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RARE EARTHS [ADVANCE RELEASE]

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Rare Earths

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In 2014, world rare-earth mine production was 125,000 metric tons (t) of rare-earth oxide (REO) and was primarily from the minerals bastnäsite, loparite, monazite, and xenotime (tables 1, 6). China continued to dominate the global production and consumption of rare-earth metals and compounds. Rare-earth ores were mined primarily in China, with smaller amounts mined in Australia, India, Malaysia, Russia, Thailand, the United States, and Vietnam (table 6). In the United States, mining and processing of rare-earth ores and concentrates took place at the Mountain Pass Mine in California and, owing to processing issues, production decreased to 5,400 t. Prices for most rare-earth metals and compounds declined significantly relative to those in 2013 (table 3).

The rare earths are a moderately abundant group of 17 elements comprising the 15 lanthanides, scandium, and yttrium. The lanthanides are the elements with atomic numbers 57 through 71, in order of atomic number: lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium. In rock-forming minerals, rare earths typically occur in compounds as trivalent cations in carbonates, oxides, phosphates, and silicates (Mason and Moore, 1982, p. 46).

A rare-earth element (REE) can be classified as either a light rare-earth element (LREE) or a heavy rare-earth element (HREE). The LREEs include the lanthanide elements from atomic number 57 (lanthanum) through atomic number 64 (gadolinium), and the HREEs include the lanthanide elements from atomic number 65 (terbium) through atomic number 71 (lutetium). The division is based on the LREEs having unpaired electrons in the 4f electron shell and HREEs having paired electrons in the 4f electron shell.

Scandium (atomic number 21), a transition metal, is the lightest REE but it is not classified as one of the group of LREEs nor one of the HREEs. Scandium is a soft, lightweight, silvery-white metal, similar in appearance and weight to aluminum. Although its occurrence in crustal rocks is greater than that of lead, mercury, and the precious metals, scandium rarely occurs in concentrated quantities because it does not selectively combine with the common ore-forming anions.

Yttrium (atomic number 39), a transition metal, is chemically similar to the lanthanides and commonly occurs in the same minerals as a result of its similar ionic radius. Yttrium is included as an HREE even though it is not part of the lanthanide series.

The elemental forms of rare earths are iron-gray to silvery lustrous metals that are typically soft, malleable, ductile, and usually reactive, especially at elevated temperatures or when finely divided. Melting points range from 798 °C for cerium to 1,663 °C for lutetium. The unique properties of rare earths make them useful in a wide variety of applications such as batteries, catalysts, magnets, nonferrous alloys, phosphors, and polishing compounds. The principal REE-bearing ore minerals are bastnäsite, loparite, monazite, xenotime, and the lateritic ion-adsorption clays (table 2).

Legislation and Government Programs

The U.S. Geological Survey (USGS) supported numerous projects related to rare earths through funding either wholly or in part by its Mineral Resources Program (MRP). MRP research and assessments provide information for land planners and decision makers about where deposits of mineral commodities are known and suspected in the Earth's crust and the environmental issues associated with those commodities. In 2014, the USGS MRP initiated several research projects in topics related to rare earths. The MRP research topics included airborne geophysics for REE deposits; geophysical and geochemical approaches to evaluating REE resources in the southeastern United States; REE deposits studies in Bokan, AK, and the southeast Mojave Desert; and the formation of deposits of nonconventional REE materials (U.S. Geological Survey, 2014).

In October, the U.S. Department of Defense, Defense Logistics Agency Strategic Materials (DLA Strategic Materials) announced the fiscal year (FY) 2015 annual materials plan (AMP) for the National Defense Stockpile (NDS). The AMP included potential acquisitions of new NDS stocks. These included 0.5 t of dysprosium metal and 10 t of yttrium oxide. The potential REE acquisitions were authorized by Congress under the National Defense Authorization Act for FY 2014 and were to be acquired between FY 2015 and FY 2017 (Defense Logistics Agency Strategic Materials, 2014).

The DLA Strategic Materials submitted a report to Congress entitled "Diversification of Supply Chain and Reclamation Activities Related to Rare Earths." Although details of this report were not publicly available, the DLA Strategic Materials presented a mitigation strategy for rare earths for U.S. defense needs, focusing on alternative sources of rare-earth supply and in particular the reclamation of rare earths from waste. The DLA Strategic Materials supported a research program to determine efficient and environmentally friendly processing techniques that could be used to domestically produce strategic materials such as rare-earth metals (Defense Logistics Agency Strategic Materials, 2015).

Researchers at the Critical Materials Institute (CMI), funded by the U.S. Department of Energy, were working to diversify supplies of critical materials, develop substitutes, improve reuse and recycling, and study the cost and material supply chains of critical materials. CMI's projects covered a broad range of research areas including the recovery of REE from other commodity process streams, the development of substitutes for

REEs in magnets and phosphors, and improving manufacturing techniques and recycling (Critical Materials Institute, undated).

Production

Molycorp, Inc. (Greenwood Village, CO) was the sole U.S. producer of rare-earth mineral concentrates from its mining and separation operations at Mountain Pass, CA. Based on publicly reported data, mineral concentrate production was estimated to be 5,400 t of REO equivalent compared with 5,500 t of REO equivalent in 2013. In 2014, Molycorp reported a consolidated REO equivalent production of 4,770 t from the Mountain Pass operation that included unseparated LREE concentrates, HREE concentrates, separated REOs (lanthanum, cerium, and neodymium/praseodymium), and rare-earth-based water treatment products. At yearend, Molycorp's estimated proven and probable ore reserves were 17.8 million metric tons (Mt), with an average grade of 8.10% REO (Molycorp, Inc., 2015, p. 45).

