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Germanium

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In 2011 in the United States, germanium-bearing concentrates were produced at a zinc mine in Alaska owned by Teck Resources Ltd. (Vancouver, British Columbia, Canada). No germanium was recovered from zinc concentrates or coal in the United States. The germanium-bearing concentrates were exported to Canada for processing or directly to customers in Asia and Europe. Two refineries in New York and Oklahoma produced germanium dioxide, germanium metal, and germanium tetrachloride from manufacturers' scrap, post-consumer scrap, and processed imported germanium compounds.

Domestic refinery production, estimated by the U.S. Geological Survey (USGS) based on data provided by North American producers, of germanium metal from imported primary material and germanium compounds was about 9,300 kilograms (kg). In 2011, the world's total production of germanium was estimated to be between 100 and 120 metric tons (t). This comprised germanium recovered from zinc concentrates, fly ash from burning coal, and recycled material. The recycling level remained about the same as that in 2010 and supplied about 30% of the world's total supply of germanium. As a byproduct metal, the supply of germanium was heavily reliant on zinc production, which increased on a global basis in 2011 owing to increased production in China, India, Mexico, and Russia.

Germanium is a hard, brittle semimetal that first was used about a half century ago as a semiconductor material in radar units and as the material for the first transistors. Today, it is used principally as a polymerization catalyst for polyethylene terephthalate (PET), a commercially important plastic; as a component of glass in telecommunications fiber optics; as a lens or window in infrared night-vision devices; and as a semiconductor and substrate in electronic circuitry and solar cells.

Legislation and Government Programs

As a strategic and critical material, germanium was included in the National Defense Stockpile in 1984. The Defense Logistics Agency, DLA Strategic Materials reported that there were no germanium metal sales in 2011. Germanium was last sold in February 2009 at an average price of $1,331 per kilogram. As of December 31, 2011, the total inventory of germanium metal held by the DLA was 16,362 kg valued at $19.4 million.

During fiscal year 2011 (October 1, 2010, through September 30, 2011), the DLA did not sell any units of germanium metal. The Annual Materials Plan for fiscal year 2012 (October 1, 2011, through September 30, 2012) allocated of 3,000 kg germanium metal for sale (Defense Logistics Agency, DLA Strategic Materials, 2011).

As part of its attempt to evolve from manager of the strategic stockpile of materials that was established during the cold war and address more current availability concerns, the DLA conducted material risk assessments on 28 materials deemed to be in short supply. Germanium substrates were included in the list of materials that were studied for possible supply risks. DLA planned to address potential material bottlenecks or shortages by developing strategies and solutions with industry to avoid shortfalls rather than purchasing and stockpiling materials as it had in the past (Tunna, 2011).

Production

The multiple stages of the germanium production process yield germanium compounds and metals that are associated with specific applications. Germanium is initially recovered from the leaching of zinc residues or coal ash followed by precipitation of a germanium concentrate. All germanium concentrates are purified using similar techniques, regardless of the source of the concentrates. The concentrated germanium is chlorinated and distilled to form the first usable product, germanium tetrachloride, a colorless liquid that is primarily used as a reagent in fiber-optic cable production. Germanium tetrachloride can be hydrolyzed and dried to produce germanium dioxide, another commonly used compound. Germanium dioxide is a white powder and is used to manufacture certain types of optical lenses and as a catalyst in the production of PET resin. Germanium dioxide can be reduced with hydrogen to produce a germanium metal powder, which is subsequently melted and cast into first-reduction bars. The germanium bars are then zone-refined (a refining process that involves melting and cooling germanium bars to isolate and remove impurities and ultimately yield extremely pure germanium) to produce electronic-grade germanium metal. Zone-refined germanium metal can then be grown into crystals and sliced for use as semiconductors or recast into forms suitable for lenses or window blanks in infrared optical devices.

In 2011, no germanium was recovered from zinc concentrates or coal in the United States. The USGS estimated that U.S. refinery production of germanium metal from imported primary material and germanium compounds was about 9,300 kg. Domestic refinery production of germanium metal recovered from end-of-life products, such as decommissioned military vehicles and thermal weapons sights, was estimated to be about 3,000 kg in 2011.

