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GERMANIUM [ADVANCE RELEASE]

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Germanium

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In 2015, three domestic zinc operations produced recoverable byproduct germanium. In Alaska, the Red Dog Mine, owned by Teck Resources Ltd. (Canada), produced zinc concentrates that were exported to Teck's facilities in Canada for processing and to processors in Asia and Europe. Teck Washington Inc. (a wholly owned subsidiary of Teck Resources) operated the underground Pend Oreille zinc and lead mine in northeast Washington. All concentrates were shipped to Teck's facilities in Canada for processing. In Tennessee, the Clarksville zinc smelter, owned by Nyrstar NV (Belgium), produced and exported germanium leach concentrates recovered from processing zinc concentrates from its Middle Tennessee mine complex. This complex was put on care-and-maintenance status in December 2015. The U.S. Geological Survey (USGS) estimated that in 2015 the combined U.S. refinery production of germanium metal recovered from end-of-life products, such as decommissioned military vehicles and thermal weapons sights, industry-generated scrap, and imported germanium dioxide, was between 5,000 and 15,000 kilograms (kg). The total world production (excluding the United States) of germanium in metal and compounds, including germanium recovered from zinc concentrates, coal fly ash, and recycled material, was estimated to be about 160,000 kg, the same as 2014. The amount of germanium recovered from scrap in 2015 was estimated to be about 30% of world production of germanium metal.

Germanium is a hard, brittle semimetal that first was used about 60 years ago as a semiconductor material in radar units and as the material for the first transistors. It is commercially available as tetrachloride, high-purity oxide, and various forms of metal. Its current principal uses include lenses or windows in infrared night-vision devices; a component of glass in telecommunications fiber-optic cable; polymerization catalysts for polyethylene terephthalate (PET), a commercially important plastic; and semiconductors and substrates in electronic circuitry and solar cells.

The germanium production process yields various germanium compounds and metal for use in specific applications. Germanium is initially recovered through the leaching of zinc-refining residues or coal fly ash, followed by precipitation of a germanium concentrate from the leachate. The concentrate, regardless of its source, is chlorinated, distilled, and purified to form the first usable product, germanium tetrachloride, which is a colorless liquid that is primarily used in fiber-optic cable production. Germanium tetrachloride can be hydrolyzed and dried to produce germanium dioxide, which is a white powder that is used in the manufacture of certain types of optical lenses and as a catalyst in the production of PET resin. Germanium metal powder is produced through the reduction of germanium dioxide with hydrogen, and first-reduction bars are cast from melted powder. The germanium bars are zone-refined (a process that involves melting and cooling to isolate and remove impurities) to produce high-purity electronic-grade germanium metal. Zone-refined germanium metal is grown into crystals that are sliced for use as semiconductors or recast into forms suitable for lenses or window blanks for infrared optical devices.

Legislation and Government Programs

As a strategic and critical material, germanium was added to the National Defense Stockpile (NDS) in 1984. The Defense Logistics Agency Strategic Materials (DLA Strategic Materials) reported that no germanium metal was sold in 2015. Germanium was last sold in February 2009 at an average price of $1,331 per kilogram. As of December 31, 2015, the total inventory of germanium metal held by the DLA Strategic Materials was 13,364 kg with a market value of $24.5 million. The Annual Materials Plan (AMP) for fiscal year (FY) 2016 (October 1, 2015, through September 30, 2016) did not allocate germanium metal for sale, and the DLA Strategic Materials could potentially acquire up to 1,600 kg of germanium metal in FY 2016. In FY 2012, the DLA Strategic Materials awarded two contracts to convert 3,000 kg of the germanium ingots held in the stockpile to epitaxial wafers for use as substrates required by the National Security Space Strategy photovoltaic solar cell applications. As of yearend 2015, 101,899 wafers (market value of $8.04 million) were held in the stockpile compared with 101,939 held at yearend 2014.

