Weld in Australia contains 15.00% Nd with an expected 22,000 mtpa production. Other mines in Canada and South Africa planned to start production in the coming years have deposits with 15 to 22.76% Nd. The Minor Metal trade Association (UK) reported an estimate of 8 million MT for neodymium world reserves.

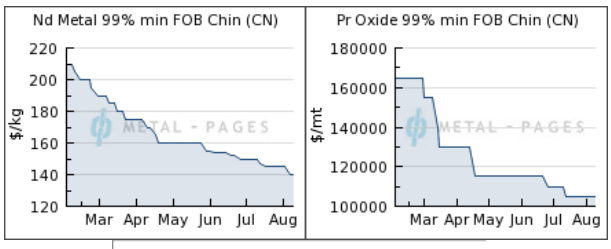
Primary Sources of U.S. REEs Imports (2007-2010):

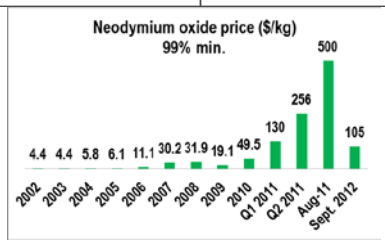
China, 79%; France, 6%; Estonia, 4%, Japan, 3% and others, 8%

U.S. Import Dependence = 100% (2011)

MARKET FORECAST FOR NEODYMIUM OXIDE (MT)			
Demand 2010	Supply 2010	Demand 2014	Supply 2014
27,000	24,400	40,900	27,900

Price of Neodymium (2012)





Is neodymium recycled, reused, or recovered?

The United Nations Environment Programme estimates that the post-consumer end of life recycling is less than 1%. Some REE producers are looking at the possibility of recycling REE-containing products.

Stockpile Inventory

0 metric tons

Predicted Shortage

2,162 metric tons Base case

Are there substitutes for neodymium?

Substitutions are not available for most applications, and those that are, remain generally less effective

Sources

USGS, mineral commodity http://minerals.usgs.gov/minerals/pubs/commodity/

USGS, *The future of rare earth elements*, open file report 2011-1189

British Geological Survey, *Rare Earth Elements,* Nov. 2011

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PRASEODYMIUM

Photo courtesy of General Electric

What is praseodymium?

Praseodymium (Pr, Z=59), is a soft, silvery, malleable and ductile metal. Its average concentration in earth's crust is ~ 7.1 mg/kg, more abundant than silver, gold, or antimony. It is found in nature associated with other REEs. Monazite and bastnasite are the two principal commercial sources for praseodymium production, even though it is also found in apatite, trachyte, fergusonite, and eudialyte. It has one natural isotope and 29 radioisotopes. It is one of the most refractory materials known. It is contained in misch metal (~ 5%) used to make cigarette lighters.

Where is praseodymium found?

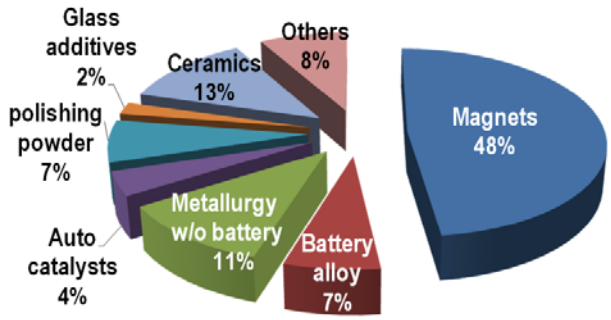
Current production occurs mostly in China, notably at the Bayan Obo rare earth and iron mine. Additional production has resumed in California at the Mountain Pass mine where praseodymium represents 4.24% of the REOs content (40,000 mtpa expected). Production also started in Western Australia at the Mount Weld deposit (4.00% Pr_2O_3 and 22,000 mtpa expected). All non-xenotime-based REE deposits have a high percentage of praseodymium. Many other projects worldwide are in various stages of development and most have ~4.0% Pr_2O_3 in their REOs content.

2010 WORLD SUPPLY OF PRASEODYMIUM OXIDE ~7,000 MT

What are the common uses of praseodymium?

- Carbon-arc lights and CAT scan scintillators
- Projector lights
- Welder's and glass blower's goggles
- Doping agent in fiber optic cables and in several metal alloys
- Thermal resistance alloys
- Colorant in glasses and enamels
- Ferrocerium firesteel products
- Catalyst to make polyethylene

DISTRIBUTION OF PRASEODYMIUM OXIDE USE



- Misch metal (a mix of lanthanum, cerium, neodymium and 5% praseodymium) used as minor alloy for the casting of steel and iron
- Optical lenses, optical filters, coatings
- Ceramic capacitors, semiconductors, and other components for LCD and electronics
- Magnets for MRI machines

What are the important defense applications of praseodymium?

- NdFeB magnets
- Alloyed with Mg in aircraft engines
- Lasers

What are some of the energy-related uses of praseodymium?

- Energy-efficient lighting
- Catalytic converters
- Magnets for wind turbines and transportation

What are the risks associated with the supply of praseodymium?

Until the end of 2012, the US was completely dependent on importation for its supply of praseodymium. With the Mountain Pass starting production, there will be some domestic supply even if not sufficient to fulfill demand. The Minor Metal trade association (UK) reported that the estimated world reserves of praseodymium are ~2 million MT .

The forecast for praseodymium oxide demand is expected to surpass supply, at least until the mine projects in development start production around 2015.

Primary Sources of U.S. REEs Imports (2007-2010):

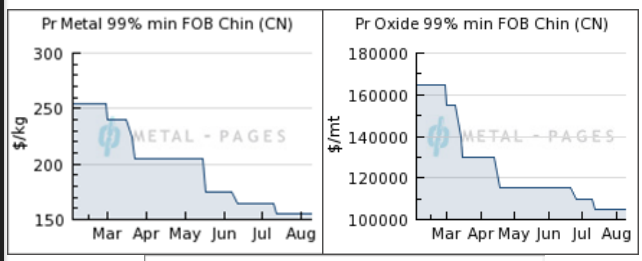
China, 79%; France, 6%; Estonia, 4%, Japan, 3% and others, 8%

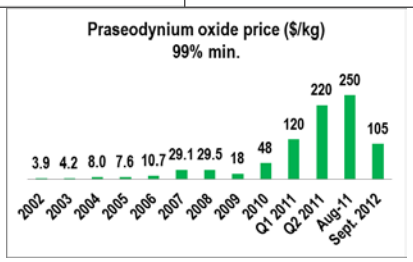
U.S. Import Dependence = 100% (2011)

Market forecast for praseodymium oxiide (MT)			
Demand 2010	Supply 2010	Demand 2014	Supply 2014
9,800	7,000	14,400	8,300

World mines reserves (MT of REOs)	
United States	13,000,000
Australia	1,600,000
Brazil	48,000
China	55,000,000
Commonwealth of Independent States	19,000,000
India	3,100,000
Malaysia	30,000
Other countries	22,000,000
World total (rounded)	110,000,000

2012 price of praseodymium





Stockpile inventory

0 metric tons

Predicted Shortage

0 metric tons for base case

Is praseodymium recycled, reused, or recovered?

The United Nations Environment Programme estimates that the post-consumer end of life recycling is less than 1%.

Are there substitutes for praseodymium?

Substitutions are not available for most applications, and those that are, remain generally less effective

Sources

USGS, mineral commodity http://minerals.usgs.gov/minerals/pubs/commodity/

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PROMETHIUM

Photo courtesy of U.S. Army

What is promethium?

Promethium (Pm, Z=61), is a man-made element. It is detected in uranium fission products. All the isotopes of promethium are radioactive. It is the rarest of the lanthanide elements. Promethium has very limited applications. This element has been found in natural neodymium in equilibrium in quantities below 10^{-20} grams of promethium per one gram of neodymium. Promethium can be formed in nature as a product of spontaneous fission of uranium-238. Only trace amounts can be found in naturally occurring ores: a sample of pitchblende has been found to contain promethium at a concentration of four parts per quintillion (10^{-18}) by mass.

Where is promethium found?

Promethium-147 is the commercially used radioisotope. It is produced from fission product wastes by bombarding uranium-235 with thermal neutrons; the yield is ~2.25%.Currently, Russia is the only country producing promethium-147 on a relatively large scale.

2010 WORLD SUPPLY OF PROMETHIUM OXIDE IS NOT AVAILABLE BUT IS ESTIMATED TO BE VERY LOW

What are the common uses of promethium?

- Beta radiation sources for thickness gauges
- Possible x-ray source
- Phosphor lights to produce signals
- Pr-149 used in cancer treatment as a beta emitter
- Applied on watch hand and dials to glow in the dark
- The radiation from Pr is used as a thickness gauge for thin plastics, sheet metal, rubber, textiles, and paper.
- Electric blanket thermostats

What are the important defense applications of promethium?

- Luminescent paint for night sights for shoulder-fired missiles (LAW launcher)

What are some of the energy-related uses of promethium?

- Nuclear batteries (useful life of 5 years)

What are the risks associated with the supply of promethium?

A number of important isotopes such as Pr-147 are needed in the US that are not currently available in sufficient amounts and quality for special applications in medical research, applied clinical nuclear medicine, science, oil exploration, construction, homeland security, national security, and defense. In the US, no Pr-147 was produced since the 1970s, and the stock has been depleted. At ORNL, an alternate method of producing promethium-147 was proposed, using the High Flux Isotope Reactor (HFIR), in which enriched neodymium-146 could be irradiated and create neodymium-147 in the peripheral target positions. Nd-147 would decay to promethium-147. The yield from the HFIR process would be lower than that from uranium fission but could provide promethium-147 in useful quantities of 500 to 1000 curies for research and development.

U.S. IMPORT DEPENDENCE = UNKNOWN (2011)

THERE IS NO PRICE AVAILABLE FOR PROMETHIUM

STOCKPILE INVENTORY
0 metric tons

PREDICTED SHORTAGE
0 metric tons

Is promethium recycled, reused, or recovered?

There is no recovery or recycling for promethium

Are there substitutes for promethium?

Substitutions are not available for most applications, and those that are, remain generally less effective.

Sources

USGS, mineral commodity http://minerals.usgs.gov/minerals/pubs/commodity/

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Proedge wire, Rare metal blog, *http://www.reehandbook.com/promethium.html*

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SAMARIUM

Photo courtesy of Raytheon

What is samarium?

Samarium (Sm, Z=62) is a bright silver metal that is reasonably stable in air. It occurs in nature widely distributed but in trace quantities always associated with other REEs. It is found in the earth's crust at an average of ~4.7 mg/kg. The commercial source of samarium is from carbonatites and bastnasite. It is also found in Precambrian granite rocks, shale, and in minerals such as xenotime and basalt. Misch metal contains ~1% samarium metal. Samarium has 7 natural isotopes and 22 radioisotopes.

Where is samarium found?

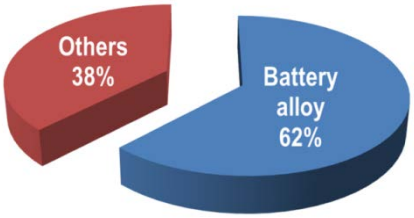
Most economical world resources are contained primary in bastnasite (US and China) and secondarily in monazite: ~2.8% Sm_2O_3 in the REOs content (Australia, Brazil, China, India, Malaysia, South Africa, Sri Lanka, Thailand, and the US). Samarium from loparite is recovered in Russia. Mountain Pass mine in California started production and is expected to produce 40,000 mtpa; the ore contains 0.800% Sm_2O_3 in the total REOs. Mount Weld deposit in Australia contains 1.800% Sm_2O_3 in the REOs and has an expected production of 22,000 mtpa. Many other projects worldwide are in various stages of development.

2010 WORLD SUPPLY OF SAMARIUM OXIDE
~ 3,300 MT

What are the common uses of samarium?

- Sm-Co permanent magnets
- Music industry (precise pickups)
- Infrared absorption glass
- Optical glass
- Capacitor for microwave frequencies
- In cancer drug "Quadramet"
- Thermoionic generating devices

DISTRIBUTION OF SAMARIUM OXIDE USE



- Carbon arc lighting
- Catalyst for the production of ethyl alcohol
- Chemical reagent in organic synthesis

What are the important defense applications of samarium?