Teck Alaska Inc. (a wholly owned subsidiary of Teck Resources) produced germanium-containing zinc concentrates at its Red Dog zinc-lead open pit mine in Alaska. Approximately 25% of the zinc concentrate produced at Red Dog was sent to Teck's metallurgical complex in Trail, British Columbia, Canada. Residues from zinc concentrates were treated in roasters or pressure-leach facilities and purified to produce germanium dioxide, germanium tetrachloride, and other byproduct metals. Teck reported that zinc concentrate production at Red Dog in 2011 was 572,000 t, 7% greater than that of 2010 owing to an increase in mill throughput (Teck Resources Ltd., 2012, p. 34).

In 2011, Umicore Optical Materials USA Inc. (a subsidiary of Umicore s.a., Brussels, Belgium) continued production of germanium metal and compounds at its plant in Quapaw, OK, and remained the leading domestic producer of germanium and germanium-base materials. Umicore recovered and refined germanium from industry-generated new scrap and from imported germanium compounds. The Quapaw facility refined the material into germanium tetrachloride, germanium metal, and proprietary [chalcogenide glass (GASIR®)] lenses, which were designed for large-scale commercial and military infrared optical systems. In December 2011, Umicore announced it intended to consolidate all of its germanium-base optics production to its Quapaw facility because it was closer to the main customer base of these products. Umicore anticipated that optics production at its Olen, Belgium, facility would be phased out by yearend 2013 (Umicore s.a., 2012, p. 33–34).

Several companies were involved in refining or processing imported germanium material. Germanium Corp. of America (a subsidiary of Indium Corp. of America, Clinton, NY) produced germanium products, including germanium dioxide, germanium metal, and germanium tetrachloride at its facility in Utica, NY. Sylarus Technologies, LLC (St. George, UT) produced germanium substrates for optical, semiconductor, and solar applications from germanium dioxide feedstock primarily imported from Canada through an agreement with its parent company, 5N Plus Inc. (Montreal, Quebec, Canada). Voltaix, LLC (Branchburg, NJ) produced germane gas from imported germanium dioxide for use in semiconductors and solar cells. In September, Voltaix executed a memorandum of understanding with Sparton Energy Inc. (Toronto, Ontario, Canada) for the purchase of all germanium production from the Huajun Mine in Yunnan Province, China (Voltaix, LLC, 2011). Exotic Electro-Optics, Inc. (Murrieta, CA), E.R. Precision Optical (Orlando, FL), and Lattice Materials, LLC (Bozeman, MT) produced germanium blanks and lenses for use in infrared optics.

Nyrstar N.V. (Balen, Belgium), a leading global zinc and lead producer, owned and operated the Middle Tennessee zinc mining complex near Gordonsville, TN. The complex consisted of zinc mines in Cumberland, Elmwood, and Gordonsville, TN, which had historically produced zinc concentrates containing germanium and gallium. Nyrstar also owned the Clarksville, TN, smelter, which was originally built to treat concentrates from the Middle Tennessee zinc mining complex, and the mine complex was expected to be an important source of concentrate for the Clarksville zinc smelter. Nyrstar began ramping up production at the mines in 2010 and by yearend 2011, all three of the Middle Tennessee mines had been completely dewatered and returned to commercial production. The mines were considered a potential source of germanium but Nyrstar had not released details of plans to recover germanium from zinc residues by yearend 2011 (Nyrstar N.V., 2012, p. 14).

Consumption

The USGS estimated that domestic apparent consumption of germanium decreased to about 36,000 kg in 2011 from 40,000 kg in 2010 owing partially to decreased demand for germanium for use in infrared-optics, a segment that is heavily reliant on Government spending. Worldwide, the end-use pattern of germanium was estimated to be as follows: infrared optics, 30%; fiber optics, 20%; catalysts for PET, 20%; electronics and solar applications, 15%; and other uses (such as phosphors, metallurgy, and chemotherapy), 15%. The domestic end-use pattern, however, was different, with infrared optics accounting for 50%; fiber optics, 30%; electronics and solar applications, 15%; and other uses (phosphors, metallurgy, and chemotherapy), 5%. Germanium was not used in PET catalysts in the United States.