In 2015, the DLA Strategic Materials entered into a collaborative program with Army Contracting Command-Warren (ACC-Warren) and Anniston Army Depot (ANAD) to recover germanium from excess Army components. Under an ACC-Warren contract, germanium-containing end-of-life components started to be shipped from ANAD to a contractor. The contractor was to demilitarize the components, remove any radioactive coatings from the germanium lenses and windows, and send the germanium scrap to the NDS. In FY 2015, demilitarization began on the first batch of items, and germanium shipments to the NDS were expected to start in FY 2016 (Defense Logistics Agency Strategic Materials, 2015a, b; U.S. Department of Defense, 2016, p. 5, 8).

Production

In 2015, germanium intermediates were domestically recovered from zinc concentrates at the Clarksville smelter in Tennessee. Secondary germanium metal was recovered by secondary processors from end-of-life products, such as decommissioned military vehicles and thermal weapons sights.

In the third quarter of 2012, Nyrstar began to produce germanium precipitate from leaching of zinc smelter residues product at its Clarksville zinc smelter. The germanium-bearing zinc concentrates processed at Clarksville were from Nyrstar's Middle Tennessee mine complex (the Cumberland

Mine, Elmwood Mine, and Gordonsville Mine and mill) where mining resumed in 2009 after being idle for about 1 year. The company did not disclose how much germanium leach product was produced in 2015, but Nyrstar reported that production was slightly reduced by supply shortfalls of zinc concentrates from the Middle Tennessee Mines. The Clarksville smelter reportedly had the capacity to produce 20 metric tons per year (t/yr) of germanium-rich, zinc-refining residues (Jorgenson, 2004, p. 32.1). In early December 2015, Nyrstar placed the Middle Tennessee mines on care-and-maintenance status, reportedly owing primarily to the decline in the price of zinc (Nyrstar NV, 2013, p. 16–17; 2015a, p. 25; 2016a, p. 25).

Teck Alaska Inc. produced germanium-containing zinc concentrates at its Red Dog zinc-lead open pit mine in Alaska. Approximately 30% of the zinc concentrate produced at Red Dog was sent to Teck's metallurgical complex in Trail, British Columbia, Canada, for processing. Residues from zinc concentrates were treated in roasters or pressure-leach facilities and purified to produce germanium dioxide, germanium tetrachloride, and other byproduct metals. In December 2014, Teck restarted the Pend Oreille Mine in Washington, and by yearend 2015, the mine had nearly reached full production. The mine, which produced germanium-containing zinc concentrates that were processed at Teck's Trail plant, was expected to operate for 4.5 years (Teck Resources Ltd., 2016, p. 20).

Consumption

The USGS estimated that domestic consumption of germanium metal (including metal content of compounds) was about 34,000 kg in 2015 (table 1). Consumption for fiber optics and substrates for space-based applications increased from that in 2014, but use in infrared optics for defense applications declined (Umicore S.A., 2016). Germanium-containing infrared optics was primarily for military use, and defense-related spending has declined during the past few years. Growth in the commercial and personal markets for thermal-imaging devices that use germanium lenses partially offset the decline in defense consumption. The major domestic and global end uses were fiber-optic systems, infrared optics, electronics and solar applications, polymerization catalysts, electronics and solar applications, and other uses (such as phosphors, metallurgy, and chemotherapy). Germanium was not used in polymerization catalysts in the United States.

Infrared Systems.—Germanium was used to manufacture lenses and windows for infrared optical systems owing to its transparency to part of the infrared spectrum and to its high refractive index. Global demand outside of China for germanium infrared products declined in 2015 partially due to a reduction in defense spending. FLIR Systems, Inc. (Wilsonville, OR), a leading domestic producer of infrared surveillance devices, reported a decrease in U.S. Government spending for surveillance products (their largest grossing segment of infrared imaging products), resulting in a 3% decline in sales revenue in 2015 compared with that in 2014 (FLIR Systems, Inc., 2016, p. 38–39).