- Sm-Co permanent magnets such as those used for navigation in the M1A2 Abrams tanks
- Present in NYAG (neodymium-yttrium-aluminum-garnet) laser glass

What are some of the energy-related uses of samarium?

- Sm-Co permanent magnets
- Neutron absorber in nuclear reactors

What are the risks associated with the supply of samarium?

The US is totally dependent on importation for the supply of samarium; however, the start of Mountain Pass mine production should cover some of the domestic needs. Apparently, samarium does not appear to be as scarce as other REEs. The Minor Metals Trade Association (UK) indicated an ~2 million MT reserve of samarium worldwide. Samarium will be produced in several of the new mine developments that will start producing in the next few years. Bear Lodge mine expected to open in 2015 contains 2.341% Sm_2O_3 (~ 7,000 mtpa expected).

Similarly in Canada, three near-future projects contain 2.6 to 3.91% of Sm (two are supposed to start production in 2015).

Primary Sources of U.S. REEs Imports (2007-2010):

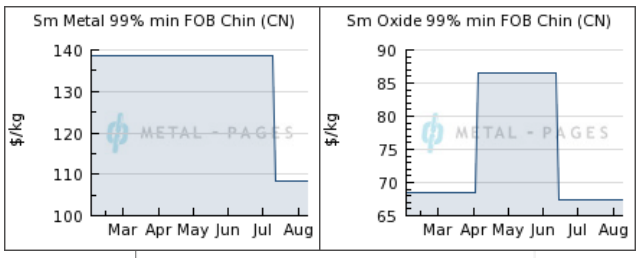
China, 79%; France, 6%; Estonia, 4%, Japan, 3% and others, 8%

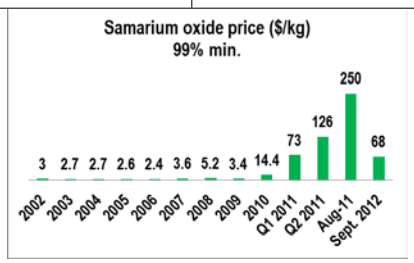
U.S. Import Dependence = 100% (2011)

World mines reserves (MT of REOs)	
United States	13,000,000
Australia	1,600,000
Brazil	48,000
China	55,000,000
Commonwealth of Independent States	19,000,000
India	3,100,000
Malaysia	30,000
Other countries	22,000,000
World total (rounded)	110,000,000

MARKET FORECAST FOR SAMARIUM OXIDE (MT)			
Demand 2010	Supply 2010	Demand 2014	Supply 2014
600	3,300	1,100	2,900

Price of Samarium (2012)





Stockpile Inventory

0 metric tons

Predicted Shortage

40 metric tons Basic case

Is samarium recycled, reused, or recovered?

The United Nations Environment Programme estimates that the post-consumer end of life recycling is less than 1%.

Are there substitutes for samarium?

Substitutions are not available for most applications, and those that are, remain generally less effective.

Sources

USGS, mineral commodity http://minerals.usgs.gov/minerals/pubs/commodity/

USGS, *The future of rare earth elements*, open file report 2011-1189

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SCANDIUM

Photo courtesy of Hrd10 (Wikipedia)

What is scandium?

Scandium (Sc, Z=21) is a transition metal that is silvery white, soft and light. It has one naturally occurring isotope and 15 radioisotopes. It is found widely dispersed in low concentrations in many minerals. Scandium's concentration in the earth's crust is ~14 mg/kg. It is found in ~800 different minerals, but primarily as a trace constituent of ferro magnesium minerals. The world market for this metal is small. It is estimated that 20 kg of scandium are used yearly in the US (80 kg in the world) to produce high-intensity lights.

Where is scandium found?

One of the few minerals having a notable scandium content is thortveitite, which is the primary source of scandium. Uranium mill tailings by-products also are an important source. Other rare minerals that contain scandium are bazzite, kolbeckite, ixiolite-Sc, perrierite-Sc, and magbasite. Norway, Madagascar, and the United States have thortveitite, which contains from 44 to 48% scandium oxide (ScO_2). Scandium is found as a by-product material either during processing of various ores (aluminum, cobalt, iron, molybdenum, nickel, phosphate, tantalum, tin, titanium, tungsten, zinc, and zirconium) or recovered from previously processed tailings (in MT, OK, Co and UT in the US) or residues (tungsten, tantalum, uranium). By-product scandium was produced in China, Kazakhstan, Russia, and Ukraine. The main source for scandium is the Bayan Obo rare-earth mine in China.

What are the common uses of scandium?

- Additive in mercury-vapor lamps
- Sports equipment such as baseball bats, lacrosse sticks and bicycle frames
- Frames in scandium alloy for Smith and Wesson revolvers
- Analytical standards
- Electronics

2010 WORLD SUPPLY OF SCANDIUM OXIDE IS ESTIMATED TO BE ~ 5 MT

What are the important defense applications of scandium?

- Light aluminum-scandium alloy for aerospace components
- Lasers
- High-intensity lamps for landing gear

What are some of the energy-related uses of scandium?

- High-intensity discharge lamps
- Radioactive Sc-46 is used as a tracer for crude oil

What are the risks associated with the supply of scandium?

The scandium used in the United States was almost all produced by foreign countries, with China thought to be the main source. No scandium was mined nor recovered from tailings in the United States since 1990. However, sufficient quantities to meet demand were available in domestic tailings. New demands for scandium are expected to come from future fuel-cell markets and aerospace applications. However, there is no reliable, secure, stable, and long-term production for this metal. Undiscovered scandium resources are thought to be very large, besides those already known in Australia, China, Kazakhstan, Madagascar, Norway, Russia, and Ukraine.

U.S. IMPORT DEPENDENCE = 100% (2011)

Scandium is an expensive material

PRICE OF DIFFERENT SCANDIUM PRODUCTS

	2007	2008	2009	2010	2011
Oxide, 99.0% ($/kg)	700	900	900	900	900
Sc-Al alloy ($/kg)	74	74	74	74	220
Metal ingot ($/gram)	131	152	155	158	163

Is scandium recycled, reused, or recovered?

The United Nations Environment Programme estimates that the post-consumer end of life recycling is less than 1%.

Are there substitutes for scandium?

There is no substitute for lighting and laser applications; however, the use of high-intensity lights is decreasing to the costs of LEDs. For sport applications, materials such as carbon fiber and carbon nanotubes, and titanium and aluminum high-strength alloys are available.

STOCKPILE INVENTORY
0 metric tons

PREDICTED SHORTAGE
0 metric tons

Sources

USGS, http://minerals.usgs.gov/minerals/pubs/commodity/scandium/index.html

Wikipedia, http://en.wikipedia.org/

Patnaik, Pradyot , Handbook of Inorganic Chemicals, 2003, McGraw-Hill

UNEP, *Recycling Rates of Metals—A Status Report,* 2011, http://www.unep.org/resourcepanel/metals_recycling/

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STRONTIUM

Photo courtesy of U.S. DoD

What is strontium?

Strontium (Sr, Z=38) is a silvery-white metal. It is found in nature in two minerals, celestite (strontium sulfate) and strontianite (strontium carbonate). Strontium sulfate is the most common. Strontium's abundance in the earth's crust is ~320 mg/kg and 7.9 mg/kg in seawater. Strontium is used mostly as a compound, rarely as a pure metal. Strontium has four stable natural isotopes and 23 artificial radioisotopes.

Where is strontium found?

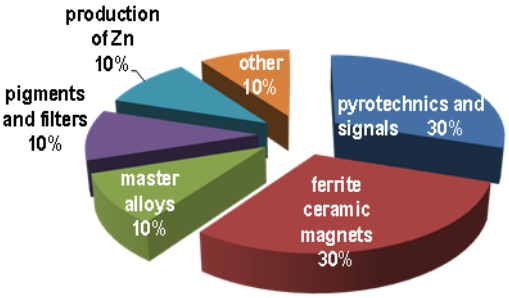
Over half of all strontium is mined in China, and Spain and Mexico are also large producers. The United States' resources of celestite are primarily in California and Texas. These mines have not been producing since 1959.

What are the common uses of strontium?

- Pyrotechnics and signals
- Ferrite ceramic magnets
- Dielectrics and electronic materials
- Ceramics and glasses
- Alloys
- Pigments and fillers
- Electrolytic production of zinc
- Strontium oxide and carbonate are used as nontoxic alternatives to lead and barium in glass frit
- Getter for vacuum tubes
- Sr-89 used in cancer treatment

World Mine Production (MT)		
	2010	2011
Argentina	7,000	7,100
China	220,000	210,000
Mexico	31,400	35,000
Morocco	2,500	2,500
Spain	140,000	120,000
Other Countries	3,600	3,600
World Total	405,000	380,000

Major Uses Of Strontium



What are the important defense applications of strontium?

- Dielectrics
- Pyrotechnics and tracer ammunition
- The radioactive Sr-90 is a nuclear-electric power source in space vehicle and remote weather stations

What are some of the energy-related uses of strontium?

- Dielectric
- Ferrite ceramic magnets
- Solid oxide fuel cells

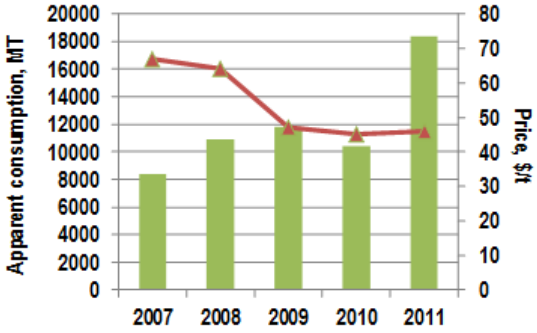
What are the risks associated with the supply of strontium?

The US is heavily reliant on importing strontium (e.g. minerals and compounds). For the period 2007–2010, 79% of total imports of strontium came from Mexico, 10% from Germany and the remaining 11% from other countries. Domestic production is primarily small amounts of downstream chemicals. Production of strontium carbonate ceased domestically in 2006 even though deposits of strontium are widely distributed within the country. A few companies produce small amounts of strontium chemicals.

The world reserves of strontium are thought to exceed 1 billion MT, with China having ~6,800,000.

U.S. IMPORT DEPENDENCE = 100% (2011)

U.S. APPARENT CONSUMPTION AND METAL PRICE



Is strontium recycled, reused, or recovered?

The United Nations Environment Programme estimates that the post-consumer end of life recycling is less than 1%.

STOCKPILE INVENTORY
0 metric tons

PREDICTED SHORTAGE
0 metric tons

Are there substitutes for strontium ?

Barium can be substituted for strontium in ferrite ceramic magnets, but the performance is lower. In other applications, substitutes are not available.

Sources

USGS, http://minerals.usgs.gov/minerals/pubs/commodity/strontium/index.html

Patnaik, Pradyot , Handbook of Inorganic Chemicals, 2003, McGraw-Hill

UNEP, *Recycling Rates of Metals—A Status Report,* 2011, http://www.unep.org/resourcepanel/metals_recycling/

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TERBIUM

Photo courtesy of US DoD

What is terbium?

Terbium (Tb, Z=65) is a silvery-grey rare earth metal that is malleable and ductile, soft enough to be cut with a knife, and relatively stable in air compared with other lanthanides. Terbium's concentration in the upper crust of the earth is ~0.7 mg/kg. Terbium is found in nature associated with other REEs in xenotime, euxenite, cerite, monazite and gadolinite at concentrations typically < 1% REOs. Terbium has one natural isotope and 25 radioisotopes. It is an expensive material.

Where is terbium found?

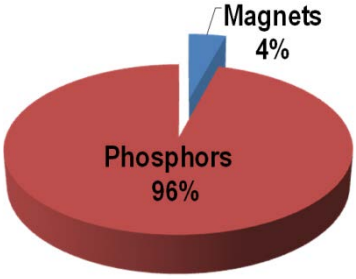
Large resources of terbium are contained in heavy REE enriched minerals such as monazite and xenotime, carbonatites, uranium ores and weathered clays. Mountain Pass mine in California does not contain terbium, but Mount Weld deposit in Australia contains ~0.100% terbium in its REOs. Large sub-economic resources are found in Canada (Elliot lake, Hoidas lake, Thor lake and Kipawa). The main source of terbium is the ion-absorption lateritic clays in the southern provinces of China.