Infrared Systems.—Germanium was used in the manufacture of lenses and windows for infrared optical systems owing to its transparency to part of the infrared spectrum and to its high refractive index. Germanium is easily machinable, relatively strong, resistant to atmospheric oxidation, and able to withstand exposure to chemicals and moisture. The lenses and windows manufactured from germanium are often incorporated into thermal imaging systems that detect infrared radiation and convert it into an electronic signal, which is then processed and displayed on a video screen. Thermal imaging systems are different from other types of "low light" vision systems in that they are not adversely affected by the presence of light, so they can be used day or night. It was estimated that about 60% of lower- and midrange infrared-optical systems and 50% of all high-end devices used lenses made from germanium crystals (Maozhong, 2010, p. 10).

According to the most recent data available, the 2009 sales value of the global infrared thermal imaging market was estimated to be about $6.6 billion. Military and other Government applications represented 88% of this market, with commercial applications accounting for the remaining 12%. All branches of the military continued to rely heavily on infrared devices for around-the-clock force protection and intelligence, surveillance, and reconnaissance (ISR) as well as target acquisition applications on multiple platforms. Products used by the military typically range in price from under $10,000 for handheld and weapon-mounted systems to more than $1 million for advanced stabilized targeting systems. The majority of infrared imaging systems use cooled technology to identify objects from long distances; however, the number of uncooled thermal imaging systems was increasing rapidly in certain markets such as weapon sights, handheld monoculars/binoculars, military vehicles, and unmanned aerial vehicles. These devices are substantially smaller and more lightweight than their cooled counterparts because they operate at ambient temperatures while retaining their sensitivity to infrared light. Air-, land-, and sea-based vehicles were routinely equipped with multiple infrared systems that allowed soldiers to perform a variety of combat-related functions in even the most adverse battlefield conditions. A typical ground transport vehicle might be outfitted with separate infrared imaging systems for driver and observer's vision enhancers, weapons sights, and roof-mounted imaging systems that perform long-range scans in search of improvised explosive devices. A leading domestic producer of infrared devices for military use reported a reduction in procurement activity by the U.S. Government in 2011 compared with that in 2010 (FLIR Systems, Inc., 2012, p. 31).

Many thermal imaging manufacturers have made efforts to enter the commercial market to pursue growth opportunities that are expected in the near future. As the cost of infrared imaging technology has declined, demand has increased in markets such as airborne law enforcement, automotive night-vision, commercial security, firefighting, and recreational marine applications. Handheld thermal imaging systems that can detect and measure small temperature differences were used for a variety of commercial and industrial applications, such as predictive and preventive maintenance. A leading thermal imaging device manufacturer reported that its revenue from commercial vision systems increased at a compound annual rate of 16% from 2006 to 2011 (FLIR Systems, Inc., 2012, p. 1).

Fiber Optics.—In the fiber-optics sector, germanium tetrachloride is converted to germanium dioxide and used as a dopant (a substance added in small amounts to the pure silica glass core to increase its refractive index, preventing signal loss while not absorbing light) within the core of optical fibers. In 2011, an estimated $300 billion of capital expenditure was dedicated globally to construction and improvements of telecommunication infrastructure. Growth areas that utilize fiber optics to meet increasing demand for more bandwidth included enterprise data-storage applications, fiber-to-the-home (FTTH) installations, and wireless communications networks. Increases in demand for fiber-optic cable in North America have been slower since 2008, a reflection of an overall reduction in business activity owing to the global financial slowdown. In September 2011, the Fiber-to-the-Home Council estimated that about 22 million homes in North America had FTTH connectivity available compared with 17.2 million in September 2010. Corning Inc. indicated that global net sales for its telecommunications segment (inclusive of fiber-optic products for FTTH and enterprise networking applications) in 2011 were greater than those in 2010 (Fiber-to-the-Home Council, 2011; Corning Inc., 2012, p. 33).