Rare-earth compounds and chemical intermediates are imported and processed into a variety of value-added products. Leading producers of rare-earth-bearing catalysts and chemical intermediates in the United States included Albemarle Corp. (Baton Rouge, LA), BASF (Florham Park, NJ), Molycorp, Solvay Chemicals, Inc. (Houston, TX), and W.R. Grace & Co. (Columbia, MD). Globe Metallurgical Inc. (Beverly, OH) and CC Metals and Alloys, LLC (Calvert City, KY) produced specialty ferroalloys containing REEs. U.S. processors of rare-earth magnet alloys or rare-earth magnets included Arnold Magnetic Technologies Corp. (Rochester, NY), Electron Energy Corp. (Landisville, PA), Eutectix, LLC (formerly Great Western Technologies, Troy, MI), Hitachi Metals America, Ltd. (China Grove, NC), and Molycorp. ETREMA Products (Ames, IA) produced the magneto-restrictive alloy Terfenol-D® containing dysprosium, iron, and terbium. A variety of scandium compounds were produced from imported materials in limited quantities. All domestic, commercially produced scandium and yttrium products were derived from imported compounds primarily sourced from China.

Great Western Minerals Group Ltd. (GWMG) sold its Great Western Technologies subsidiary in Troy, MI, to Eutectix, LLC in 2014. Eutectix planned to manufacture and process metal alloys and battery electrodes at the Troy operation. GWMG's other subsidiaries also produced specialty alloys and included Less Common Metals Ltd. based in Birkenhead, United Kingdom (Eutectix, LLC, 2014).

Rare Element Resources Ltd. filed a National Instrument (NI) 43–101 Technical Report summarizing the results of an updated prefeasibility study (PFS) on its Bear Lodge project in Wyoming. The study indicated that the project would have a 45-year life and (as of October) measured and indicated resources of the project were 16.3 Mt averaging 3.07% REO using a cutoff grade of 1.5% REO. Using a 3% cutoff, the measured and indicated resources were estimated to be 6.2 Mt averaging 4.52% REO. At yearend, none of the resources had been classified as reserves; however, the environmental permitting process was underway, patents were filed on the company's REO separation process, and a feasibility study was expected to begin in 2015 (Rare Element Resources Ltd., 2015, p. 11, 36, 37).

In September, Texas Rare Earth Resources Corp. (TRER) announced that it was using a lower volume and staged approach to developing the Round Top REE project. The goal was to develop an operation designed to produce about 400 metric tons per year (t/yr) of a selected group of separated REE products. The remaining REEs produced at the operation were expected to be stored as a mixed rare-earth concentrate for future separation. TRER's analysis indicated that the estimated initial capital cost for the project was in the range of $60 million to $90 million. A previously completed estimate of measured and indicated resources was 529 Mt containing 307,000 t of REO, using a cutoff grade of 428 grams per metric ton of yttrium equivalent (Texas Rare Earth Resources Corp., 2013, p. 90, 151; 2014).

In June, the Alaska Industrial Development and Export Authority was approved to issue bonds up to $145 million to help finance the infrastructure and construction costs of Ucore Rare Metals Inc.'s Bokan-Dotson Ridge REE project. In September, Ucore completed a drilling program on the Bokan-Dotson project with the intent of moving existing inferred resources to the indicated category under NI 43–101 guidelines. In October, Ucore announced it had put forth a request for proposals to conduct a bankable feasibility study on the Bokan-Dotson Ridge REE project (Ucore Rare Metals Inc., 2014, 2015).

Consumption

In 2014, global consumption of rare earths was on the rise. According to estimates published by Roskill Information Services Ltd., global consumption of REO was about 119,000 t in 2014. Global consumption was led by catalysts (23%), magnets (22%), metallurgy (16%), and polishing (13%). Other end uses (26%) included ceramics, glass, phosphors, pigments, and miscellaneous other uses (Roskill Information Services Ltd., 2015, p. 152).

Data on domestic rare-earth consumption were developed by surveying known processors and manufacturers and evaluating industry reports and trade statistics. Based on import data and industry reports, U.S. consumption of REE metals and compounds was estimated to be 17,000 t of REO in 2014. Data retrieved from the PIERS trade database and other industry sources indicated that the estimated use of rare earths in 2014 was primarily in catalysts (60%), metallurgical applications and alloys (10%), permanent magnets (10%), glass polishing (10%), and other uses (10%) (JOC Group Inc., undated).

Import data suggest imports of yttrium in metals and compounds were about 200 to 300 t of REO equivalent in 2014. Increased yttrium imports in 2014 compared with those of 2013 may have been caused by lower prices for yttrium products. Yttrium compounds were used primarily in ceramics, metallurgical applications, and phosphors (JOC Group Inc., undated). Global consumption of scandium was estimated to be 15 to 20 t. Although not quantified, the domestic end uses of scandium were primarily for fuel cells and as an additive in aluminum alloys; however, scandium for these applications was thought to be imported in the form of value-added intermediate products rather than imported under the Harmonized Tariff Schedule of the United States (HTS) codes for rare-earth metals (2805.30) and rare-earth compounds (2846).

Prices

Prices for most rare-earth products experienced yet another year of decline following the price spike in 2011. In general, prices for REOs reflect global market prices and were undermined by excessive capacity and illegal production in China (Shen, 2014a, b). Prices for cerium, lanthanum, samarium, and yttrium compounds decreased most significantly compared with those in 2013. Prices of rare-earth materials used in magnet applications experienced somewhat less severe declines, and in some instances, such as praseodymium oxide, prices increased. Prices for scandium materials were more stable and were supported by scandium used for aluminum alloys and fuel cells.

Foreign Trade

Data in this section are based on gross weight; data totals in the tables are also converted to REO equivalent content. U.S. exports of all forms of rare-earth metals and compounds totaled 6,180 t of REO equivalent, a 30% decrease compared with those of 2013 (table 4). Rare-earth metals under HTS 2805.30 excluding ferrocerium decreased most significantly, by 87% compared with 2013. In contrast to total rare-earth exports, exports of ferrocerium and other pyrophoric alloys under HTS 3606.90, primarily used for ductile irons and in steelmaking, increased by 15% compared with 2013. A significant portion of rare-earth exports were classified as unspecified compounds (HTS 2846.90) and exported primarily to China and Estonia. Increased domestic production of mixed rare-earth compounds caused U.S. exports to increase.

U.S. imports totaled 11,400 t of REO equivalent, a 26% increase compared with those of 2013 (table 5). China continued to dominate most import categories, and most of the REE alloys and compounds imported from other countries were derived from Chinese feedstocks. Imports of lanthanum oxide, lanthanum carbonates, and lanthanum metal were determined to be 4,600 t, 573 t, and 61 t, respectively, of REO equivalent (46% of total REO equivalent imports). Cerium compounds were 13% of total REO equivalent imports in 2014.