2010 WORLD SUPPLY OF TERBIUM OXIDE
~ 380 MT

What are the common uses of terbium?

- Green phosphors for trichromatic lighting technology used in compact fluorescent light bulbs and liquid crystal displays
- Magnetostrictive alloys, materials that change shape or dimensions when magnetized, which are used in solid-state transducers, mechanical resonators, and high-precision actuators, positioners
- Dopant for calcium fluoride, sodium borate and strontium molybdate materials
- Terbium-doped silica glass and Tb:YAG crystals are used in fiber-optic temperature sensors
- Component of Terfenol-D, a material used in transducers
- Magneto-optic recording of data
- Solid state devices

DISTRIBUTION OF TERBIUM OXIDE USE



What are the important defense applications of terbium?

- Green phosphors for video displays and night vision goggles
- Additive to high-strength neodymium-iron-boron magnets (Tb added as much as 5%)
- Lasers

What are some of the energy-related uses of terbium?

- Fluorescent lamps
- High-precision liquid fuel injectors
- Crystal stabilizer in fuel cells

What are the risks associated with the supply of terbium?

The United States is completely dependent upon imports for its supply of terbium. Bear Lodge mine, scheduled to produce in 2015, contains 0.171% in its REOs. The supply of terbium is expected to be in deficit in the foreseeable future.

Primary Sources of U.S. REEs Imports (2007-2010):

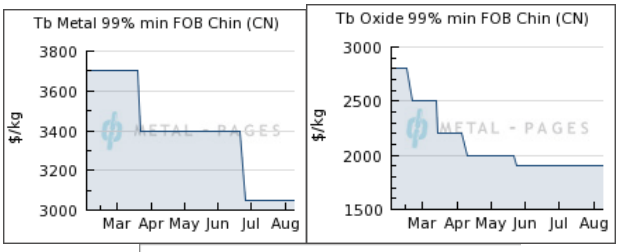
China, 79%; France, 6%; Estonia, 4%, Japan, 3% and others, 8%

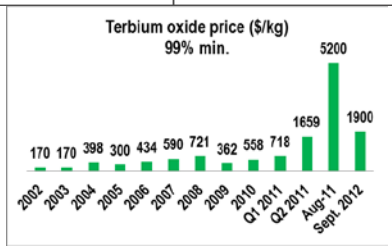
U.S. Import Dependence = 100% (2011)

MARKET FORECAST FOR TERBIUM OXIDE (MT)			
Demand 2010	Supply 2010	Demand 2014	Supply 2014
440	380	600	250

World mines reserves (MT of REOs)	
United States	13,000,000
Australia	1,600,000
Brazil	48,000
China	55,000,000
Commonwealth of Independent States	19,000,000
India	3,100,000
Malaysia	30,000
Other countries	22,000,000
World total (rounded)	110,000,000

Price of Terbium





Is terbium recycled, reused, or recovered?

The United Nations Environment Programme estimates that the post-consumer end of life recycling is less than 1%.

Stockpile Inventory

0 metric tons

Estimated DoD Demand

18 metric tons (2011-2015)

Predicted Shortage

6 metric tons

45 metric tons base case analysis

Are there substitutes for terbium?

Substitutions are not available for most applications, and those that are, remain generally less effective.

Sources

USGS, mineral commodity http://minerals.usgs.gov/minerals/pubs/commodity/

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THULIUM

Photo courtesy of Wikipedia

What is thulium?

Thulium (Tm, Z=69), is a silvery-white lustrous metal. It is soft, malleable and ductile. Thulium is the second rarest element after promethium. Its concentration in the upper continental crust is ~0.30 mg/kg. It is found in small quantities with other REEs in several yttrium-rich minerals such as xenotime, gadolinite, euxenite, loparite, fergusonite, yttroparisite and samaskite, but it is extracted commercially from monazite which contains ~0.007% Tm. It is very difficult to separate from the other REEs. Because of its scarcity and high price, there are not many application for this element. There is one natural isotope and 30 radioisotopes for thulium.

Where is thulium found?

Xenotime contains 1.1 to 1.3% Tm_2O_3. Neither Mountain Pass mine in California nor Mount Weld deposit in Australia produces thulium. The main source of thulium is the ion-absorption lateritic clays in Southern China. The Longnan ore contains 0.13 to 0.7% Tm_2O_3, and Xunwu's ore from traces to 0.3%. Sub-economic resources are present in Canada at Eden Lake, Hoidas Lake, Thor Lake, and Kipawa. In Russia, loparite concentrates contain 0.1% Tm_2O_3 , and in Kyrgyzstan synchysite concentrates have 0.25 to 0.3% Tm_2O_3 .

REOs World mine production (MT)		
	2010	2011
Brazil	550	550
China	130,000	130,000
India	2,800	3,000
Malaysia	30	30

2010 WORLD SUPPLY OF THULIUM OXIDE IS ESTIMATED TO BE LOW

What are the common uses of thulium?

- Portable x-ray devices for medical and dental applications when electric power is not available (Tm-169)
- Scientific experimentation
- Cr,Tm,Ho:YAG lasers used in surgery, dentistry, atmospheric testing, and remote sensing

What are the important defense applications of thulium?

- Was used to create laser light, but the production costs were too high to sustain commercial production
- Could be used in ceramic magnets for microwave equipment

What are some of the energy-related uses of thulium?

- High temperature superconductors
- Metal halide lamps

What are the risks associated with the supply of thulium?

The US is completely dependent upon imports for its supply of Thulium; however, the applications for that material are limited. The production is scarce, and in the 10 mine development projects expected to start production in a few years, only 8 contain some thulium. Among those mines, only 3 have Tm content above 0.1% REOs. Strange Lake in Canada apparently contains 0.501% Tm (12,000 mtpa) and the Norra Karr project in Sweden would have 0.573%, but this project is not in near-future production.

Primary Sources of U.S. REEs Imports (2007-2010):

China, 79%; France, 6%; Estonia, 4%, Japan, 3% and others, 8%

U.S. Import Dependence = 100% (2011)

World mines reserves (MT of REOs)	
United States	13,000,000
Australia	1,600,000
Brazil	48,000
China	55,000,000
Commonwealth of Independent States	19,000,000
India	3,100,000
Malaysia	30,000
Other countries	22,000,000
World total (rounded)	110,000,000

THERE IS NO PRICE AVAILABLE FOR THULIUM

Is thulium recycled, reused, or recovered?

The United Nations Environment Programme estimates that the post-consumer end of life recycling is less than 1%.

Are there substitutes for thulium?

Substitutions are not available for most applications, and those that are, remain generally less effective

Stockpile Inventory

0 metric tons

Predicted Shortage

0 metric tons

Sources

USGS, mineral commodity http://minerals.usgs.gov/minerals/pubs/commodity/

USGS, *The future of rare earth elements*, open file report 2011-1189

British Geological Survey, *Rare Earth Elements,* Nov. 2011

Öko-Institute e.V., *Study on Rare Earths and their Recycling,* Jan. 2011

United Nations Environment Programme, *Recycling Rates of Metals, 2011*

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YTTERBIUM

Photo courtesy of General Electric

What is ytterbium?

Ytterbium (Yb, Z=70), is a soft, malleable, and ductile silvery metal. Its concentration in the upper continental crust is ~1.96 mg/kg. It is found in nature in the minerals euxenite, gadolinite, monazite and xenotime, but it is principally commercially extracted from monazite sand that contains ~0.03% Yb. Ytterbium has seven natural occurring isotopes and 23 radioisotopes.

Where is ytterbium found?

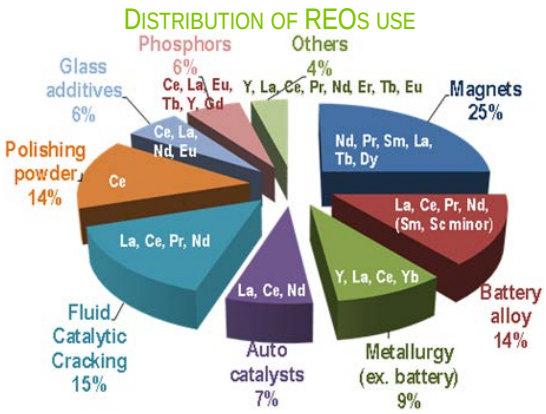
Ytterbium is present at mines in Canada— Thor Lake and Kipawa. It is found in Russia in loparite (0.2% Yb_2O_3 REO grade); in the US at Lemhi Pass the monazite ore contains 0.21% Yb_2O_3; in Kyrgyzstan, a synchysite concentrate contained 1.2 to 3.3% Yb_2O_3. At Mount Weld in Australia, ytterbium is present at 0.100% of REOs. The main source of Yb is in China in ion-absorbed lateritic clays containing 0.3 to 0.6% Yb_2O_3 in the Xunwu ore and 2.5 to 3.5% in Longnan ore, both located in the southern provinces of China.

REOs World mine production (MT)		
	2010	2011
Brazil	550	550
China	130,000	130,000
India	2,800	3,000
Malaysia	30	30

WORLD PRODUCTION OF YTTERBIUM IS ESTIMATED TO BE ~ 50 MT PER YEAR

What are the common uses of ytterbium?

- Portable x-ray machines when electricity is not available
- Doping of stainless steel
- Chemical reducing agent
- Optical glasses, crystals and ceramics
- In titanate insulated capacitors



- Pulsed green ytterbium fiber lasers are used in ablation, micromachining, texturing and marking vehicle part identification numbers, medical products, and implants
- Ytterbium lasers are used to drill into diamonds to remove imperfections.
- Heat-treatment with ytterbium lasers is used to surface-harden turbine blades, threads on industrial tools, and piston rings.
- To fight cancerous cells (implanted radioactiveYb-169)
- Stress gauges to monitor ground deformations from earthquakes.

What are the important defense applications of ytterbium?

- Super alloys for jet engines
- Infrared lasers
- Doping agent for high-power solid state lasers

What are some of the energy-related uses of ytterbium?

- Solar cells to convert infrared energy into electricity
- Carbon rods for industrial lighting

What are the risks associated with the supply of ytterbium?

The US is completely dependent upon imports for its supply of ytterbium. This element is scarce and not abundant in the ore it is contained in. Mountain Pass doe not contain Yb, and Bear Lodge has 0.032% Yb_2O_3 among the total REOs. Three mine projects in development have higher concentrations of Yb_2O_3: Strange Lake in Canada contains 2.803% (12,000 mtpa expected in 2015), Dubbo in Australia contains 1.008% (2.,580 mtpa expected in 2014), and Holdas Lake contains 1.300%. Four other projects contain ytterbium, but at low concentrations, 0.032 to 0.23%.

Primary Sources of U.S. REEs Imports (2007-2010):

China, 79%; France, 6%; Estonia, 4%, Japan, 3% and others, 8%

U.S. Import Dependence = 100% (2011)

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India	3,100,000
Malaysia	30,000
Other countries	22,000,000
World total (rounded)	110,000,000

THERE IS NO PRICE AVAILABLE FOR YTTERBIUM

Is ytterbium recycled, reused, or recovered?

The United Nations Environment Programme estimates that the post-consumer end of life recycling is less than 1%.

Stockpile Inventory

0 metric tons

Predicted Shortage

0 metric tons

Are there substitutes for ytterbium?

Substitutions are not available for most applications, and those that are, remain generally less effective

Sources

USGS, mineral commodity http://minerals.usgs.gov/minerals/pubs/commodity/

USGS, *The future of rare earth elements*, open file report 2011-1189

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YTTRIUM

Photo courtesy of DOE

What is yttrium?

Yttrium (Y, Z=39) is a soft, silver-colored metal which has similar properties to the lanthanides and is classified with the REEs. Its abundance in the earth's crust is ~ 21 mg/kg, making it the 28th most abundant element in the earth's crust. Yttrium occurs with most rare earths deposits. It has one naturally occurring isotope and 24 radioisotopes.

Where is yttrium found?

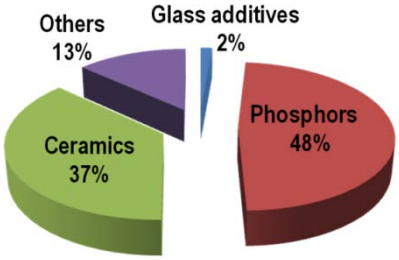
Yttrium is recovered commercially from monazite sand, which contains about 3% yttrium. It is found in bastnasite at ~0.2%. China supplied most of the world's needs from its weathered clay-ion ore deposits from the southern provinces, which are extremely low-grade but large-tonnage sources. Yttrium is also present in large sub-economic deposits as a by-product of other minerals from varied deposit types worldwide. Several western deposits are in the early stages of development in Alaska, Texas, Missouri, and Canada. Currently producing niobium and tantalum mines in Brazil produce tailings which are high in yttrium.