Solar Cells.—Germanium-based solar cells are used in space-based applications and terrestrial installations. Demand for satellites has increased steadily from 2007 to 2011 owing to demand for commercial, military, and scientific applications. It was estimated that about 400,000 germanium substrates were consumed each year for space-based applications, and the majority of all satellites were powered by germanium-based solar cells. Germanium substrates were smaller in size and weight, more efficient at converting light into energy, and provided greater power output than the most common alternative substrate, silicon. Germanium substrates constitute the building blocks of multilayer (often referred to as multijunction) solar cells. Ultrathin layer combinations of materials, such as gallium, indium, phosphide, and gallium arsenide, are "grown" on top of the germanium substrate, each capturing a specific part of the solar spectrum and converting it into electricity. The solar energy conversion efficiency of these multijunction cells was typically greater than 25%. Currently, triple-junction cells are most common, but technological advancements have allowed for multijunction cells to combine more layers and junctions onto one cell, increasing performance capabilities. Spectrolab Inc. (a subsidiary of The Boeing Co.), in Sylmar, CA, began adapting space-based solar technology for terrestrial applications in 2001 and has been able to convert concentrated sunlight to electricity at efficiencies as great as 41.6% (Spectrolab Inc., 2010; Umicore s.a., 2010a, p. 52).

Several other manufacturers of germanium substrates, multijunction solar cells, and solar systems have focused capital investment and research efforts on the emerging terrestrial solar market. While there is fairly widespread agreement that global demand for solar power generation and other sources of renewable energy will continue to increase during the next several decades, multiple solar cell technologies are expected to compete for a portion of the solar power market. The multijunction solar cells that use germanium substrates and germanium layers are typically more expensive to manufacture than other technologies, such as cadmium telluride, crystalline silicon, or copper-indium-gallium diselenide thin-film cells, but are considerably more efficient at converting solar energy into electricity so fewer cells are required in a panel to produce equivalent amounts of power. To obtain the most energy possible from each multijunction cell in a solar panel, concentrator photovoltaic (CPV) technology is used. A concentrator system uses optics (mirrors or lenses) to focus high concentrations of direct sunlight onto the solar cells. The lenses or mirrors concentrate sunlight hundreds of times before it reaches the solar cell, making each cell more efficient. Concentrating panels must receive direct sunlight to operate so CPV installations are limited to geographic regions that receive proper levels of sunlight. CPV systems typically require tracking systems that allow the solar panels to follow the Sun's path during the day. CPV systems are marketed to the large-scale power generation industry and are not considered a feasible solar power option for private homeowners.

As of 2011, CPV installations in China, Europe, and North America had capacity of about 28 megawatts (MW). New CPV projects that could increase capacity to as much as 689 MW were under development in the United States and several other countries. It was estimated that, in current CPV installations, 1 MW of solar power generation capacity required about 10 kg of germanium contained in 1,500 substrates. Multijunction solar cells have continued to become a viable option for use in large-scale concentrated solar power projects because their energy conversion efficiencies have been increasing at a rate of about 1% per year during the past decade. The U.S. Government has also been actively involved in advancing solar energy technologies, including CPV systems. The U.S. Department of Energy (DOE) Solar Energy Technologies Program (SETP) was aggressively funding a diverse set of photovoltaic (PV) technologies that had potential applications in a range of different markets. Through its primary research and development efforts, the PV subprogram's goal was for PV technology to achieve grid parity (the point at which the cost of generating electricity using alternative technologies such as solar power is at least equal to the cost of generating electricity from conventional sources such as burning coal) by 2015. The DOE's goals included increasing the use of CSP in the United States, making CSP competitive in the intermediate power market by 2015, and developing advanced technologies that would reduce systems and storage costs, enabling CSP to be competitive in the baseload power market by 2020. Separately, Emcore Corp. (Albuquerque, NM) was collaborating with the National Renewable Energy Laboratory and the U.S. Air Force Research Laboratory to develop new advanced multijunction solar cells that could achieve greater conversion efficiencies than existing multijunction cells. These new inverted metamorphic multijunction cells were built using a different manufacturing process where the layers of the semiconductor were grown "upside down" on the germanium substrate so that the top layer of the cell is grown on the bottom of the stack, closest to the substrate. When completed, the cell is removed from the germanium substrate and encapsulated. The process allows for higher quality development of the most important layer of the solar cell, the top layer, and had the potential to achieve energy conversion efficiencies of 50% in the future. In 2011, a pair of prototype metamorphic multijunction solar cells that had achieved energy conversion efficiencies greater than 36% were launched into space during the final space shuttle mission for performance evaluation (Umicore s.a, 2010b, p. 5, 9; Cameron, 2011; Emcore Corp., 2011a, p. 16–17, b; U.S. Department of Energy, 2011).