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Australia.—In New South Wales, Lynas Corp. Ltd. continued to operate its Mt Weld mining operations on a campaign basis and in line with the rampup of its processing operations in Malaysia. In 2014, Lynas' Malaysian operations produced 7,200 t of REO equivalent derived from imports of Australian rare-earth concentrates, a more than fivefold increase compared with production in 2013. At yearend, 8,470 t of concentrate containing 3,230 t of REO was ready for export to Malaysia (Lynas Corp. Ltd., 2014a–c, 2015).

Alkane Resources Ltd. continued to develop its Dubbo Zirconia project in New South Wales with planned production of hafnium, niobium, rare-earth, tantalum, and zirconium products. In 2014, Alkane's environmental impact study that was submitted to the government of New South Wales in 2013 was under review, and the company continued to refine its process design. At yearend, production was scheduled to begin in 2016. Reserves of REO for the Dubbo project were estimated at 35.9 Mt containing 316,000 t of REO (including yttrium oxide), based on a 1.5% cutoff grade [combined niobium oxide, REO, and zirconium oxide (ZrO_2)] (Alkane Resources Ltd., 2014, p. 15, 20).

In the Northern Territory, Arafura Resources Ltd. continued to work on its Nolans Bore project. In 2014, the company worked to advance environmental impact studies, lower its startup and operating costs, and secure offtake agreements and consulting services with Chinese partners. Production of as much as 20,000 t/yr of REO equivalent of mixed REE chlorides and cerium carbonate was scheduled to begin in 2019 (Arafura Resources Ltd., 2014, p. 8–10). Probable reserves of the project were estimated to contain 672,000 t of REO using a 1% cutoff grade (Arafura Resources Ltd., 2012).

Brazil.—According to the Departamento Nacional de Produção Mineral (DNPM), Brazil did not produce monazite concentrates in 2014. In 2013, 600 t of monazite exports were derived from Indústrias Nucleares do Brasil (INB) stocks of mineral concentrates in Sao Francisco do Itabapoana. DNPM had estimated INB held an additional 10,000 t of inventory (Andrade, 2015, p. 114, 115; 2016, p. 108, 109).

MBAC Fertilizer Corp. (Canada) reported that it had received approval of its mineral extraction plan and that it was in the early stages of obtaining a preliminary environmental license from DNPN for the development of its Araxá polymetallic project in the State of Minas Gerais; however, MBAC was seeking partners for the potential sale of the Araxá project. MBAC cited the company's agricultural focus as the incentive for the proposed sale (MBAC Fertilizer Corp., 2015, p. 6). In a preliminary economic assessment (PEA), the project's measured and indicated mineral resources were reported to contain 317,000 t of REO using a 2% REO cutoff grade. MBAC's PEA was based on the production of 8,750 t/yr of REO equivalent (MBAC Fertilizer Corp., 2014, p. 12).

Canada.—Avalon Rare Metals Inc. received approval for site preparation work at its Nechalacho project at Thor Lake, Northwest Territories. Project development work continued via a drilling program and in optimizing design of the mineral concentration and hydrometallurgical plants. A previously completed NI 43–101-compliant feasibility study for the project assumed a 20-year mine life with average production of 6,800 t/yr of separated REO and byproducts of tantalum, niobium, and zirconium oxides. The project's proven and probable mineral reserves were about 15 Mt containing 1.7% REO using a cutoff value of $320 per metric ton of net metal return (NMR), in situ value of all payable metals (Avalon Rare Metals Inc., 2013, p. 163–165). In 2015, the company planned to seek financing and offtake agreements to further development of the project (Avalon Rare Metals Inc., 2014).

Commerce Resources Corp. (CRC) was working on prefeasibility studies and an updated PEA on its Ashram REE project. The PEA was based on an average production of 16,850 t/yr production of REO equivalent contained in monazite and to a lesser extent in bastnäsite and xenotime. Using a 1.25% REO cutoff grade, measured and indicated resources were estimated to be 29.3 Mt containing 554,000 t of REO equivalent. In 2014, CRC conducted metallurgical studies and drilling programs to improve the resource estimate (Commerce Resources Corp., 2015).

In September, the government of Quebec through Ressources Québec Inc. (RQ) announced that it had invested Can$1 million though a private placement in Matamec Explorations Inc. RQ planned to invest an additional Can$3 million in the Matamec's Kipawa REE project. The RQ investment was part of a reported Can$6 million program in which Matamec would provide a Can$2 million portion (Matamec Explorations Inc., 2014). Proven and probable mineral reserves were estimated to be 20 Mt containing 0.41% (82,000 t) REO using a cutoff value of $48.96 per ton. When in full production, the mine was expected to produce an average of 3,760 t/yr of REO (Matamec Explorations Inc., 2013). In 2015, Matamec planned to update its previously completed feasibility study.

Quest Rare Minerals Ltd. announced that the government of Quebec was planning to support its Strange Lake rare-earth project in northeastern Quebec by providing financing for a feasibility study. The government of Quebec planned to take a minority equity position in Quest in an amount corresponding to 20% of Quest's prospectus offering, subject to a maximum investment by the government of $2 million (Quest Rare Minerals Ltd., 2014). Probable reserves at the Strange Lake project were estimated to be 43.2 Mt containing 1.16% (502,000 t) REO, using a minimum "net smelter return" value. Quest planned a 30-year mine life with a design capacity that included 13,700 t/yr of REO equivalent concentrates (Quest Rare Minerals Ltd., 2013, p. 122).

China.—China continued to dominate the global supply of rare-earth minerals, separated compounds, and metals, and accounted for nearly 90% of global mine production in 2014. China also led the global consumption of rare earths. LREE mine production was primarily from bastnäsite and monazite concentrates in Nei Mongol Autonomous Region and Sichuan Province. HREE mine production was primarily from ion-adsorption ores in Fujian, Guangdong, and Jiangxi Provinces in southeastern China.