What are the common uses of yttrium?

- Pigment and stabilizer in ceramics
- YBCO high temperature superconductors
- Host for europium in TV red phosphor (YVO_4)
- Metallic alloy component
- Garnet crystals
- LED phosphor for white and grey colors
- Deoxidizer for vanadium and other nonferrous metals
- Catalyst for the polymerization of ethylene
- Medical applications (Y-90)
- Optical and camera lenses
- Solid electrolytes
- Exhaust systems
- Refractory material
- Gas mantles for propane lanterns

World mine production (MT of Y_2O_3)		
	2010	2011
Brazil	15	15
China	8,800	8,800
India	55	55
Malaysia	4	4

DISTRIBUTION OF YTTRIUM OXIDE USE



What are the important defense applications of yttrium?

- Phosphors for visual displays
- Protective ceramic layers in jet engines
- Heat-resistant superalloys for jet engines
- Microwave and millimeterwave radar
- Laser rangefinder
- YAG (yttrium-aluminum-garnet) lasers for range finders and target designators
- YIG (yttrium-iron-garnet) essential for high-power military microwave radar devices such as filters, oscillators, and phase shifters.
- Missile and targeting ranging
- Gearbox and transmission
- Radar warning receiver, radar jammer

What are some of the energy-related uses of yttrium?

- Stabilizer in ceramic-coated particle fuel for pebble-bed-type nuclear reactors
- High-performance spark plugs
- Catalytic converters
- Oxygen sensor in automobile

What are the risks associated with the supply of yttrium?

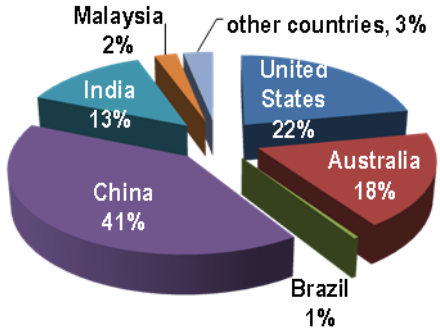
The United States is completely dependent upon imports for its supply of yttrium, which is a required material for use in phosphors and in electronics used in the military. During the 2007–2010 time frame, yttrium oxide compounds were imported from: China (63%), Japan (9%), France (6%), UK (4%), and other (18%).

The United States has roughly half the yttrium reserves of China, but all are currently classified as sub-economic.

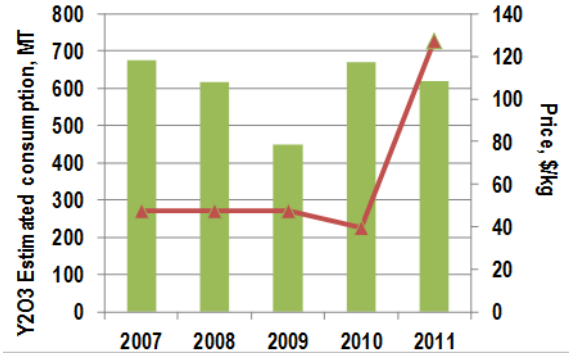
U.S. IMPORT DEPENDENCE = 100% (2011)

MARKET FORECAST FOR YTTRIUM OXIDE (MT)			
Demand 2010	Supply 2010	Demand 2014	Supply 2014
7,500	13,500	9,300	6,000

2011 WORLD MINE RESERVES (540,000 MT OF YTTRIUM OXIDE)



U.S. APPARENT CONSUMPTION AND METAL PRICE



STOCKPILE INVENTORY

0 metric tons

PREDICTED SHORTAGE

1,520 metric tons for base case

Is yttrium recycled, reused, or recovered?

Yttrium is recycled in small quantities from yttrium iron garnet and yttrium aluminum garnet laser crystals. In most applications, yttrium is present only in minute amounts and not economically viable to recover. The United Nations Environment Programme estimates that the post-consumer end of life recycling is less than 1%.

Are there substitutes for yttrium?

In the stabilization of zirconia ceramics, yttrium oxide may be substituted for calcium oxide or magnesium oxide. This substitution has the detriment of decreasing the overall toughness of the resulting ceramic.

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CHROMIUM

Photo Courtesy of U.S. Air Force

What is chromium?

Chromium (Cr, Z= 24) is a steely-gray, lustrous, hard metal that takes a high polish and has a high melting point. Chromium is remarkable for its magnetic properties: it is the only elemental solid that shows antiferromagnetic ordering at room temperature (and below). Above 38°C, it transforms into a paramagnetic state.

Where is chromium found?

Chromium is the 21st most abundant element in earth's crust with an average concentration of 100 ppm. Chromium compounds are found in the environment due to the erosion of chromium-containing rocks and can also be distributed by volcanic eruptions.

Chromium is mined as chromite ($FeCr_2O_4$) ore. About two-fifths of the chromite ores and concentrates in the world are produced in South Africa, while Kazakhstan, India, Russia, and Turkey are also substantial producers. Untapped chromite deposits are plentiful, but geographically concentrated in Kazakhstan and southern Africa.

Although rare, deposits of native chromium exist. The native metal occurs in the Udachnaya Pipe in Russia. This mine is a kimberlite pipe with a reducing environment that helped produce both elemental chromium and diamonds.

What are the common uses of chromium?

- Component in stainless steels
- Component in nickel superalloys for land-based turbines and jet engines
- Component in high speed tool steel
- Surface coatings
- Catalysts for processing hydrocarbons

WORLD MINE PRODUCTION (THOUSAND MT)		
	2009	2010
United States	0	0
India	3,760	3,800
Kazakhstan	3,330	3,400
South Africa	6,870	8,500
Other Countries	5,340	6,300
World Total	19,300	22,000

- Refractory materials
- Resistance heating wires

What are the important defense applications of chromium?

- Component in nickel superalloys for high temperature sections of jet engines
- Component in stainless steel for structural elements and fasteners

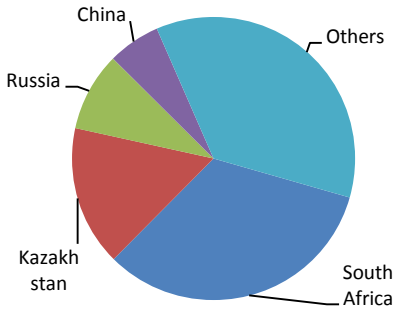
What are the risks associated with the supply of chromium?

In 2010, one U.S. company mined chromite ore in Oregon.

How are the risks being managed?

Chromium has no substitute in stainless steel (the leading end use), or in superalloys (the major strategic end use). Chromium-containing scrap can substitute for ferrochromium in some metallurgical uses.

Primary Sources of U.S. Cr Imports
U.S. Import Dependence = 100% (2010)



Stockpile Inventory

4,443 metric tons of chrome metal
155,505 metric tons of ferrochrome
0 metric tons of chromite

Predicted Shortage

0 metric tons of chrome metal
0 metric tons of ferrochrome
0 metric tons of chromite

Is chromium recycled, reused, or recovered?

In 2010, recycled chromium (contained in reported stainless steel scrap receipts) accounted for 44% of apparent consumption.

Are there substitutes for chromium?

In some applications, certain metal matrix or organic composites, high-strength grades of aluminum, pyrolytic graphite, silicon carbide, steel, or titanium may be substituted for chromium metal or chromium composites. Copper alloys containing nickel and silicon, tin, titanium, or other alloying elements or phosphor bronze alloys (copper-tin-phosphorus) may be substituted for beryllium-copper alloys, but these substitutions can result in substantially reduced performance. Aluminum nitride or boron nitride may be substituted for chromium oxide in some applications.

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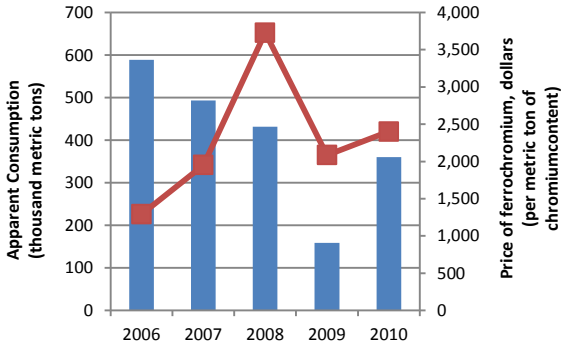
U.S. Geological Survey, Mineral Commodity Summaries, January 2011 – Chromium

Prepared by Jim Terry, 865-574-6261, terryjw@ornl.gov

U.S. Apparent Consumption and Ore Price



COBALT

Photo Courtesy of U.S. Army

What is cobalt?

Cobalt (Co, Z=27) is a lustrous, greyish-silver, brittle metal. It is also very hard and can take a high polish. Cobalt retains its strength at high temperatures and it has fairly low thermal and electrical conductivities. Cobalt is ferromagnetic, and therefore capable of being magnetized. Other properties important in industrial applications include 1) its ability to form alloys with many other metals, imparting strength at high temperatures, and 2) the ability to maintain its magnetic properties at high temperatures (up to 1,121ºC, higher than any other metal).

Where is cobalt found?

Cobalt comprises 0.0029% (29 ppm or 29 g/kg) of the earth's crust. It occurs in copper and nickel minerals and in combination with sulfur and arsenic. Cobalt is not found as a native metal, but is mainly as a by-product of nickel and copper mining activities. The main ores of cobalt are cobaltite, erythrite, glaucodot, and skutterudite.

The Bou Azzer deposit in Morocco is the only mine where cobalt is produced as the primary product. The world's largest cobalt resource occurs in the Central African Copperbelt, specifically in Congo (Kinshasa) and Zambia.

What are the common uses of cobalt?

U.S. industrial consumers reported that 49% of the cobalt consumed in the United States was used in superalloys (mainly in aircraft gas turbine engines), 7% in cemented carbides for cutting and wear-resistant applications, 15% in various other metallic applications, and 29% in a variety of chemical applications.

What are the important defense applications of cobalt?

- Component in nickel superalloys for high temperature sections of jet engines

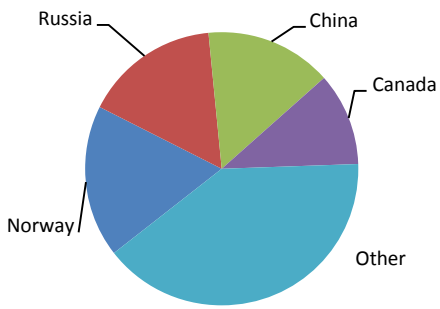
WORLD MINE PRODUCTION (MT)		
	2009	2010
United States	0	0
Australia	4,600	4,600
Brazil	1,200	1,500
Canada	4,100	2,500
China	6,000	6,200
Congo (Kinshasa)	35,500	45,000
Cuba	3,500	3,500
Morocco	1,600	1,500
New Caledonia	1,000	1,700
Russia	6,100	6,100
Zambia	5,000	11,000
Other Countries	3,700	4,700
World Total	72,300	88,000

- Maraging steel (aerospace and military use)
- Samarium-cobalt magnets for missile guidance systems,radar, electronic warfare systems, and aviation energy generation

What are some of the energy-related uses of cobalt?

- Catalyst for chemical photosynthesis (hydrogen production)
- Hydrodesulfurization of petroleum
- Hydroformylation of alkenes
- Hydrogenation of CO into liquid fuels

Primary Sources of U.S. Co Imports
U.S. Import Dependence = 100% (2010)



What are the risks associated with the supply of cobalt?

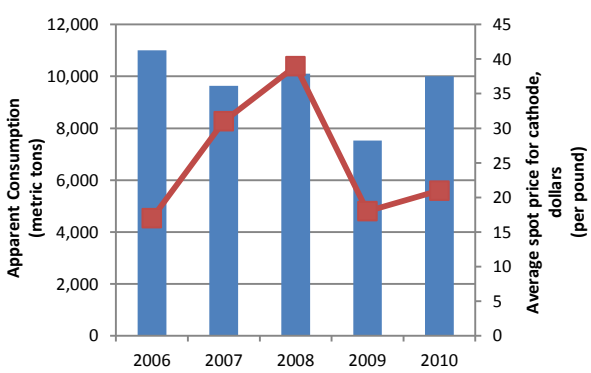
The United States did not mine or refine cobalt in 2010. The sole U.S. producer of extra-fine cobalt powder (in Pennsylvania) used cemented carbide scrap as feed.