Electronic Components.—Germanium substrate consumption for production of high-brightness LEDs used in such devices as automobile taillights, cameras, flashlights, mobile telephone display screens, televisions, and traffic signals decreased slightly in 2011 compared with that in 2010. This was partially attributed to LED manufacturers drawing down existing stocks. In electronics, silicon germanium (SiGe) components have replaced gallium arsenide in some high-tech products, such as components for cellular telephones. In high-speed wireless telecommunications devices, SiGe transistors can attain greater switching speeds and require less power than traditional, silicon-based components, increasing overall performance. Phase change memory modules made from an alloy of antimony, germanium, and titanium could potentially boost battery life in mobile devices by as much as 20% compared with the current flash memory technology used in those devices. SiGe-based microchips were also used in radar systems for automobiles to increase driving safety. Known as radar-on-chip-for-cars technology, these devices are capable of alerting drivers to impediments that are in the path of the vehicle in order to prevent potential accidents (PC Magazine, 2010).

Polymerization Catalysts.—Outside the United States, estimates indicated that after declining annually since 2007, germanium dioxide use as a catalyst for PET production increased in 2011. Japan continued to be the leading consumer of germanium for this application. Consumption of germanium dioxide used in PET was estimated to have increased in 2011 compared with that in 2010 partially owing to increased demand for beverage bottles in Japan after the earthquake and tsunami in March (Metal-Pages, 2011b; Roskill's Letters from Japan, 2012).

Prices

The market prices of germanium dioxide and metal were relatively stable during the first three quarters of 2010 and then started to increase during the last quarter. This trend continued into the first half of 2011. Free market prices for germanium dioxide in 2011, published by Metal-Pages, began the year at about $720 per kilogram and more than doubled to $1,450 per kilogram by June. The price increase was attributed to the combination of an export tax, plant closings, and possible stockpiling in China. By yearend, the germanium dioxide price had declined to $1,250 per kilogram. The free market prices for germanium metal began the year at $1,200 per kilogram, increased to $1,650 per kilogram during the second quarter of 2011 and ended the year at $1,450 per kilogram. At yearend, the price of the contained germanium in the oxide was greater than the price of germanium in metal form.

Based on DLA Strategic Materials reports, the unit price of zone-refined germanium metal in inventory that was authorized for disposal as of December 2011 was $1,185 per kilogram.

Foreign Trade

According to the U.S. Census Bureau, imports for consumption of germanium metal (wrought, unwrought, and powder) increased by 5% to 28,300 kg in 2011 from 27,000 kg in 2010. Increased imports from Belgium outweighed decreases from China, Germany, and Russia. In 2011, China, Belgium, and Russia, in descending order of quantity, accounted for 94% of germanium metal imported into the United States (table 1). The estimated germanium content of the germanium dioxide imported in 2011 was about 10,000 kg compared with 17,700 kg in 2010. Canada accounted for the majority of germanium dioxide imports in 2011.

Domestic exports of germanium metal and articles thereof, including waste and scrap, were about 5,900 kg in 2011, based on an analysis of trade data from the U.S. Census Bureau. Belgium, Canada, and Russia accounted for the majority of germanium exported from the United States in 2011. The estimated germanium content of germanium dioxide exported from the United States in 2011 was less than 100 kg.

World Review

In 2011, the world's total production of germanium was estimated to be between 100 and 120 t. This comprised germanium recovered from zinc concentrates, fly ash from burning coal, and recycled material. The recycling level remained about the same as that in 2010 and supplied about 30% of the world's total supply of germanium. Owing to the value of refined germanium, new scrap generated during the manufacture of fiber-optic cables, infrared optics, and substrates is typically reclaimed and fed back into the production process. Recycling of germanium recovered from used materials, such as fiber-optic window blanks in decommissioned military vehicles or fiber-optic cables, has increased during the past decade. Worldwide, primary germanium was recovered from zinc residues in Canada (concentrates shipped from the United

States), coal and zinc residues in China (multiple sources), zinc residues in Finland [concentrates from Congo (Kinshasa)], and coal in Russia (Sakhalin). The vast majority of germanium production was concentrated in Canada and China.

As a byproduct metal, the supply of germanium was heavily reliant on zinc production, which increased on a global basis in 2011 owing to increased production in China, India, Mexico, and Russia. While clearly an important factor, an increase in zinc mine production cannot necessarily be an absolute 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, 2011).