Fiber Optics.—Germanium dioxide is used as a dopant (a substance added in small amounts) in the pure silica glass core of optical fibers to increase the refractive index, preventing signal loss while not absorbing light. The Fiber-to-the-Home Council estimated that about $18 billion would be invested in expanding the fiber-to-the-home (FTTH) network infrastructure in North America from 2013 through 2017. During the past few years, there has been an increased emphasis placed on providing more rural parts of the United States with access to optical networks. As of May 2013, 22.7 million North American homes were connected directly into fiber-optic networks (Fiber-to-the-Home Council, 2013). Three producers in Japan (Fujikura Ltd.; Furukawa Electric Co., Ltd.; Sumitomo Electric Industries, Ltd.) and Corning Inc. in the United States accounted for a substantial portion of global production of germanium-doped silica glass used in fiber-optic cable. In 2015, Corning reported that sales of its optical communications products increased by 12% from those in 2014 owing partially to increased sales of fiber-optic cable and hardware for FTTH installations in North America (Fiber-to-the-Home Council, 2013; Yi, 2013; Corning Inc., 2016, p. 35).

Solar Cells.—Germanium-based solar cells were used in space-based applications and terrestrial installations. Umicore S.A. (Belgium), a leading germanium substrate producer, reported that sales of substrates for solar cells in space-based applications increased in 2015 for the second consecutive year. The sales increase is attributed to a broadened product offering (Umicore S.A., 2016, p. 10–11).

5N Plus Semiconductors LLC (St. George, UT), a wholly owned subsidiary of 5N Plus Inc. (Canada), primarily produced germanium substrates for solar cells used in satellites. The company had the capability to produce germanium metal from germanium dioxide at its facility in Utah and recover germanium from industry generated new scrap at other facilities.

Polymerization Catalysts.—Estimates indicated that consumption of germanium for PET outside the United States has been declining since 2011 owing to germanium price increases that led to substitutions for germanium. The majority of germanium consumed for PET resin production took place in Japan, where producers have substituted lower cost antimony and titanium-based products for germanium dioxide catalysts. In 2015, in addition to increased substitution for germanium, Japan PET resin production (using germanium oxide catalysts) decreased by 8% from that of 2014 to 619,000 t, which was about 26% less than that produced in 2011 (Roskill's Letter from Japan, 2015, 2016).

Prices

Germanium is generally traded through long-term supply contracts among consumers, producers, and traders. Publicly available prices (Argus Media group Metal-Pages) are estimates of representative prices in trades being executed on a particular day and are compiled through recurring interviews with individual traders. Reported germanium metal (minimum 99.999% germanium) prices began the year at about $1,900 per kilogram and decreased during the year to about $1,250 per kilogram at yearend. Germanium metal prices averaged at about $1,790 per kilogram for 2015 (fig. 1, table 3). Germanium dioxide prices began the year at about $1,300 per kilogram, trended downward and ended the year at $1,000 per kilogram (fig. 1, table 3).

Foreign Trade

According to the U.S. Census Bureau, imports for consumption of germanium metal (wrought, unwrought, and powder) decreased by 15% to 20,100 kg in 2015 from 23,700 kg in 2014 (table 2). Decreased imports from Belgium, China, and Russia more than offset an increase from Germany. In 2015, China and Belgium, in descending order of quantity, accounted for 89% of germanium metal imported into the United States. The estimated germanium content of the germanium dioxide imported in 2015 was about 14,300 kg compared with 12,400 kg in 2014.

Domestic exports of germanium metal and articles thereof were estimated to be about 5,000 kg in 2015 (table 1) based on trade data from the U.S. Census Bureau that were adjusted by the USGS to exclude low-value scrap. Belgium, Canada, China, Japan, and Russia accounted for the majority of germanium exported from the United States in 2015. The estimated germanium content of germanium dioxide exported from the United States in 2015 was less than 100 kg.

World Review

In 2015, the total world production of germanium recovered from zinc concentrates, coal fly ash, and recycled material was estimated to be about 160,000 kg. Scrap was estimated to have supplied about 30% of the world's total production of germanium. Owing to the high value of refined germanium, new scrap generated during the manufacture of fiber-optic cables, infrared optics, and substrates was typically reclaimed and fed back into the production process. Recycling of germanium from old scrap, such as fiber-optic windows from decommissioned military vehicles or fiber-optic cables, has increased during the past decade. Canada, China, and Russia accounted for the majority of global germanium consumption. Primary germanium was recovered from zinc residues in Belgium and Canada (concentrates shipped from the United States), coal fly ash and zinc residues in China (multiple sources), zinc residues in Finland, and coal fly ash in Russia.