Are there substitutes for cobalt?

In some applications, substitution for cobalt would result in a loss in product performance. Potential substitutes are as follows:

- Barium or strontium ferrites, neodymium-iron-boron, or nickel-iron alloys in magnets
- Cerium, iron, lead, manganese, or vanadium in paints
- Cobalt-iron-copper or iron-copper in diamond tools

U.S. Apparent Consumption and Ore Price



Stockpile Inventory
301 metric tons

Predicted Shortage
0 metric tons

- Iron-cobalt-nickel, nickel, cermets, or ceramics in cutting and wear-resistant materials
- Iron-phosphorous, manganese, nickel-cobalt-aluminum, or nickel-cobalt-manganese in lithium-ion batteries
- Nickel-based alloys or ceramics in jet engines
- Nickel in petroleum catalysts
- Rhodium in hydroformylation catalysts

Is cobalt recycled, reused, or recovered?

In 2010, cobalt contained in purchased scrap represented an estimated 24% of the reported consumption of cobalt.

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Prepared by Jim Terry, 865-574-6261, terryjw@ornl.gov

HAFNIUM

Photo Courtesy of U.S. Navy

What is hafnium?

Hafnium (Hf, Z=72) is a shiny, silvery, ductile metal that is corrosion-resistant and chemically similar to zirconium.

Where is hafnium found?

Hafnium composes about 5.8 ppm of the earth's upper crust by weight. It does not exist as a free element in nature; rather, it is found combined in solid solution for zirconium in natural zirconium compounds such as zircon, $ZrSiO_4$, which usually has about 1% to 4% of the zirconium replaced by hafnium.

World primary hafnium production statistics are not available. Hafnium occurs with zirconium in the minerals zircon and baddeleyite.

What are the common uses of hafnium?

- Control rods for nuclear reactors (primary use)
- Nickel superalloys and high temperature alloys
- Integrated circuit production for features at 45 nm and smaller
- Electrodes for plasma arc cutting

What are the important defense applications of hafnium?

- Control rods for naval nuclear reactors

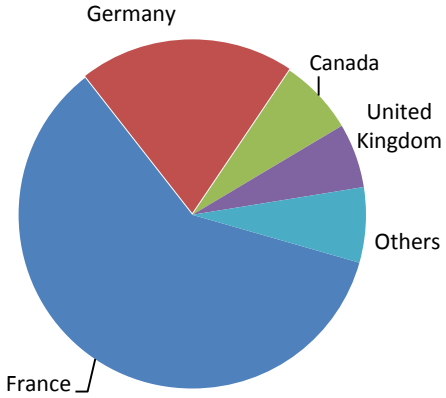
What are some of the energy-related uses of hafnium?

- Control rods for nuclear reactors

What are the risks associated with the supply of hafnium?

Hafnium is produced exclusively as a co-product of nuclear-grade zirconium.

PRIMARY SOURCES OF U.S. HF IMPORTS
U.S. IMPORT DEPENDENCE = UNAVAILABLE



How are the risks being managed?

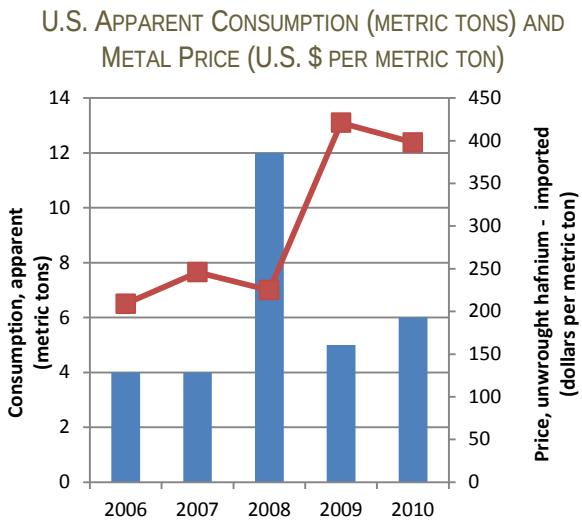
Zirconium can be used interchangeably with hafnium in certain superalloys; in others, only hafnium produces the desired or required grain boundary refinement.

Is hafnium recycled, reused or recovered?

Recycling of hafnium metal is insignificant.

STOCKPILE INVENTORY
0 metric tons

PREDICTED SHORTAGE
0 metric tons for base case



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Prepared by Jim Terry, 865-574-6261, terryjw@ornl.gov

MANGANESE

Photo Courtesy of U.S. Air Force

What is manganese?

Manganese (Mn, Z=25) is a silvery-gray metal resembling iron. It is hard and very brittle, difficult to fuse, but easy to oxidize. Manganese metal and its common ions are paramagnetic. Manganese is found as a free element in nature (often in combination with iron) and in many minerals.

Where is manganese found?

Manganese makes up about 1,000 ppm (0.1%) of the earth's crust, making it the 12th most abundant element. Soil contains 7–9,000 ppm of manganese with an average of 440 ppm. Manganese occurs principally in the ores pyrolusite, braunite, psilomelane, and to a lesser extent as rhodochrosite.

The primary mining of manganese occurs in China, Australia, and South Africa. Most of the Identified resources of manganese are in South Africa. China's resources are primarily lower grade ores that are mixed with higher grade imported ores prior to production.

What are the common uses of manganese?

- Steelmaking (85 – 90% of total demand), including stainless steel production
- Aluminum alloy production
- Additive in unleaded gasoline
- Glass making and coloring
- Batteries and dry cells
  - Disposable standard and alkaline
  - Li-MnO_2
- Alloys for chemical processing applications
- Alloys for high temperature bolts and fasteners

WORLD MINE PRODUCTION (MT)

	2009	2010
United States	0	0
Australia	2,140	2,400
Brazil	730	830
China	2,400	2,800
Gabon	881	1,400
India	980	1,100
Mexico	169	210
South Africa	1,900	2,200
Ukraine	375	580
Other countries	1,240	1,400
World Total	**10,800**	**13,000**

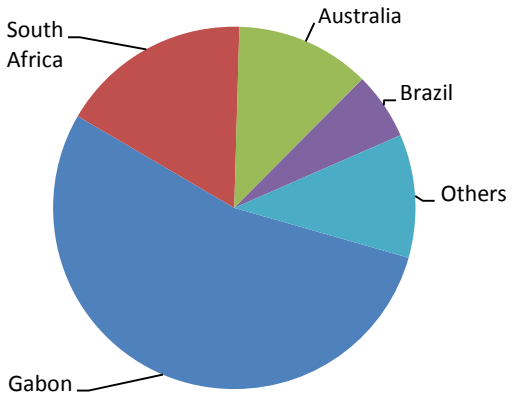
What are the important defense applications of manganese?

- Sheet steel and long steel products
- Li-MnO_2 batteries for communications and UAVs
- Alloys for naval nuclear applications

What are some of the energy-related uses of manganese?

- Alloys for civilian nuclear applications
- Alloys for oil and gas production

PRIMARY SOURCES OF U.S. MN ORE IMPORTS
U.S. IMPORT DEPENDENCE = 100% (2010)



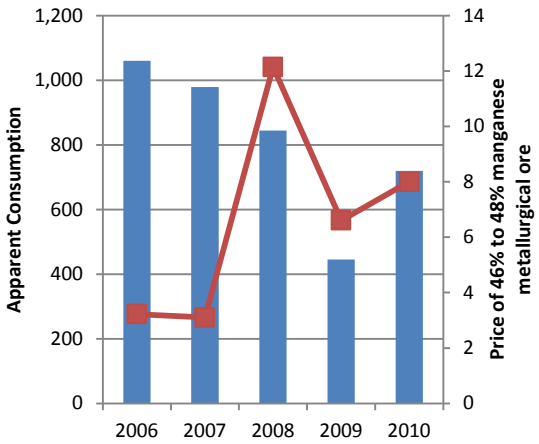
What are the risks associated with the supply of manganese?

Manganese ore containing 35% or more manganese has not been produced domestically since 1970.

How are the risks being managed?

Manganese has no satisfactory substitute in its major applications, which are related to metallurgical alloy use. In minor applications, (e.g., manganese phosphating), zinc and sometimes

U.S. APPARENT CONSUMPTION (THOUSAND METRIC TONS) AND ORE PRICE (U.S. $ PER METRIC TON)



STOCKPILE INVENTORY
0 metric tons (of electrolytic-grade Mg)

PREDICTED SHORTAGE
15,069 metric tons

vanadium are viable substitutes. In disposable battery manufacture, standard and alkaline cells using manganese will be generally replaced in the future with lithium battery technology.

Is manganese recycled, reused, or recovered?

Manganese is recycled incidentally as a minor constituent of ferrous and nonferrous scrap; however, scrap recovery specifically for manganese is negligible. Manganese is recovered along with iron from steel slag.

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Prepared by Jim Terry, 865-574-6261, terryjw@ornl.gov

MOLYBDENUM

Photo Courtesy of U.S. Army

What is molybdenum?

Molybdenum (Mo, Z=42) is a silvery-white metal with a melting point of 2,623°C (4,753°F). Of the naturally occurring elements, only five have higher melting points. The average concentration of molybdenum in the crust of the earth is about 1.2 ppm (mg/kg).

Where is molybdenum found?

Molybdenum is not found free in nature. The main ore of molybdenum is molybdenite. Commercially, the metal is obtained by mining molybdenite directly or it is recovered as a by-product of copper mining.

China is the leading producer of molybdenum. The U.S. production is second in the world but is only about one-half that of China.

What are the common uses of molybdenum?

- Tool and alloy steels
- Nickel superalloys for high temperature sections of turbine engines
- Alloys for condenser tubes used in nuclear and desalination plants

What are the important defense applications of molybdenum?

- Nickel superalloys for high temperature sections of turbine engines
- High temperature alloys for nuclear reactors
- Alloys for condenser tubes of nuclear and desalination plants
- Alloy steels for missiles

What are some of the energy-related uses of molybdenum?

- High-temperature alloys for nuclear reactors

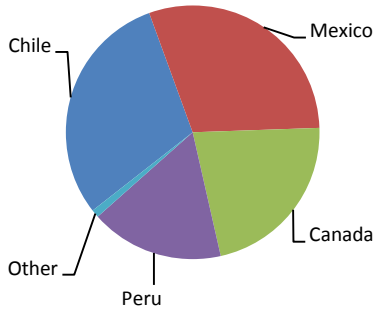
World Mine Production (MT)		
	2009	2010
United States	47,800	56,000
Armenia	4,150	4,200
Canada	8,840	9,100
Chile	34,900	39,000
China	93,500	94,000
Iran	3,700	3,700
Kazakhstan	380	400
Kyrgyzstan	250	250
Mexico	7,800	8,000
Mongolia	3,000	3,000
Peru	12,300	12,000
Russia	3,800	3,800
Uzbekistan	550	550
World Total (rounded)	221,000	234,000

- Catalysts for the removal of organic sulfur compounds
- Electrical contact for solar panel production
- Production of biofuels and ethanol

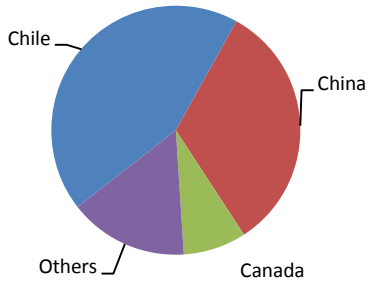
What are the risks associated with the supply of molybdenum?

The U.S. is a net exporter of molybdenum.