Market conditions for germanium dioxide were relatively tight during the first three quarters of 2011 owing to developments in China. Demand decreased for both germanium dioxide and metal during the last quarter of the year, and prices decreased during that time period. Reports indicated that producer stocks increased, production rates slowed, and consumers of germanium decreased buying activity.

Belgium.—Umicore produced germanium metal, germanium tetrachloride for fiber optics, germanium substrates, and germanium optical products at its refining and recycling plant in Olen. The company also operated an electro-optic materials research and design facility in Olen. Umicore's substrate manufacturing facility had the capacity to produce about 600,000 germanium substrates per year. The company reported that sales volumes of germanium substrates increased in 2011 from that of 2010 owing to greater consumption for use in the concentrator photovoltaic sector. Sales volumes of substrates used in light-emitting diodes (LED) decreased slightly in 2011 owing to overstocking in the lighting sector. Consumption of germanium blanks for optics applications decreased significantly as a result of a reduction in government-sponsored programs. Conversely, sales volumes of finished infrared optics were greater in 2011 than in 2010 owing to increased usage in thermographic and nonautomotive night vision systems (Umicore s.a. 2012, p. 33–34).

Canada.—The metallurgical complex operated by Teck in Trail consisted of six major metallurgical plants, one fertilizer plant, and two specialty metal plants that produced byproduct metals, including germanium and indium. Historically, Teck has been one of the leading germanium producers in the world. Teck did not disclose germanium production information to the public for 2011. The last year that the company had made germanium production information available was 2007, when Teck produced about 40,000 kg of germanium dioxide at Trail. Based on trade data published by the Canadian Government, Canada exported about 25,200 kg of germanium contained in germanium dioxide in 2011 compared with about 29,400 kg in 2010. The leading destinations of exported germanium dioxide were Japan, 45%; the Republic of Korea, 22%; the United States, 17%; and North Korea, 15% (Statistics Canada, 2012).

In 2011, 5N Plus continued to integrate its operations and announced that it had converted a $3 million debenture provided to Sylarus in 2010 into a 66.67% majority interest in the company. 5N Plus also opened a production facility in Trail, British Columbia. The new plant had capacity for semiconductor processing, purification, and recycling of several metals including germanium (American Metal Market, 2010; 5N Plus Inc., 2011).

China.—China continued to be the leading global producer of germanium metal and germanium compounds. Germanium-bearing coal ash and zinc ore were the sources for the Chinese germanium production. In 2011, five to six producers accounted for the majority of the estimated 80 to 100 t of germanium metal and germanium compounds produced in China. About 44% of this production was in the form of germanium metal, 42% was germanium dioxide (metal content), and 14% was in the form of other compounds. China consumed about 35 t of the germanium that it produced and exported the rest.

During the first 6 months of 2011, free market prices of germanium dioxide increased to $1,450 per kilogram from $720 per kilogram at yearend 2010. During the same period, free market prices of germanium metal increased to $1,650 per kilogram from $1,200 per kilogram. Factors that contributed to the germanium dioxide price increase included a 2010 export tax on germanium dioxide produced in China that tightened global supply, coupled with the shutdown of a Chinese germanium dioxide plant owing to environmental concerns in early 2011. The Chinese 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 those products. In response to the increased germanium dioxide prices, some domestic germanium consumers found it more economical to purchase germanium in pure metal form instead of as oxide. An early 2011 announcement indicating that China intended to include germanium in a strategic stockpile of rare metals, potentially tightening supply, also contributed to price increases. The market for germanium metal and germanium dioxide slowed substantially during the last half of 2011, and producer stocks began to swell. At yearend, it was announced that the 5% export tax on germanium dioxide would be unchanged in 2012. Chinese germanium producers continued to emphasize development of downstream products that could be more profitable to sell than raw materials. In August, Yunnan Chihong Zinc and Germanium Co., Ltd. established a joint venture with North Night Vision Technology Co., Ltd., an infrared optics manufacturer, to build four new infrared optic plants from 2011 to 2016. In November, Lincang Xinyuan Germanium Co. Ltd. announced two new projects, a plant to make optical lenses and another to produce high-efficiency substrates for use in satellites and electronics (Burton, 2011; Metal-Pages, 2011a; Yang, 2011a–c; 2012).