As a byproduct metal, the supply of germanium was heavily reliant on zinc mine production, which decreased by 4% in 2015 from that in 2014. Although an important factor, global changes in zinc mine production may not be an indicator of a corresponding change in the supply of germanium. It has been estimated that less than 5% of the germanium contained in zinc concentrates reaches refineries that are capable of extracting and producing germanium (Mikolajczak, 2013, p. 9).

Belgium.—Umicore produced germanium metal, germanium tetrachloride for fiber optics, germanium substrates, and germanium optical products at its refinery and recycling plant in Olen. In 2015, the company reported increased sales of substrates for solar cells used in satellites, finished optical devices containing germanium for infrared applications, and germanium tetrachloride for use in fiber optics (Umicore S.A., 2016, p. 10–11).

Canada.—The metallurgical complex operated by Teck Resources in Trail, British Columbia, included two specialty metal plants that produced byproduct metals, including germanium. Historically, Teck has been one of the leading germanium producers in the world. The last year for which the company released production data was 2007, when Teck produced about 40,000 kg of germanium dioxide. In 2015, it was estimated that Canada exported about 22,000 kg of germanium contained in dioxide (Teck Cominco Ltd., 2008; Statistics Canada, 2016).

China.—China continued to be the leading global producer of germanium metal and germanium compounds, which it recovered from germanium-bearing coal fly ash and zinc ore. In 2015, five or six producers accounted for the majority of the estimated 110,000 to 120,000 kg of the germanium metal produced in China. China's Government attempted to limit exports of raw materials and encourage the export of more processed products, such as germanium ingots and optical lenses, through export tax rebates on the products and a 5% export tax on germanium dioxide. In mid-2015, China cancelled the 5% export tax on germanium dioxide in a response to a 2014 World Trade Organization ruling on trade disputes between China and other countries. Chinese germanium dioxide producers expected to be more competitive in the global market after the export tax was removed (Heywood, 2015). China exported 10,800 kg of germanium metal in 2015, a 15% decrease from than that in 2014 (Metal-Pages, 2016). In 2015, China's State Reserve Bureau (SRB) purchased 30,000 kg of germanium for its national stockpile (30,000 kg was purchased in 2014), and analysts expected that China would continue to stockpile germanium during the next several years (Shen, 2015). The Fanya Metal Exchange (FME) in China, established for investing in "rare" metals, reportedly held about 91,100 kg of germanium in warehouses as of late November 2014 and had the capacity to hold 200,000 kg (Pugsley, 2014a, b). In June 2015, FME's accounts were frozen, and in August, it entered into a restructuring plan where no germanium was added or removed from FME warehouses.

Japan.—According to industry reports, consumption of germanium in Japan in 2015 declined from that in 2014 with the exception of fiber optics. Imports of germanium metal, power, and scrap were 3,660 kg in 2015, 4% less than that in 2014. Imports of germanium dioxide (gross weight) were 12,200 kg in 2015, 17% less than that in 2014 and more than one-half of that imported in 2011. The majority of germanium metal was imported from China, and the majority of germanium dioxide was imported from Canada. Japanese production of fiber-optic cable products increased by about 12% from the previous year, the majority of which were exported (Roskill's Letter from Japan, 2016).

Russia.—During the past few years, Russia's germanium production remained stable and exports decreased by about 11% in 2015 compared to that of 2014 (Global Trade Information Services Inc., 2016). Germanium and Applications Ltd. recently began recovering germanium from fly ash from coal mined at the massive Pavlovskoye coal deposit in the Russian Far East. The company reported that coal production from the open pit mine could yield as much as 21 t/yr of germanium, and its facilities in Moscow and Novomoskovsk had the capability to produce germanium oxide and metal, germanium blanks for optical use, and substrates for electronics (Germanium and Applications Ltd., 2014).