For 2014, the Ministry of Land and Resources set a production quota for rare-earth ores at 105,000 t of REO, of which 87,100 t was for light-rare-earth ores and 17,900 t was for ion-adsorbed rare-earth ores. The quotas for light-rare-earth ores included the mining regions of Nei Mongol (59,500 t), Sichuan (25,000 t), and Shandong (2,600 t). The quotas for heavy-rare-earth ores included the mining regions of Jiangxi (9,000 t), Guangxi Zhuang Autonomous Region (2,500 t), Guangdong (2,200 t), Hunan and Fujian (2,000 t each), and Yunnan (200 t). Compared with the 2013 quotas, the heavy-rare-earth portion was unchanged and the light-rare-earth quota was increased by 12% (Ministry of Land and Resources, 2014).

In 2014, China reported exports of rare-earth ore, metals, and compounds of 27,800 t with a total value of about $230 million. Compared with 2013, the quantity decreased by 24% whereas the total value decreased by 36%, reflecting lower prices for most rare-earth materials (Metal-Pages, 2015).

According to the China Nonferrous Metals Industry Association, China's consumption of REO equivalent was about 90,000 t in 2014 and was expected to increase to 150,000 t by 2020 (Els, 2015).

China continued to attempt to crack down on widespread illegal production and sale of rare earths. In October, the Ministry of Industry and Information Technology (MIIT) launched a nationwide special campaign to fight illegal activities in the rare-earth sector that was to be effect from October 10, 2014, until March 31, 2015. The crackdown focused on Government inspections aimed at all levels of production, sale, and export as well as an archive of rare-earth enterprises monitored by MIIT (Shen, 2014).

China was consolidating its rare-earth industry through mergers, acquisitions, and closures into six largely Province-based state-owned enterprises. The consolidated companies included Baotou Rare Earth Hi-Tech Holding Co. Ltd., China Minmetals Corp., Aluminum Corporation of China Ltd., Ganzhou Mining Group, Guangdong Rare Earth Group, and Xiamen Tungsten Group. The large rare-earth groups were to receive preferential treatment to better develop the mineral resources (Xinhua News Agency, 2014).

In March, a World Trade Organization (WTO) panel ruled that rare-earth export quotas applied by the Chinese Government were in violation of WTO rules and commitments. Although China's Ministry of Commerce appealed the ruling, the WTO Appellate Body made the final ruling, which was against China. Following the ruling, China's Ministry of Commerce and General Administration of Customs announced the removal of the rare-earth export quotas (World Trade Organization, 2015).

Greenland.—Greenland Minerals and Energy Ltd was conducting definitive feasibility studies at its polymetallic (REE-uranium-zinc) Kvanefjeld project located in southern Greenland and formed a nonbinding memorandum of understanding (MOU) with China's Non-Ferrous Metals Industry's Foreign Engineering and Construction Co. (CNF) to support the development of the project. The Kvanefjeld project could potentially supply CNF with feedstock for a planned 7,000-t/yr REO separation operation (Greenland Minerals and Energy Ltd, 2014). Unlike most REE deposits under development, steenstrupine, a complex silicate mineral, is the primary mineral host to both REEs and uranium.

India.—India's producers of rare-earth-bearing heavy-mineral concentrates included Indian Rare Earths Ltd. (IREL) and Kerala Metals & Minerals Ltd. (KMML). India's monazite production capacity was reported to be 6,000 t/yr. In 2014, IREL completed construction and began commissioning a rare-earth processing plant which could consume monazite and produce 10,400 t/yr of rare-earth chloride and 800 t/yr of rare-earth fluoride (Metal-Pages, 2014c; Indian Bureau of Mines, 2015).

Japan.—Japan's Society of Newer Metals estimated the 2014 consumption of rare earths in Japan at 14,255 t, an 8% increase compared with 13,197 t in 2013. The breakdown of consumption included cerium (5,100 t), europium (16 t), lanthanum (1,980 t), mixed rare-earth metals (3,350 t), praseodymium and neodymium (2,400 t), samarium (80 t), yttrium (720 t), and other rare-earth compounds (609 t) (Japan Society of Newer Metals, 2016).

Kazakhstan.—Summit Atom Rare Earth Co. LLP (SARECO), a joint venture between Sumitomo Corp. and Kazakhstan's Government-owned National Atomic Co. (Kazatomprom), was commissioning a rare-earth processing plant in Stepnogorsk. The SARECO plant was expected to recover REEs from uranium-ore residue and produce as much as 1,500 t/yr of rare-earth carbonates. In 2014, SARECO produced 240 t of concentrate with an unspecified REO content (Nuclear Society of Kazakhstan, 2015).

Malaysia.—Lynas continued to increase production of rare-earth compounds at its Lynas Advanced Material Plant (LAMP) near the Port of Kuantan in the State of Pahang. Production of REO from the LAMP operations in 2014 was about 7,200 t, representing a 65% capacity utilization of the operation's Phase I production capacity of 11,000 t/yr. In 2014, the Malaysian Atomic Energy Licensing Board granted Lynas a full operating license for its LAMP refinery. Lynas was required to renew the license after 2 years (Lynas Corp. Ltd., 2014a–c; 2015).

Russia.—In 2014, JSC Solikamsk Magnesium Works (SMW) in Perm Krai consumed about 7,700 t of loparite concentrates (containing 28% to 30% REO) sourced from the Lovozero GOK mining operations near Revda, Murmansk Oblast. SMW's REO concentrate consumption increased by 10% compared with that in 2013, continuing a trend that began in 2010 (JSC Solikamsk Magnesium Works, 2015, p. 16).

Russia and Kazakhstan signed an MOU to collaborate on the production of rare metals including rare earths. The MOU would see the two nuclear energy producers Rosatom State Atomic Energy Corp. (Russia) and Kazatomprom National Atomic Co. (Kazakhstan) coordinating mining and processing capabilities. The MOU followed a 2013 agreement between Russia-based Rostec Corp. and IST group to invest $1 billion in rare-earths project development (Metal-Pages, 2014b).