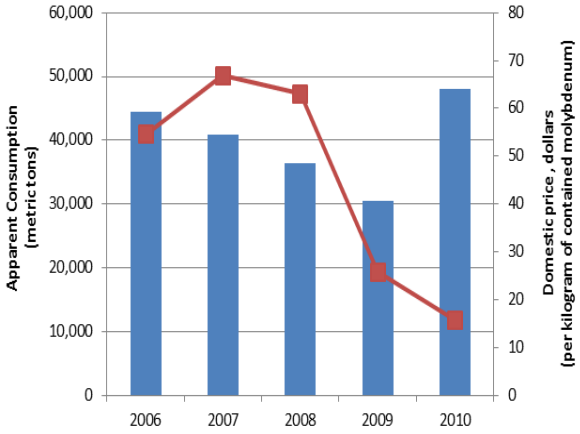
Primary Sources of U.S. Mo Ore & Concentrate Imports
U.S. Import Dependence = 0% (2010)



Primary Sources of Ferromolybdenum Imports



U.S. Apparent Consumption and Metal Price



How are the risks being managed?

There is little substitution for molybdenum in its major application as an alloying element in steels and cast irons. Potential substitutes for molybdenum include chromium, vanadium, niobium, and boron in alloy steels; tungsten in tool steels; graphite, tungsten, and tantalum for refractory materials in high-temperature electric furnaces.

Stockpile Inventory
0 metric tons

Predicted Shortage
0 metric tons

Is molybdenum recycled, reused, or recovered?

Small amounts of molybdenum in the form of molybdenum metal or superalloys are recovered. Recycling of steel alloys is significant, and possibly as much as 30% of the apparent supply of molybdenum is reutilized.

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Prepared by Jim Terry, 865-574-6261, terryjw@ornl.gov

NICKEL

Photo Courtesy of U.S. Air Force

What is nickel?

Nickel (Ni, Z=28) is a silvery-white, lustrous metal with a slight golden tinge. Nickel belongs to the transition metals and is hard and ductile. Nickel is reactive with oxygen making native nickel rare on earth's surface. Native nickel is always found in combination with iron.

Where is nickel found?

Nickel occurs most often in combination with sulfur and iron in pentlandite, with sulfur in millerite, with arsenic in the mineral nickeline, and with arsenic and sulfur in nickel galena.

Identified land-based resources averaging 1% nickel or greater contain at least 130 million tons of nickel available in identified deposits. Seventy-eight million tons or 60 percent of the total available nickel is in laterite deposits: a deposit in which rain and surface water has leached nickel-rich rock and concentrated the nickel at or near the surface of the earth. Nickel sulfide deposits contain the remaining forty percent (52 million tons).

What are the common uses of nickel?

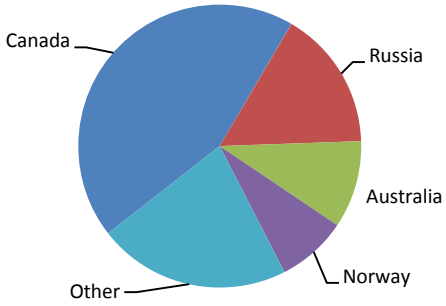
U.S. industrial consumers reported that approximately 44% of the primary nickel consumed went into stainless and alloy steel production, 42% into nonferrous alloys and superalloys, 9% into electroplating, and 5% into other uses. End uses were as follows: transportation, 32%; chemical industry, 14%; electrical equipment, 10%; construction, fabricated metal products, and petroleum industry, 8% each; household appliances and industrial machinery, 6% each; and other, 8%.

- Turbines blades for land-based turbines, jet aircraft engines, and large-scale power generation
- Liquid gas storage
- High speed steels

World Mine Production (MT)		
	2009	2010
United States	0	0
Australia	165,000	139,000
Botswana	28,600	32,400
Brazil	54,100	66,200
Canada	137,000	155,000
China	79,400	77,000
Columbia	72,000	70,200
Cuba	67,300	74,000
Dominican Republic	0	3,100
Indonesia	203,000	232,000
Madagascar	0	7,500
New Caledonia	92,800	138,000
Philippines	137,000	156,000
Russia	262,000	265,000
World Total	1,298,200	1,415,400

- Maraging steels (iron nickel alloys)
- Permanent magnets (Alnico)
- Nickel-titanium memory alloys (eyeglasses frames)
- Batteries
- Nickel cadmium (NiCd)
- Nickel metal hydride (NiMH)
- Reforming hydrocarbons
- Production of fertilizers, pesticides and fungicides

PRIMARY SOURCES OF U.S. NI IMPORTS
U.S. IMPORT DEPENDENCE = NEAR 100% (2010)



What are the important defense applications of nickel?

- Major component in nickel superalloys for high temperature sections of jet engines
- Maraging steel (aerospace and military use)

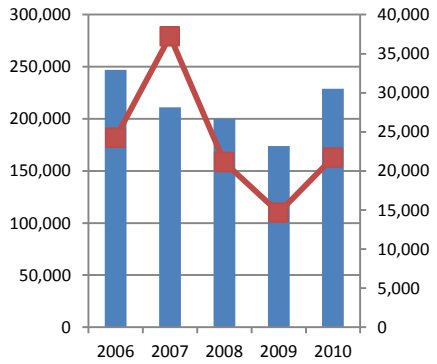
What are some of the energy-related uses of nickel?

- Nickel superalloys used to improve efficiency of large-scale power generation
- Corrosion-resistant alloys for petroleum production and refining

What are the risks associated with the supply of nickel?

The United States had no active nickel mines in 2010. Limited amounts of by-product nickel were recovered from copper and palladium-platinum ores

U.S. APPARENT CONSUMPTION (MT) AND ORE PRICE (U.S. $ PER MT)



STOCKPILE INVENTORY

0 metric tons

PREDICTED SHORTAGE

0 metric tons

mined in the Western United States. Six nickel-related mining projects were in varying stages of development in the Lake Superior region.

How are the risks being managed?

To offset high and fluctuating nickel prices, engineers have been substituting low-nickel, duplex, or ultrahigh-chromium stainless steels for austenitic grades in construction applications. Nickel-free specialty steels are sometimes used in place of stainless steel within the power-generating and petrochemical industries. Titanium alloys can substitute for nickel metal or nickel-based alloys in corrosive chemical environments. Cost savings in manufacturing lithium-ion batteries allow them to compete against nickel-metal hydride in certain applications.

Is nickel recycled, reused, or recovered?

About 100,000 tons of nickel were recovered from purchased scrap in 2010. This represented about 44% of reported secondary plus apparent primary consumption for the year.

Sources

http://en.wikipedia.org/wiki/Nickel

http://www.webelements.com/nickel/geology.html

U.S. Geological Survey, Mineral Commodity Summaries, January 2011 – Nickel

U.S. Geological Survey, Mineral Commodity Summaries, January 2007 – Nickel

British Geological Survey, MineralsUK, Nickel, http://www.mineralsUK.com

http://www. Nickel -- Encyclopedia of Earth.htm

Prepared by Jim Terry, 865-574-6261, terryjw@ornl.gov

NIOBIUM

Photo Courtesy of U.S. Navy

What is niobium?

Niobium (Nb, Z=41, formerly known as columbium) is a lustrous, grey, ductile, paramagnetic metal. In elemental form, the melting point of niobium is 2,468°C. Compared to other refractory metals like tantalum and tungsten, niobium has a low density. Additionally, niobium is corrosion resistant and it exhibits superconductivity properties.

Where is niobium found?

Niobium is estimated to make up about 22 ppm of the earth's crust by weight. Niobium is often found in minerals that also contain tantalum, such as columbite and columbite-tantalite (or coltan). Less common are the niobates of calcium, uranium, thorium, and the rare earth elements such as pyrochlore and euxenite.

Brazil is the leading producer of niobium and ferroniobium, an alloy of niobium and iron. The United States has approximately 150,000 tons of niobium resources in identified deposits, all of which were considered uneconomical at 2010 prices for niobium.

What are the common uses of niobium?

Primary applications

- Alloying element in steels and stainless steels
- Superalloys – nickel, cobalt, and iron-based
  - Jet engine components
  - Gas turbines
  - Rocket sub-assemblies
  - Heat resistant and combustion equipment
- Tool bits and cutting tools

Minor applications

- Electroceramics – $LiNbO_3$ (ferroelectric)

WORLD MINE PRODUCTION (MT)		
	2009	2010
United States	0	0
Brazil	58,000	58,000
Canada	4,330	4,400
Other Countries	530	600
World Total	62,900	63,000

- Superconducting magnets
  - Magnetic resonance imaging and nuclear magnetic imaging
  - Particle accelerators
- Superconducting, other
  - RF cavities for free electron lasers
  - Bolometers for radiotelescopes

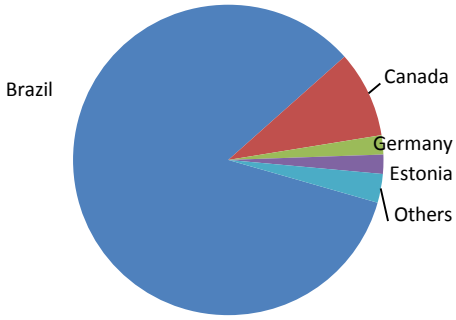
What are the important defense applications of niobium?

- Component in nickel superalloys for high temperature sections of jet engines
- Memory metal applications such as hydraulic couplings

What are some of the energy-related uses of niobium?

- Superconducting materials for power storage devices and transformers
- Superconducting materials for power transmission
- Superconducting magnets for magnetic levitation devices

PRIMARY SOURCES OF U.S. NB IMPORTS
U.S. IMPORT DEPENDENCE = 100% (2010)



What are the risks associated with the supply of niobium?

No niobium is produced in the United States.

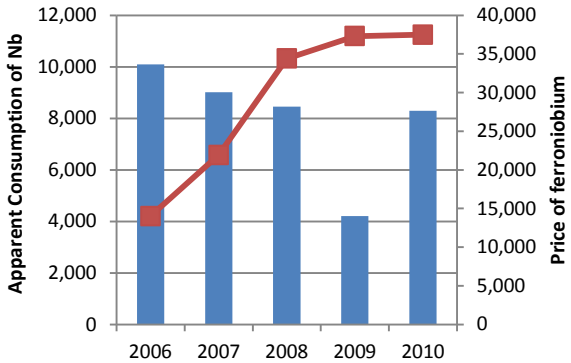
From 2002 through 2009, the U.S. exports of niobium by weight ranged from 2% to almost 11% of the niobium imports.

How are the risks being managed?

Niobium can be substituted by other materials, but higher costs or loss in performance may result. The list of substitutes is as follows:

- Molybdenum and vanadium, as alloying elements in high-strength low-alloy steels

U.S. APPARENT CONSUMPTION (MT) AND ORE PRICE (U.S. $ METRIC TONS)



STOCKPILE INVENTORY
10 metric tons

PREDICTED SHORTAGE
450 metric tons

- Tantalum and titanium, as alloying elements in stainless and high-strength steels
- Ceramics, molybdenum, tantalum, and tungsten in high-temperature applications

Is niobium recycled, reused, or recovered?

Niobium is recycled when niobium-bearing steels and superalloys are recycled; scrap recovery specifically for niobium content is negligible. The amount of niobium recycled is not available, but it may be as much as 20% of apparent consumption.

Sources

http://en.wikipedia.org/wiki/Niobium

U.S. Geological Survey, Mineral Commodity Summaries, January 2011 – Niobium

British Geological Survey, MineralsUK, Niobium and Tantalum, http://www.mineralsUK.com

Prepared by Jim Terry, 865-574-6261, terryjw@ornl.gov

RHENIUM

Photo Courtesy of U.S. Air Force

What is rhenium?

Rhenium (Re, Z=75) is a silvery-white, heavy, transition group metal. With an average concentration of less than 1 ppb (ng/kg), rhenium is one of the rarest elements in the earth's crust. The free element has the third-highest melting point and highest boiling point of any element. Rhenium is also one of the densest elements, exceeded only by platinum, iridium, and osmium.

Where is rhenium found?

Most rhenium occurs with molybdenum in porphyry copper deposits. In Kazakhstan, rhenium also exists in sedimentary copper deposits.

Chile has the world's largest rhenium reserves (part of its copper ore deposits) and is the leading producer. The U.S. production is second in the world and is about one-fourth that of Chile.

What are the common uses of rhenium?

- Components in nickel superalloys for high temperature sections of jet engines
- Catalysts for petroleum-reforming for the production of high-octane hydrocarbons
- Alloys for crucibles, electrical contacts, electromagnets, electron tubes and targets, heating elements, ionization gauges, mass spectrographs, metallic coatings, semiconductors, temperature controls, thermocouples, and vacuum tubes

What are the important defense applications of rhenium?