Japan.—Japanese consumption of germanium was met entirely by imports. In 2011, Japan imported 25,100 kg of germanium dioxide, a 46% increase from that in 2010. The increase in imports was partially attributed to greater consumption of PET for bottles after the earthquake, tsunami, and ensuing events that caused massive damage in March 2011. The natural disaster and subsequent damage to a nuclear reactor caused many people to stock up on extra bottles of water and other drinks out of fear of radiation exposure. Germanium dioxide prices increased substantially after the tsunami as producers anticipated a surge in demand from

Japan. The increase in imports could also have been a sign that PET producers were overstocked in 2010 and had returned to importing a more normal level of germanium dioxide in 2011. In 2011, Japan imported 5,380 kg of germanium metal, powder, and scrap, a 34 % decrease from that in 2010. Consumption of germanium tetrachloride for use by the fiber-optic industry decreased slightly in 2011 from that in 2010 owing to production disruptions after the earthquake. (Metal-Pages, 2011b; Roskill's Letters from Japan, 2011; 2012a, b).

United Kingdom.—The British Geological Survey published a 2011 supply risk index for 52 mineral commodities. Rankings of the mineral commodities were determined by a number of factors including abundance, location of production and reserves, and political stability in production locations. The mineral commodities that were deemed to have the highest risk levels had restricted supply bases that were in countries with relatively low political stability. China was the leading producer of 28 out of the 52 metals that appeared on the list. Germanium was relatively high on the supply risk index, ranking 15 out of the 52 mineral commodities (Metal Bulletin, 2012).

Outlook

Global germanium consumption is likely to increase, possibly slightly, during the next several years owing to the growth that is expected in the major end-use sectors. Germanium-based optical blanks and windows that are incorporated in infrared devices were expected to continue to be heavily used by military and law enforcement agencies. New applications for these products in commercial and industrial markets also were expected to become more prevalent and represented a large potential growth area. In China, germanium producers will emphasize integrated operations and will manufacture finished infrared products for export.

Global demand for fiber-optic cable, led by the emerging Asian economies and Brazil, was forecast to increase at a compound annual growth rate of 5% through 2015. Global support for the increased use of solar energy during the next several years is expected to increase demand for germanium substrates that are used to manufacture high-efficiency multijunction solar cells. New satellites launched for defense and private industry uses were expected to continue to fuel consumption of germanium substrates in solar cells. As energy conversion efficiencies continue to improve, terrestrial-based solar cell systems will be a more feasible option for large-scale power generation. Owing to the massive size of the installations, growth in the terrestrial-based solar cell market could significantly boost annual germanium substrate consumption. Germanium substrate use in high-brightness LEDs was expected to continue to increase substantially through 2014. As an alternative to gallium arsenide in LEDs, germanium substrates are less expensive, stronger, and do not contain toxic substances (Mikolajczak, 2011).

Germanium substrates used in thermophotovoltaic (TPV) cells that convert heat radiation (instead of sunlight) generated from sources such as furnaces or water boilers into electricity could be a future growth area. Most TPV cells were used almost exclusively for military applications, but this technology could be applied in industrial or residential settings. In an industrial setting, for example, TPV cells could generate electricity from the heat created during the production of materials such as glass or steel.

On the supply side, the zinc mines in Tennessee are a potential new domestic source of germanium. Several germanium recovery projects in China that were in late stages of development or early production also could bring more germanium to the market if demand continues to increase. In addition to primary germanium production, the availability of recycled germanium recovered from end-of-life products, such as fiber optics, military vehicles, and solar cells, was expected to increase during the next two decades as these aging products are taken out of service. Overall, the germanium market is expected to remain tight during the next several years owing to the emerging end uses and limited sources of supply.

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

	2010		2011	
Country	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Belgium	1,560	$2,700,000	5,300	$7,900,000
Canada	70	15,500	215	235,000
China	18,100	14,500,000	17,400	24,600,000
France	70	70,300	--	--
Germany	2,320	3,310,000	776	1,120,000
Russia	4,620	5,050,000 r	4,040	5,140,000
Taiwan	60	58,800	500	301,000
Other	252 r	185,000 r	83	30,400
Total	27,000	25,900,000	28,300	39,400,000

r Revised. -- 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.