South Africa.—GWMG continued its efforts to develop its Steenkampskraal (SKK) project in the Western Cape. GWMG signed an agreement with an undisclosed party for rare-earth separation services. According to GWMG, the agreement was expected to advance production sooner, lower upfront capital requirements, and reduce project risk at SKK (Metal-Pages, 2014a). In April, GWMG announced the completion of a feasibility study on its SKK project. NI 43–101-compliant proven mineral reserves contained 12,800 t of REO and probable reserves contained 56,600 t of REO. Using a 1% REO (including yttrium oxide) cutoff grade, measured and indicated resources were estimated to be 559,000 t containing 83,600 t of REO. NI 43–101-compliant indicated resources attributed to mine tailings from prior mining operations were 46,000 t containing 3,300 t of REO. The project was based on annual mine production of approximately 5,000 t/yr of REO; however, lanthanum and cerium were not expected to be produced unless market conditions were favorable (Great Western Minerals Group Ltd., 2014).

Sweden.—In 2014, Tasman Metals Ltd. initiated a PFS on its Norra Karr project in southern Sweden. Previously, Tasman released a PEA on the project. Using a 0.4% REO cutoff grade, the Norra Karr NI 43–101-compliant indicated mineral resource was 41.6 Mt containing 0.57% (230,000 t) REO as well as 1.70% ZrO_2. At yearend, Tasman completed a drilling program and the PFS neared completion (Tasman Metals Ltd., 2012, 2014).

Vietnam.—Shin-Etsu Chemical Co., Ltd. was adding rare-earth magnet production capacity in Hai Phong Province. One-half of the 2,000-t/yr capacity was scheduled to be completed in 2015 with the remaining capacity to be added in 2016. Shin-Etsu recently completed separation and alloy production operations in Vietnam and operated rare-earth alloy, separation, and magnet production facilities in China, Japan, Malaysia, and Vietnam (Shin-Etsu Chemical Co., Ltd., 2014; 2015, p. 72–73).

Rare-earth resources in Vietnam were reported to be concentrated in Lai Chau (Nam Xe, Dong Pao) and Yen Bai (Yen Phu) Provinces and in mineral sands in the coastal Provinces from Thanh Hoa to Ba Ria-Vung Tau. Lai Chau Rare Earth Co. and Japan's Dong Pao Rare Earth Development Co. were developing the Dong Pao deposit in Lai Chau. If successful, the venture was targeted to mine and process 10,000 t/yr of REO. Limited production of rare-earth minerals was reported from artisanal mining in 2014; however, commercial production was expected to begin by the end of 2016 (Vietnam National Coal Mineral Industries Holding Co. Ltd., 2015, 2016).

Outlook

China is expected to continue to dominate the global supply of and demand for rare-earth compounds, metals, and mineral feedstocks. Excess inventory and production capacity in China are expected to limit the expansion of mine production outside of China in the near term. Global markets for rare-earth consumption are expected to be led by (in descending order by tonnage) permanent magnets, hydrogen alloys, catalysts, polishing compounds, and phosphors.

Consumption of neodymium-iron-boron magnets containing dysprosium, neodymium, praseodymium, and terbium will likely be driven by large downstream demand for permanent magnets in industrial applications (for example, motors and magnetic separation equipment), transportation (for example, automobiles and electric bicycles), and consumer electronics (for example, cell phones and hard disk drives). According to the Association of China Rare Earth Industry, consumption of REO in China is forecast to increase to about 150,000 t in 2020 from 90,000 t in 2014 (Els, 2015).

In 2014, global sales of hybrid electric vehicles (HEVs) were close to 2 million units and most used REE-bearing nickel-metal-hydride (NiMH) batteries. Although global HEV sales have been projected to reach about 5 million units in 2020, the use of NiMH battery technology in HEVs is expected to decrease owing to competition with lithium and other battery technologies (Pillot, 2014, p. 15, 18, 27).

Cerium, lanthanum, and yttrium lead the overall consumption of REEs. Rising prices in 2011 led companies to create recycling programs for batteries, phosphors, and polishing compounds and to pursue substitution with low-rare-earth or rare-earth-free catalysts, magnets, and phosphors; however, recent declines in prices for REEs are expected to result in a resurgence in demand from polishing compounds, catalysts, and magnet markets. Demand for REEs in phosphors is expected to be lessened by changes in lighting technology to those that are less REE intensive.

Surges in prices for rare-earth materials in 2011 compelled many companies to explore and develop rare-earth deposits throughout the world. Financing as well as obtaining environmental approvals and offtake agreements are expected to be key factors in the success of these projects. Pricing of rare-earth materials is expected to influence the pace of exploration and development.

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TABLE 1
SALIENT U.S. RARE EARTH STATISTICS[1]

		2010	2011	2012	2013	2014
Production of rare-earth concentrates, rare-earth oxide (REO) basis[e, 2, 3]	metric tons	--	--	3,000	5,500	5,400
Exports, REO basis:[e]						
Compounds:						
Cerium compounds	do.	1,350	1,640	996	734	608
Other rare-earth compounds	do.	1,690	3,620	1,830	5,570	3,800
Metals:						
Ferrocerium and pyrophoric alloys	do.	3,460	2,010	960	1,420	1,640
Rare-earth metals, scandium, yttrium	do.	1,380	3,030	2,080	1,050	140
Imports for consumption, REO basis:[e]						
Compounds:						
Cerium compounds	do.	1,770	1,120	1,390	1,110	1,440
Other rare-earth compounds	do.	10,500	6,020	3,400	7,330 r	9,270
Metals:						
Ferrocerium and pyrophoric alloys	do.	131	186	276	313	371
Rare-earth metals, scandium, yttrium	do.	525	468	240	393	348
World production, REO basis	do.	99,500 r	104,000 r	105,000 r	107,000 r	125,000
Prices, yearend:						
Bastnäsite concentrate, REO basis[e]	dollars per kilogram	6.87	NA	NA	NA	NA
Monazite concentrate, REO basis[e]	do.	0.87	2.70	2.30	2.00	3.50
Mischmetal, 65% cerium, 35% lanthanum, metal basis[4]	do.	57.00–60.00	47.00–49.00	14.00–16.00	9.00–10.00	9.00–10.00

[e]Estimated. [r]Revised. do. Ditto. NA Not available. -- Zero.
[1]Data are rounded to no more than three significant digits.
[2]Includes only the rare earths derived from bastnäsite.
[3]Source: Molycorp, Inc., 2015, Form 10–K—2014: Greenwood Village, CO, Molycorp Inc., 145 p. (Accessed June 30, 2016, at http://www.molycorp.com/investors.)
[4]Source: Metal-Pages, Kingston, United Kingdom.