- Component in nickel superalloys for high temperature sections of jet engines

World Mine Production		
	2009	2010
United States	5,580	6,000
Armenia	400	400
Canada	1,800	1,800
Chile	25,000	25,000
Kazakhstan	3,000	2,500
Peru	5,000	5,000
Poland	2,400	4,500
Russia	1,500	1,500
Other Countries	1,500	1,500
World Total	46,200	48,000

What are some of the energy-related uses of rhenium?

- Catalysts for petroleum-reforming for the production of high-octane hydrocarbons

What are the risks associated with the supply of rhenium?

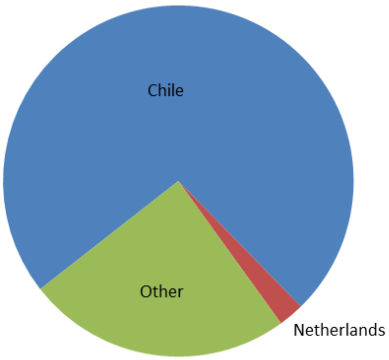
The primary forms of rhenium imports are metal powder and ammonium perrhenate.

How are the risks being managed?

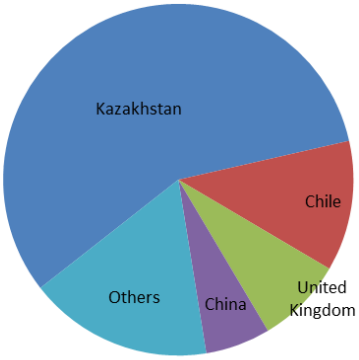
Substitutes for rhenium in platinum-rhenium catalysts are being evaluated continually. Iridium and tin have achieved commercial success in one

Photo credit: *http://www.eglin.af.mil/shared/media/photodb/photos/2012%5C07%5C120711-f-zz999-100.jpg*

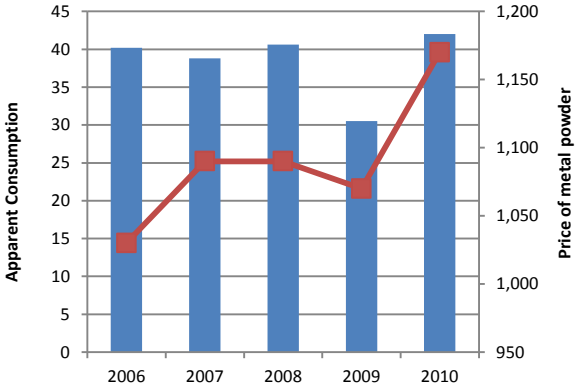
Primary Sources of U.S. Re Metal Powder Imports
U.S. Import Dependence = 80% (2006), 86% (2010)



Primary Sources of Ammonium Perrhenate Imports



U.S. Apparent Consumption (MT) and Ore Price (U.S. $ per kilogram at 99.99% content)



Stockpile Inventory
0 metric tons

Predicted Shortage
8 metric tons

such application. Other metals being evaluated for catalytic use include gallium, germanium, indium, selenium, silicon, tungsten, and vanadium. The use of these and other metals in bimetallic catalysts might decrease rhenium's share of the existing catalyst market; however, this would likely be offset by rhenium-bearing catalysts being considered for use in several proposed gas-to-liquid projects.

Materials that can substitute for rhenium in various end uses are as follows:

- Cobalt and tungsten for coatings on copper X-ray targets
- Rhodium and rhodium-iridium for high-temperature thermocouples
- Tungsten and platinum-ruthenium for coatings on electrical contacts
- Tungsten and tantalum for electron emitters

Is rhenium recycled, reused, or recovered?

Small amounts of molybdenum-rhenium and tungsten-rhenium scrap have been processed by several companies during the past few years. All spent platinum-rhenium catalysts were recycled.

Sources

http://en.wikipedia.org/wiki/Rhenium

U.S. Geological Survey, Mineral Commodity Summaries, January 2011 – Rhenium

British Geological Survey, MineralsUK, Rhenium and Tantalum, http://www.mineralsUK.com

Prepared by Jim Terry, 865-574-6261, terryjw@ornl.gov

TANTALUM

Photo Courtesy of U.S. Navy

What is tantalum?

Tantalum (Ta, Z=73) is a rare, hard, blue-gray, lustrous transition metal that is highly corrosion resistant. At temperatures below 150°C, tantalum is almost completely immune to attack by the aqua regia. It can be dissolved with hydrofluoric acid or acidic solutions containing the fluoride ion and sulfur trioxide, as well as with a solution of potassium hydroxide.

Tantalum's high melting point of 3,017°C is exceeded only by tungsten, rhenium, osmium, and carbon. Tantalum is part of the refractory metals group, which are widely used as minor components in alloys.

Where is tantalum found?

Tantalum is estimated to make up about 1-2 ppm of the earth's crust by weight. Tantalum, always together with the chemically similar niobium, occurs in the minerals tantalite, columbite, and coltan (a mix of columbite and tantalite). The mining of tantalum primarily occurs in Brazil.

The United States has about 1,500 tons of tantalum resources in identified deposits, all of which are considered uneconomical at 2010 prices. Most of the identified resources of tantalum are in Australia and Brazil.

What are the common uses of tantalum?

- Tantalum capacitors in electronics
- Chemical processing equipment
- Heat exchangers
- Corrosion resistant fasteners (e.g., screws)
- Anti-lock brake systems
- Airbag activation systems and engine management modules
- High temperature aerospace engine parts

World Mine Production (MT)		
	2009	2010
United States	0	0
Australia	81	80
Brazil	180	180
Canada	25	25
Mozambique	113	110
Rwanda	104	100
Other countries	162	170
World Total	665	670

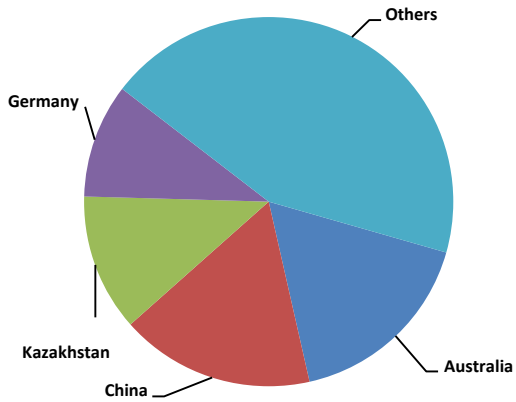
What are the important defense applications of tantalum?

- Component in nickel superalloys for high temperature sections of jet engines
- Shaped charge and explosively formed penetrator liners
- Missile systems
- Ignition systems
- Night vision goggles
- Global positioning systems

What are some of the energy-related uses of tantalum?

- Coolant containment for liquid metal cooled nuclear reactors

PRIMARY SOURCES OF U.S. TA IMPORTS
U.S. IMPORT DEPENDENCE = 100% (2010)



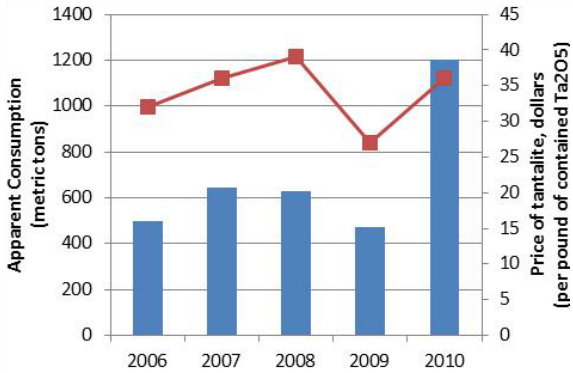
What are the risks associated with the supply of tantalum?

The United States does not mine tantalum. All new tantalum is imported. Tantalum waste and scrap are the leading forms of tantalum imports (42% combined). From 2002 through 2009, the U.S. exports of tantalum by weight were over 40% of the tantalum imports; conversely, domestic consumption was less than 60% of the imports during the stated period.

How are the risks being managed?

Tantalum can be substituted by other materials, but usually with a loss in performance. The list of substitutes is as follows: niobium in carbides; aluminum and ceramics in electronic capacitors;

U.S. APPARENT CONSUMPTION (MT) AND TANTALITE PRICE (U.S. $ PER LB OF CONTAINED TA_2O_5)



STOCKPILE INVENTORY
1.7 metric tons

PREDICTED SHORTAGE
3,584 metric tons

glass, niobium, platinum, titanium, and zirconium in corrosion-resistant equipment; and hafnium, iridium, molybdenum, niobium, rhenium, and tungsten in high-temperature applications.

Is tantalum recycled, reused, or recovered?

Tantalum is recycled primarily from new scrap generated during the manufacture of tantalum-containing electronic components and from tantalum-containing cemented carbide and superalloy scrap. Metal and alloys are recovered from foreign and domestic scrap.

Sources

http://www.webelements.com/tantalum/uses.html

U.S. Geological Survey, Mineral Commodity Summaries, January 2011 – Tantalum

U.S. Geological Survey, Mineral Commodity Summaries, January 2007 – Tantalum

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http://www.hi-tempmetals.com/products.html

http://www.steelforge.com/nonferrous/refractorymetals.htm

British Geological Survey, MineralsUK, Niobium – Tantalum, http://www.mineralsUK.com

Prepared by Jim Terry, 865-574-6261, terryjw@ornl.gov

TUNGSTEN

Photo Courtesy of U.S. Navy

What is tungsten?

Tungsten (W, Z=74) is a hard steel-gray metal that is often brittle and hard to work. Of all metals in pure form, tungsten has the highest melting point (3,422°C), lowest vapor pressure (at temperatures above 1,650°C), and the highest tensile strength. Tungsten has the lowest coefficient of thermal expansion of any pure metal. The metal oxidizes in air and must be protected at elevated temperatures. Tungsten has excellent corrosion resistance and is attacked only slightly by most mineral acids.

Like uranium and thorium, tungsten is believed to have no stable isotopes. The decay of ^{180}W by alpha emission has been observed. The half-life of ^{180}W is about 100 million times the age of the universe. The other notionally stable tungsten isotopes (^{182}W, ^{183}W, ^{184}W and ^{186}W) are believed to decay by alpha emission with half-lives longer than ^{180}W.

Where is tungsten found?

Tungsten is estimated to make up about 1.1 ppm of the earth's crust by weight. Tungsten is found in the minerals wolframite (iron-manganese tungstate), scheelite (calcium tungstate), ferberite (iron tungstate), and hübnerite (manganese tungstate).

The primary mining of tungsten occurs in China. Most of the identified resources of tungsten are in China. One mine in California produced tungsten concentrates in 2010.

What are the common uses of tungsten?

- Cemented carbide parts for cutting and wear-resistant materials, primarily in the construction, metalworking, mining, and oil- and gas-drilling industries
- Steels
- Wear-resistant alloys

WORLD MINE PRODUCTION (MT)		
	2009	2010
United States	W[1]	W[1]
Austria	900	1,000
Bolivia	1,000	1,100
Canada	2,000	300
Portugal	900	950
Russia	2,500	2,500
Other countries	3,000	3,300
World Total	61,300[2]	61,000

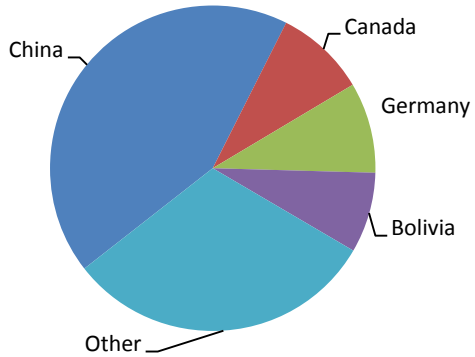
[1] Information withdrawn to protect proprietary information of single reporting company
[2] Excludes U.S. production

- Tungsten heavy alloys requiring high-density electrodes, filaments, wires, etc. for electronic, heating, lighting, and welding applications
- Aircraft weights and counterweights
- Counterweights for well logging and automobile racing engines

What are the important defense applications of tungsten?