JSC Germanium operated an integrated refinery in Krasnoyarsk with the capabilities to process germanium from concentrates, fly ash, and waste, and to produce intermediate and finished germanium products. The company reported that it produces about 20,000 kg of germanium per year, but it did not specify if that included the metal content of finished products such as germanium lenses. JSC exported more than 80% of the germanium that it produced (JSC Germanium, 2016).

Outlook

Global germanium consumption in the fiber-optics sector is likely to increase during the next several years. Global demand for fiber-optic cable, led by the emerging Asian economies and Brazil, is forecast to increase during the next several years. The increases in fiber-optics consumption may be partially offset by declines in consumption for other applications such as optical blanks. Germanium-based optical blanks and windows that are incorporated in infrared devices are expected to continue to be heavily used by military and law enforcement agencies; however, cuts in Government military spending could limit growth in this area. Increased substitution of specialty glass for pure germanium in infrared applications may continue to be attractive to some consumers owing to the high price of germanium. New applications for infrared products that use germanium lenses in commercial and industrial markets are expected to become more prevalent and represent a significant potential for consumption growth. Infrared cameras that are designed to be used with smartphones could become more appealing for commercial uses as prices decline and quality increases. These cameras typically use small quantities of germanium per unit, but the overall volume could be great based on the global proliferation of smartphones.

On the supply side, limited new germanium production capacity is expected to open in the next few years. In 2015, Nyrstar NV announced plans to upgrade production capacity at its zinc smelter in Hobart, Tasmania, Australia. The upgrades included construction of a side-leach plant that would enable the smelter to split base metals from minor metals and produce germanium and indium. The development project was expected continue in 2016 and be completed by yearend 2018 (Nyrstar NV, 2015b, 2016b). Germanium production will continue to be reliant on the zinc market. The availability of recycled germanium recovered from end-of-life products, such as fiber optics, military vehicles, and solar cells, is expected to increase during the next two decades as aging products are taken out of service. In China, germanium producers are expected to continue to expand to downstream products and manufacture finished infrared products for export. Overall, the germanium market is expected to remain relatively balanced during the next several years owing to limited sources of supply and modest increases in consumption. This could change if some of the germanium stocks held in China begin to enter the global market; however, it is believed that the SRB would continue purchasing germanium through 2017 (Pugsley, 2014b).

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TABLE 1
SALIENT GERMANIUM STATISTICS[1]

		2011	2012	2013	2014	2015
United States:						
Refinery production[e]	kilograms	3,000	W	W	W	W
Imports for consumption of metal (gross weight)	do.	28,300	37,500	34,300	23,700	20,100
Exports of metal (gross weight)[2]	do.	5,900	15,300	12,500	12,000	5,000
Consumption of metal[e, 3]	do.	36,000	38,000	38,000	32,000	34,000
Price, germanium metal, average[4]	dollars per kilogram	1,539	1,464	1,772	1,917	1,785
Price, germanium dioxide, average[5]	do.	1,218	1,179	1,309	1,291	1,207
Stocks, December 31, U.S. Government[6]	kilograms	16,400	16,400	16,400	13,400	13,400
World, refinery production:[e]						
China	do.	110,000	105,000	110,000	115,000	115,000
Russia	do.	5,000	5,000	5,000	5,000	5,000
Other[7]	do.	33,000	30,000	40,000	40,000	40,000
Total	do.	148,000	140,000	155,000	160,000	160,000

[e]Estimated. do. Ditto. W Withheld to avoid disclosing company proprietary data; not included in "World, refinery production."
[1]Data are rounded to no more than three significant digits, except prices.
[2]Trade data have been adjusted to exclude low value shipments.
[3]Estimated consumption of germanium contained in metal and germanium dioxide.
[4]Minimum 99.99% germanium. Source: Argus Media group Metal-Pages.
[5]Minimum 99.99% germanium dioxide, approximately 69% metal content. Source: Argus Media group Metal-Pages.
[6]Uncommitted germanium metal only. Source: Defense Logistics Agency Strategic Materials.
[7]Includes Belgium, Canada, Germany, and others.