TABLE 2
RARE EARTH CONTENTS OF SELECTED SOURCE MINERALS[1, 2]

(Percentage of total rare-earth oxide)

			Rare earth element symbol														
Primary source	Country	Location	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Y
Bastnäsite	China	Bayan Obo, Nei Mongol Autonomous Region[3]	23.00	50.00	6.20	18.50	0.80	0.20	0.70	0.10	0.10	NA	NA	NA	NA	NA	NA
Do.	do.	Dechang, Sichuan Province[4]	35.63	43.81	4.73	13.06	1.22	0.23	0.52	0.06	0.09	0.05	0.04	0.01	0.06	NA	0.40
Do.	do.	Maoniuping, Sichuan Province[4]	29.49	47.56	4.42	15.18	1.24	0.23	0.65	0.12	0.21	0.05	0.06	0.04	0.05	0.01	0.70
Do.	do.	Weishan, Shandong Province[4]	35.46	47.76	3.95	10.90	0.79	0.13	0.53	0.14	NA	NA	NA	NA	0.03	NA	0.76
Do.	United States	Mountain Pass, CA[5]	34.00	48.80	4.20	11.70	0.79	0.13	0.21	NA	NA	NA	NA	NA	NA	NA	0.12
Loparite	Russia	Revda, Murmansk Oblast[6]	25.00	50.50	5.00	15.00	0.70	0.09	0.60	NA	0.60	0.70	0.80	0.10	0.20	0.15	1.30
Monazite	Australia	Mount Weld Central Lanthanide, Western Australia[7]	23.88	47.55	5.16	18.13	2.44	0.53	1.09	0.09	0.25	0.03	0.06	0.01	0.03	NA	0.76
Do.	China	Nangang, Guangdong Province[4]	23.00	42.70	4.10	17.00	3.00	0.10	2.00	0.70	0.80	0.12	0.30	NA	2.40	0.14	2.40
Do.	India	Manavalakurichi, Tamil Nadu[8]	22.00	46.00	5.50	20.00	2.50	0.02	1.20	0.06	0.18	0.02	0.01	0.00	0.00	0.00	0.45
Rare-earth laterite	China	Xunwu, Jiangxi Province[4]	38.00	3.50	7.41	30.18	5.32	0.51	4.21	0.46	1.77	0.27	0.88	0.13	0.62	0.13	10.07
Do.	do.	Xinfeng, Jiangxi Province[4]	27.26	3.23	5.62	17.55	4.54	0.93	5.96	0.68	3.71	0.74	2.48	0.27	1.13	0.21	24.26
Do.	do.	Longnan, Jiangxi Province[4]	2.18	<1.09	1.08	3.47	2.34	<0.37	5.69	1.13	7.48	1.60	4.26	0.60	3.34	0.47	64.90
Xenotime	do.	Southeast Guangdong Province[9]	1.20	3.00	0.60	3.50	2.20	0.20	5.00	1.20	9.10	2.60	5.60	1.30	6.00	1.80	59.30

Do., do. Ditto. NA Not available.

[1]Data are rounded to no more than three significant digits; rows may not add to 100 percent.

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TABLE 3
RARE-EARTH OXIDE PRICES[1]
(Dollars per kilogram)

Product (oxide)	Purity (percentage)	2013	2014
Scandium[2]	99.990	5,000	5,000
Yttrium[3]	99.999	25	16
Lanthanum[3]	99.000	8	5
Cerium[3]	99.000	8	5
Praseodymium[3]	99.000	94	121
Neodymium[3]	99.000	70	63
Samarium[3]	99.000	14	7
Europium[3]	99.900	1,130	822
Gadolinium[3]	99.000	47	47
Terbium[3]	99.000	949	713
Dysprosium[3]	99.000	540	395

[1]Products are listed in order of atomic number.
[2]Source: Stanford Metals Corp.
[3]Source: Metal-Pages.

TABLE 4

U.S. EXPORTS OF RARE EARTHS, BY COUNTRY[1]

Category[2] and country	2013 Gross weight (kilograms)	2013 Value	2014 Gross weight (kilograms)	2014 Value
Compounds:				
Cerium compounds (2846.10.0000):				
Austria	53,300	$1,330,000	41,200	$726,000
Brazil	26,400	188,000	5,570	71,200
Canada	13,200	420,000	12,000	396,000
China	122,000	2,260,000	59,200	827,000
Egypt	38,400	566,000	76,800	669,000
Germany	108,000	1,210,000	119,000	1,090,000
India	29,300	294,000	12,900	272,000
Ireland	24,700	545,000	3,160	319,000
Israel	134,000	1,450,000	22,700	263,000
Japan	25,500	601,000	47,700	735,000
Mexico	40,500	675,000	119,000	979,000
Taiwan	22,700	503,000	11,100	222,000
United Kingdom	25,700	359,000	11,000	229,000
Other	70,000 r	1,950,000 r	66,700	2,410,000
Total	734,000	12,400,000 r	608,000	9,210,000
Total estimated equivalent rare-earth oxide (REO) content	734,000	XX	608,000	XX
Other rare-earth compounds[3] (2846.90.0000):				
China	846,000	10,500,000	1,870,000	4,770,000
Estonia	3,490,000	9,330,000	3,330,000	8,610,000
Germany	282,000	2,480,000	894,000	3,250,000
Taiwan	29,100	1,560,000	258,000	8,940,000
Vietnam	133,000 r	6,350,000	67,200	3,560,000
Other	791,000 r	19,500,000 r	496,000	14,600,000
Total	5,570,000	49,700,000	6,910,000	43,700,000
Total estimated equivalent REO content	5,570,000	XX	3,800,000	XX
Metals:				
Ferrocerium and other pyrophoric alloys (3606.90.0000):				
Bahamas	17,500	71,500	18,200	37,400
Barbados	24,600	102,000	30,100	112,000
Brazil	57,400	210,000	6,820	99,400
Canada	452,000	2,040,000	598,000	2,070,000
Costa Rica	13,900	36,300	102,000	164,000
Dominican Republic	185,000	258,000	265,000	376,000
Germany	13,400	347,000	28,900	508,000
Hong Kong	281,000	1,960,000	93,600	1,660,000
Jamaica	4,280	22,400	40,200	87,400
Japan	125,000	1,170,000	212,000	1,700,000
Mexico	21,000	324,000	46,400	2,310,000
Netherlands	20,000	46,000	34,700	110,000
Panama	21,500	85,500	31,500	75,000
Singapore	42,500	228,000	13,800	127,000
Trinidad and Tobago	6,740	111,000	60,700	131,000
United Kingdom	114,000	303,000	115,000	3,460,000
Other	202,000 r	7,300,000 r	145,000	4,990,000
Total	1,600,000	14,600,000	1,840,000	18,000,000
Total estimated equivalent REO content	1,420,000	XX	1,630,000	XX
Rare-earth metals and alloys (2805.30.0000):				
China	404,000	2,340,000	28,700	514,000
Hong Kong	169,000	725,000	1,060	105,000
Japan	24,900	327,000	1,560	155,000
Netherlands	139,000	827,000	35,600	245,000
Thailand	92,000	3,870,000	500	22,100
Other	41,700 r	1,520,000 r	49,600	2,450,000
Total	871,000	9,600,000	117,000	3,490,000
Total estimated equivalent REO content	1,040,000	XX	140,000	XX