- Component in nickel superalloys for high temperature sections of jet engines
- Armor penetrating projectiles
- Aircraft weights and counterweights
- Small arms ammunition
- Bunker buster bombs

PRIMARY SOURCES OF U.S. W IMPORTS
U.S. IMPORT DEPENDENCE = NEAR 100% (2010)



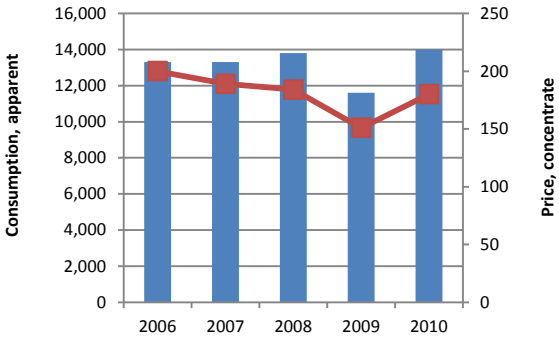
What are some of the energy-related uses of tungsten?

- Counterweights for well logging
- Radioactive source containers
- Gamma radiography
- Shields and source holders for oil well logging and industrial instrumentation
- Collimators and shielding in cancer therapy machines
- Syringe protection for radioactive injections

What are the risks associated with the supply of tungsten?

One U.S. mine produced tungsten concentrates in 2010. From 2002 through 2009, the US exports of tungsten by weight ranged from 28% to 54% of the tungsten imports establishing that not all imported tungsten is needed to meet needs in the United States.

U.S. APPARENT CONSUMPTION (MT) AND PRICE (U.S. $ PER MTU WO_3 AVERAGE)



STOCKPILE INVENTORY
17,156 metric tons

PREDICTED SHORTAGE
0 metric tons

How are the risks being managed?

Tungsten can be substituted by other materials, but higher costs or loss in performance may result. The list of substitutes is as follows: cemented carbides, ceramics, ceramic-metallic composites (cermets), diamond tools, tool steels, molybdenum, molybdenum steels, lighting based on carbon nanotube filaments, induction technology, light-emitting diodes, depleted uranium, and depleted uranium alloys.

Is tungsten recycled, reused, or recovered?

Between 35 and 40% of tungsten is recycled. The tungsten processing industry is able to treat almost every kind of tungsten-containing scrap and waste to recover tungsten and, if present, other valuable constituents. Recovery and reclamation rates during manufacturing operations may exceed 98%.

Sources

http://en.wikipedia.org/wiki/Tungsten

http://www.webelements.com/tungsten/geology.html

http://www.eaglealloys.com/t-tungs_alloysheavy.aspx

U.S. Geological Survey, Mineral Commodity Summaries, January 2011 – Tungsten

British Geological Survey, MineralsUK, Tungsten, http://www.mineralsUK.com

Prepared by Jim Terry, 865-574-6261, terryjw@ornl.gov

VANADIUM

Photo Courtesy of U.S. Air Force

What is vanadium?

Vanadium (V, Z=23) is a hard, silvery gray, ductile, and malleable metal. The formation of an oxide layer stabilizes the metal against oxidation. The element is found only in chemically combined forms in nature. Vanadium has good corrosion resistance to alkalis, sulfuric acid, hydrochloric acid, and salt waters. The metal oxidizes readily above 660°C to form V_2O_5.

Vanadium's melting point is 2,193°C and its boiling point is 3,400°C. Naturally occurring vanadium is composed of one stable isotope, ^{51}V, and one radioactive isotope, ^{50}V. The latter has a half-life of 1.5×10^{17} years and a natural abundance of 0.25%. Vanadium is harder than most other metals and steels. Industrially, most vanadium is used as an additive to improve steels.

Where is vanadium found?

Vanadium is estimated to make up about 120 ppm of the earth's crust by weight. Vanadium is not found free in nature but is found combined in about 65 different minerals. Vanadium is also found in bauxite and in fossil fuel deposits. Commercially, production of the metal is by calcium reduction of the pentoxide (V_2O_5). The primary mining of vanadium is in China, Russia, and South Africa.

What are the common uses of vanadium?

- Domestic consumption
  - Carbon steel – 15%
  - Full-alloy steel – 45%
  - High strength low-alloy steel – 34%
- Catalysts for production of maleic anhydride and sulfuric acid
- Titanium-aluminum-vanadium alloys in jet engines and high-speed aircraft
- Cladding titanium to steel

World Mine Production (MT)		
	2010	2011
United States	W*	W
China	22,000	23,000
Russia	15,000	15,000
South Africa	19,000	20,000
Other countries	1,600	1,500
World Total	57,600	60,000

* Withheld to protect proprietary information (one unnamed company)

- Vanadium-gallium tape in superconducting magnets
- Coatings
  - On glass, to block infrared but not visible light
  - On steel, to prevent corrosion

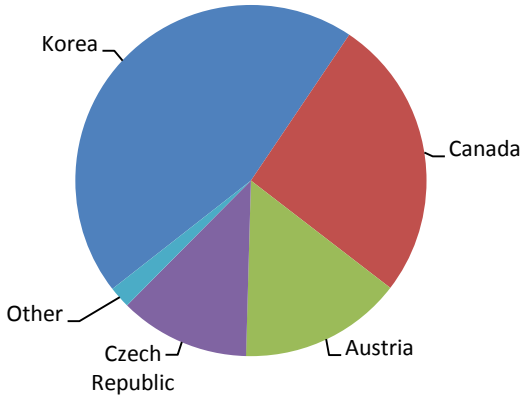
What are the important defense applications of vanadium?

- Titanium-aluminum-vanadium alloys in jet engines and high-speed aircraft
- Microalloyed steels either increase armor or reduce the weight of current combat vehicles, tactical bridges, material handling equipment, aircraft, watercraft, rails, steel structures, etc.

What are some of the energy-related uses of vanadium?

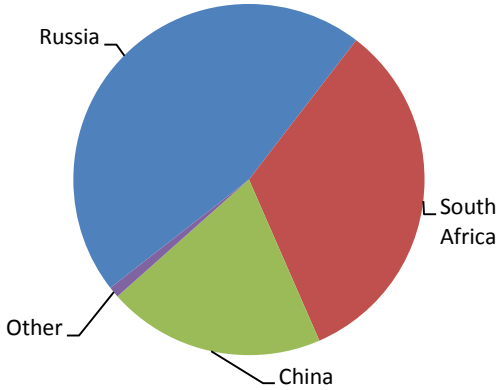
- Inner structure of a fusion reactor
- Energy storage (vanadium redox battery), possibly coupled with wind turbines

Primary Sources of Ferrovanadium Imports
U.S. Import Dependence = ~80% (2010)*



**The exact amount produced in the United States is not specified.*

Primary Sources of Vanadium Pentoxide Imports



What are the risks associated with the supply of vanadium?

There is a single U.S. mine, and the output is not specified by USGS. The USGS lists eight categories of imported vanadium. The two major categories of imported vanadium are ferrovanadium and vanadium pentoxide, with vanadium pentoxide being greater in quantity.

Stockpile Inventory
0 metric tons

Predicted Shortage
0 metric tons

How are the risks being managed?

Steels containing various combinations of other alloying elements can be substituted for steels containing vanadium. Certain metals, such as manganese, molybdenum, niobium, titanium, and tungsten, are to some degree interchangeable with vanadium as alloying elements in steel. Platinum and nickel can replace vanadium compounds as catalysts in some chemical processes. There is currently no acceptable substitute for vanadium in aerospace titanium alloys.

Is vanadium recycled, reused, or recovered?

Some tool steel scrap was recycled primarily for its vanadium content. The vanadium content of other recycled steels was lost to slag during processing and was not recovered. Vanadium recycled from spent chemical process catalysts was significant and may comprise as much as 40% of total supply.

Sources

http://www.webelements.com/vanadium/uses.html

U.S. Geological Survey, Mineral Commodity Summaries, January 2012 – Vanadium

http://www.chemicool.com/elements/vanadium.html

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ZIRCONIUM

Photo Courtesy of U.S. Navy

What is zirconium?

Zirconium (Zr, Z=40) is a lustrous, grayish-white, soft, ductile, and malleable metal which is solid at room temperature, though it becomes hard and brittle at lower purities. In powder form, zirconium is highly flammable, but the solid form is far less prone to ignition. Zirconium is highly resistant to corrosion by alkalis, acids, salt water, and other agents.

An alloy with zinc, $ZrZn_2$, becomes magnetic below 35K. This alloy is one of only two substances to exhibit superconductivity and ferromagnetism simultaneously, with the other being UGe_2.

Commercial zirconium metal typically contains 1 to 2.5% of hafnium, which is not problematic because the chemical properties of hafnium and zirconium are similar. Hafnium must be separated from zirconium for nuclear applications because hafnium has a very high neutron absorption cross-section – 600 times higher than zirconium.

Where is zirconium found?

Zirconium has a concentration of about 130 ppm (mg/kg) within the earth's crust. Zirconium is not found in nature as a native metal. The principal commercial source of zirconium is zircon ($ZrSiO_4$).

Zirconium also occurs in the commercially useful ores baddeleyite and kosnarite.

What are the common uses of zirconium?

- Space vehicles parts (fabricated from zirconium metal and its oxide, zirconia [ZrO_2])
- Abrasives (e.g., grinding wheels, sandpaper)
- Ceramic layers protecting high temperature parts (usually composed of a mixture of zirconia and yttria [YO_2]).
- Opacifier , giving a white, opaque appearance to decorative ceramics (primary use)

World Mine Production (MT)		
	2009	2010
United States	W*	W
Australia	476	481
Brazil	18	18
China	130	140
India	31	31
Indonesia	63	60
South Africa	392	390
Ukraine	35	35
Other Countries	19	30
World Total	1,160	1,190

* Withheld to protect proprietary information

- Molds for molten metals
- Metallurgical furnaces
- Ceramic knives
- Alloys for nuclear energy uses (zircalloy)
- Artificial joints and limbs

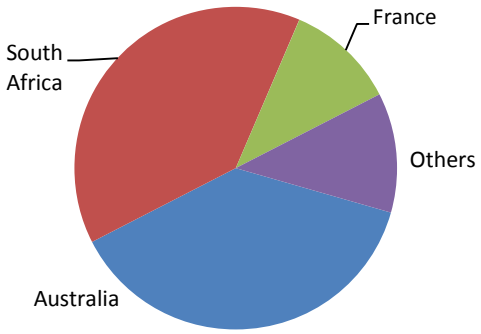
What are the important defense applications of zirconium?

- Alloys for naval nuclear applications
- Incendiaries

What are some of the energy-related uses of zirconium?

Consuming about 1% of the Zr supply, zirconium is used for cladding nuclear reactor fuels. For this

PRIMARY SOURCES OF U.S. ZR IMPORTS
U.S. IMPORT DEPENDENCE = 0% (2010)



STOCKPILE INVENTORY
0 metric tons

PREDICTED SHORTAGE
0 metric tons

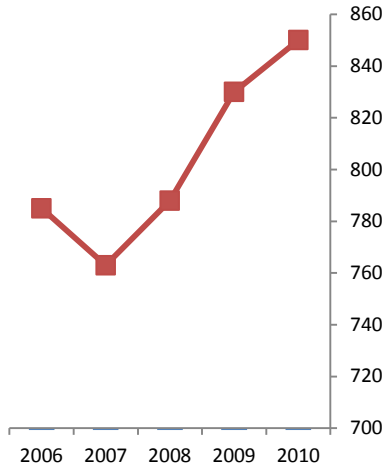
purpose, it is mainly used in the form of zircaloys. The benefits of Zr alloys are their low neutron-capture cross-section and good resistance to corrosion under normal service conditions.

What are the risks associated with the supply of zirconium?

Chromite and olivine can be used instead of zircon for some foundry applications. Dolomite and spinel refractories can also substitute for zircon in certain high-temperature applications. Niobium, stainless steel, and tantalum provide limited substitution in nuclear applications, while titanium and synthetic materials may substitute in some chemical plant uses.

The U.S. is a net exporter of zirconium.

DOMESTIC PRICE OF ZIRCON
(U.S. $ PER MT, GROSS WEIGHT)



Is zirconium recycled, reused, or recovered?

From 2006 through 2010, in-plant recycled zirconium came from scrap generated during metal production and fabrication and was recycled by companies in Oregon and Utah. Scrap zirconium metal and alloys were recycled by companies in California and Oregon. Zircon foundry mold cores and spent or rejected zirconia refractories are often recycled.

Sources

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U.S. Geological Survey, Minerals Yearbook 2010 - Zirconium and Hafnium

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