TABLE 2
U.S. IMPORTS FOR CONSUMPTION OF GERMANIUM METAL, BY COUNTRY[1, 2]

Country	2014		2015	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Belgium	7,610 r	$14,400,000	5,590	$9,260,000
China	13,100 r	21,800,000 r	12,200	18,400,000
Germany	1,180	2,270,000	1,300	2,310,000
Israel	--	--	36	87,900
Romania	--	--	153	292,000
Russia	1,280 r	1,720,000 r	607	827,000
South Africa	1	19,100	26	19,200
United Kingdom	6	7,430	173	114,000
Other (5 countries)	522 r	135,000 r	8	15,600
Total	23,700 r	40,300,000 r	20,100	31,400,000

rRevised. -- Zero.
[1]Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Data include wrought, unwrought, and powder, but exclude germanium dioxide.

Source: U.S. Census Bureau.

TABLE 3
ANNUAL AVERAGE PRICES

(Dollars per kilogram)

	Germanium dioxide (min. 99.99% purity)	Germanium metal (min. 99.99% purity)
2006	564	834
2007	767	1,106
2008	948	1,456
2009	677	1,054
2010	575	953
2011	1,218	1,539
2012	1,179	1,464
2013	1,309	1,772
2014	1,291	1,917
2015	1,207	1,785
Average	974	1,388

Source: Argus Media group Metal-Pages.

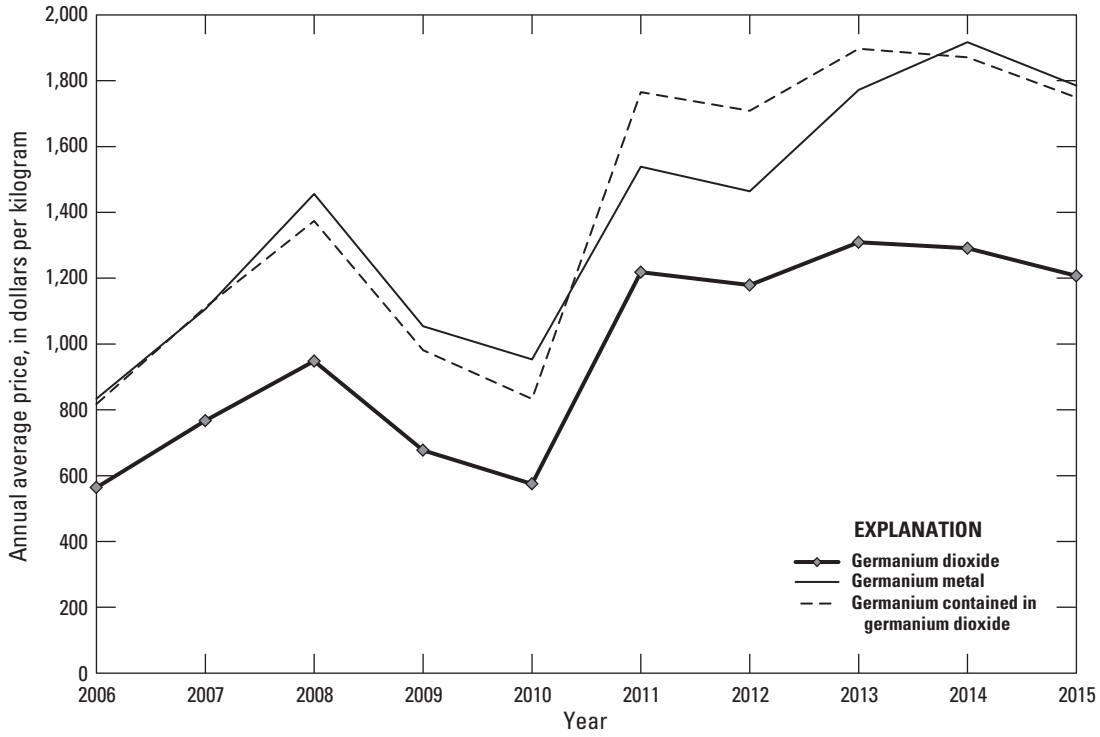

Figure 1. Average annual prices for germanium metal (minimum 99.99% metal) and germanium dioxide and estimated price of germanium contained in germanium dioxide (assuming 69% germanium content) from 2006 through 2015. Source: Argus Media group Metal-Pages