See footnotes at end of table.

TABLE 4—Continued

U.S. EXPORTS OF RARE EARTHS, BY COUNTRY[1]

[r]Revised. XX Not applicable.

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Harmonized Tariff Schedule of the United States code.

[3]Inorganic and organic.

Source: U.S. Census Bureau.

TABLE 5

U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY[1]

Category[2] and country	2013 Gross weight (kilograms)	2013 Value	2014 Gross weight (kilograms)	2014 Value
Compounds:				
Cerium compounds:				
Cerium compounds, unspecified (2846.10.0000):				
Austria	73,400	$1,780,000	XX	XX
China	360,000	2,890,000	XX	XX
Estonia	30,200	416,000	XX	XX
Japan	77,200	3,580,000	XX	XX
Other	57,700	812,000	XX	XX
Total	598,000	9,480,000	XX	XX
Total estimated equivalent rare-earth oxide (REO) content	400,000	XX	XX	XX
Cerium oxides (2846.10.0010):				
Austria	105,000	1,360,000	5,550	$151,000
China	195,000	1,120,000	307,000	1,680,000
Japan	88,600	3,600,000	309,000	12,300,000
Other	28,700	1,340,000	68,000	747,000
Total	417,000	7,410,000	690,000	14,900,000
Total estimated equivalent (REO) content	417,000	XX	690,000	XX
Cerium compounds, other than cerium oxide (2846.10.0050):				
Austria	23,200	428,000	101,000	1,500,000
China	187,000	1,060,000	576,000	2,870,000
Estonia	196,000	900,000	385,000	1,860,000
Other	25,900 r	57,000 r	57,000	3,440,000
Total	432,000	2,440,000 r	1,120,000	9,670,000
Total estimated equivalent (REO) content	289,000	XX	749,000	XX
Other rare-earth compounds:				
Scandium or yttrium compounds:				
Scandium or yttrium oxides (2846.90.2015):				
Estonia	XX	XX	58,100	401,000
France	XX	XX	5,860	662,000
Other	XX	XX	4,460	160,000
Total	XX	XX	68,500	1,220,000
Total estimated equivalent (REO) content	XX	XX	68,500	XX
Scandium or yttrium oxides mixtures (2846.90.8050):				
China	46,300	994,000	162,000	2,150,000
Korea	9,400 r	262,000 r	9,910	194,000
Other	8,300 r	733,000 r	14,900	1,040,000
Total	63,900 r	1,990,000 r	186,000	3,380,000
Total estimated equivalent (REO) content	63,900 r	XX	186,000	XX
Scandium or yttrium chlorides and chloride mixtures (2846.90.8060, 2846.90.2082):				
China	12,000	264,000	5,000	118,000
Other	608	87,400	15	13,500
Total	12,600	351,000	5,020	131,000
Total estimated equivalent (REO) content	4,670 r	XX	1,860	XX
Yttrium materials and compounds content by weight greater than 19% but less than 85% oxide equivalent (2846.90.4000):				
China	37,200	6,960,000	152,000	12,400,000
Germany	28,000	4,500,000	38	490,000
Japan	10,500	4,780,000	25,400	11,800,000
Other	727 r	487,000 r	2,660	407,000
Total	76,500 r	16,700,000 r	180,000	25,100,000
Total estimated equivalent (REO) content	45,900 r	XX	108,000	XX
Carbonates:				
Lanthanum carbonates mixtures (2846.90.8070):				
China	830,000	5,610,000	694,000	4,050,000
Estonia	58,100	394,000	42,100	515,000

See footnotes at end of table.

TABLE 5—Continued

U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY[1]

Category[2] and country	2013 Gross weight (kilograms)	2013 Value	2014 Gross weight (kilograms)	2014 Value
Compounds—Continued:				
Carbonates—Continued:				
Lanthanum carbonates mixtures (2846.90.8070)—Continued:				
Malaysia	--	--	83,200	77,200
Other	17 r	144,000 r	17,800	167,000
Total	888,000	6,140,000	837,000	4,810,000
Total estimated equivalent (REO) content	608,000	XX	573,000	XX
Other rare-earth carbonates mixtures (2846.90.8075):				
China	302	8,890	4,810	459,000
Estonia	58,800	428,000	38,000	150,000
Other	1,020 r	64,800 r	114	32,000
Total	60,100	501,000	42,900	642,000
Total estimated equivalent (REO) content	33,000	XX	23,600	XX
Chlorides and chloride mixtures (2846.90.2050, 2846.90.2080, 2846.90.2090):				
China	559,000	5,520,000	131,000	1,220,000
France	36,700	1,430,000	22,100	1,010,000
Hong Kong	135,000	867,000	--	--
Other	44,700	6,240,000	12,600	1,900,000
Total	776,000	14,100,000	165,000	4,130,000
Total estimated equivalent (REO) content	357,000	XX	76,100	XX
Oxides:				
Lanthanum oxides (2846.90.2005):				
China	1,520,000	10,000,000	4,290,000	24,100,000
Other	98,900	4,200,000	311,000	5,250,000
Total	1,620,000	14,200,000	4,600,000	29,300,000
Total estimated equivalent (REO) content	1,620,000	XX	4,600,000	XX
REOs except cerium oxide (2846.90.2010, 2846.90.2040):				
China	352,000	3,950,000	40,500	1,820,000
Estonia	200,000	2,160,000	9,970	904,000
Other	46,300 r	4,010,000 r	16,300	2,930,000
Total	598,000	10,100,000	66,700	5,650,000
Total estimated equivalent REO content	598,000	XX	66,700	XX
REOs except cerium or lanthanum oxide (2846.90.2045):				
China	6,730	4,460,000	40,800	1,360,000
Estonia	156,000	1,500,000	191,000	1,620,000
Other	5,800 r	713,000 r	17,700	2,300,000
Total	169,000	6,670,000	249,000	5,280,000
Total estimated equivalent REO content	169,000	XX	249,000	XX
Other rare-earth compounds or mixtures:				
Unspecified compounds or mixtures (2846.90.8000, 2846.90.8090):				
China	5,960,000 r	85,700,000 r	4,350,000	40,000,000
France	347,000	28,500,000	259,000	4,890,000
Malaysia	20,000	126,000	497,000	2,780,000
Japan	368,000	9,130,000	24,500	3,980,000
Other	276,000 r	24,400,000 r	831,000	18,200,000
Total	6,970,000 r	148,000,000 r	5,960,000	69,900,000
Total estimated equivalent REO content	3,830,000 r	XX	3,280,000	XX
Unspecified mixtures of oxides or chlorides (2846.90.2084):				
China	XX	XX	46,400	433,000
Estonia	XX	XX	11,400	720,000
France	XX	XX	14,100	517,000
Other	XX	XX	1,060	83,700
Total	XX	XX	73,000	1,750,000
Total estimated equivalent REO content	XX	XX	40,200	XX

See footnotes at end of table.

TABLE 5—Continued

U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY[1]

Category[2] and country	2013 Gross weight (kilograms)	2013 Value	2014 Gross weight (kilograms)	2014 Value
Metals:				
Ferrocerium and other pyrophoric alloys (3606.90.3000):				
Austria	88,200	1,010,000	90,900	974,000
China	113,000	1,870,000	144,000	2,210,000
France	140,000	4,930,000	174,000	5,100,000
Other	11,100	132,000	9,120	69,400
Total	353,000	7,940,000	418,000	8,350,000
Total estimated equivalent REO content	313,000	XX	371,000	XX
Rare-earth metals and alloys:				
Cerium, unalloyed (2805.30.0010):				
China	75,900	990,000	48,500	407,000
Hong Kong	--	--	53,100	431,000
Other	--	--	10,300	109,000
Total	75,900	990,000	112,000	947,000
Total estimated equivalent REO content	91,100	XX	134,000	XX
Lanthanum, unalloyed (2805.30.0005):				
China	7,500	113,000	48,400	626,000
Hong Kong	16,700	158,000	--	--
Other	250	3,750	2,280	--
Total	24,400	275,000	50,700	626,000
Total estimated equivalent REO content	29,300	XX	60,800	XX
Neodymium, unalloyed (2805.30.0020):				
China	202	41,100	802	149,000
Japan	11,600	744,000	--	--
Thailand	--	--	1,500	720,000
Total	11,800	785,000	2,300	869,000
Total estimated equivalent REO content	14,100	XX	2,760	XX
Other rare-earth metals, unalloyed (2805.30.0050):				
China	14,000	486,000	24,200	616,000
Other	415	95,800	940	157,000
Total	14,400	582,000	25,100	772,000
Total estimated equivalent REO content	17,300	XX	30,100	XX
Other rare-earth metals, alloys (2805.30.0090):				
Austria	544	34,100	11,200	163,000
China	31,700	1,250,000	79,400	1,490,000
Other	3,500 r	247,000 r	9,530	693,000
Total	35,800	1,530,000	100,000	2,350,000
Total estimated equivalent REO content	42,900	XX	120,000	XX
Unspecified rare-earth metals and alloys (2805.30.0000):				
China	105,000	2,360,000	XX	XX
Japan	26,800	1,710,000	XX	XX
South Africa	10,500	225,000	XX	XX
Vietnam	16,000	618,000	XX	XX
Other	7,630 r	548,000 r	XX	XX
Total	166,000	5,460,000	XX	XX
Total estimated equivalent REO content	199,000	XX	XX	XX

[r]Revised. XX Not applicable. -- Zero.

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Harmonized Tariff Schedule of the United States code.

Source: U.S. Census Bureau.

TABLE 6

RARE EARTHS: ESTIMATED WORLD MINE PRODUCTION, BY COUNTRY[1, 2]

(Metric tons of rare-earth oxide equivalent)

Country[3]	2010	2011	2012	2013	2014
Australia	--	2,188 [4]	3,222 [4]	3,000 [r]	8,000
Brazil	140 [4]	140	110	330	--
China[5]	89,200 [r]	93,800 [r]	93,800 [r]	93,800 [r]	105,000
India[6]	1,700 [r]	1,700 [r]	1,700 [r]	1,700 [r]	1,700
Kazakhstan	--	--	--	--	140
Malaysia	380	410	100	180	240
Russia	2,300	2,500	2,400	2,500	2,600
Thailand[7]	5,600	3,100	120 [r]	130 [r]	1,900
United States	--	--	3,000	5,500	5,400
Vietnam[7]	170	200	200	100	--
Total	99,500 [r]	104,000 [r]	105,000 [r]	107,000 [r]	125,000

[r]Revised. -- Zero.

[1]World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

[2]Includes data available through August 26, 2016.

[3]In addition to the countries listed, rare-earth minerals are thought to be produced in Indonesia, Nigeria, North Korea, and some Commonwealth of Independent States countries, but information is inadequate for formulation of reliable estimates of output levels.

[4]Reported figure.

[5]Official production quota. Illegal production could not be quantified.

[6]India's Department of Atomic Energy will not disclose monazite production data.

[7]Rare-earth oxide content of exports.