



2015 Minerals Yearbook

RARE EARTHS [ADVANCE RELEASE]

RARE EARTHS

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In 2015, world rare-earth mine production was an estimated 130,000 metric tons (t) of rare-earth oxide (REO) (tables 1, 6). China continued to dominate the global production and consumption of rare-earth metals and compounds. Rare-earth mineral concentrates were produced in China, with smaller amounts produced in Australia, Brazil, India, Malaysia, Russia, Thailand, the United States, and Vietnam (table 6). The unique properties of rare earths make them useful in a wide variety of applications, such as alloys, batteries, catalysts, magnets, phosphors, and polishing compounds. In the United States, owing to low prices, mining and processing of rare-earth ores and concentrates were idled at the Mountain Pass operation in California, although production increased from the prior year to 5,900 t. Prices for most rare-earth metals and compounds price declined between 21% and 59% relative to those in 2014 (table 3).

The rare earths are a moderately abundant group of 17 elements comprising the 15 lanthanides, scandium (Sc), and yttrium (Y). The lanthanides are the elements with atomic numbers 57 through 71, in order of atomic number: lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu). 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). The principal economic rare-earth minerals are bastnäsite, loparite, monazite, xenotime, and the lateritic ion-adsorption clays. The percentage distribution of REOs in mineral concentrates varied significantly based on mineral source and location (table 2).

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 (La) through atomic number 64 (Gd), and the HREEs include the lanthanide elements from atomic number 65 (Tb) through atomic number 71 (Lu). 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.

Legislation and Government Programs

In October, the U.S. Department of Defense (DOD), Defense Logistics Agency Strategic Materials (DLA Strategic Materials) announced the fiscal year (FY) 2016 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 initially authorized by Congress under the National Defense Authorization Act for FY 2014. The FY 2016 AMP was effective until September 30, 2016 (Defense Logistics Agency Strategic Materials, 2015a).

In September, DLA Strategic Materials awarded Texas Rare Earth Resources Corp. (TRER) funding to demonstrate the separation of REOs using continuous ion exchange and chromatography technologies. At a bench scale, TRER planned to separate and refine yttrium oxide (minimum of 99.999% purity), ytterbium oxide (minimum of 99.99% purity) and a third REO, which was not specifically disclosed. The feedstock used in the demonstration was expected to be from the Round Top deposit near El Paso, TX, and separation was planned at K-Technologies, Inc.'s (K-Tech) Lakeland, FL, facility (Texas Rare Earth Resources Corp., 2015b). In 2015, TRER and K-Tech announced plans to form a joint venture to develop K-Tech's technology for the extraction of REEs (Texas Rare Earth Resources Corp., 2015a).

In December, DLA Strategic Materials was soliciting proposals for innovative research under the Small Business Innovation Research program to address the economic recovery or reclamation of rare-earth materials from manufactured products. Successful awardees were expected to provide a feasibility plan and subsequently demonstrate a discrete-parts manufacturing process and address approaches for insertion of recovered materials into the DOD supply chain (Defense Logistics Agency Strategic Materials, 2015b).

Researchers at the Critical Materials Institute (CMI), funded by the U.S. Department of Energy (DOE), were working to diversify supplies of critical materials, develop substitutes, improve rates of 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 REEs 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). In 2015, CMI issued a license to

U.S. Rare Earths, Inc., an exploration company with mining claims in Colorado, Idaho, and Montana, for a membrane-solvent extraction system designed to recover REEs. The technology invented by CMI partners Oak Ridge and Idaho National Laboratories was the first commercially licensed technology developed through the CMI. U.S. Rare Earths planned to apply the technology to recover REEs from old electronics and from mineral concentrates (Oak Ridge National Laboratory, 2015). In a CMI collaborative effort, General Electric and Lawrence Livermore and Oak Ridge National Laboratories developed new fluorescent lighting phosphors that use significantly less REEs than current technology. The new phosphors included a green phosphor, which reduced the Tb content by 90% and eliminated La, and a red phosphor that eliminated both Eu and Y. The collaboration planned to continue to develop the technology for commercial lighting (Lawrence Livermore National Laboratory, 2015). Among CMI's other projects, researchers at Ames Laboratory examined recycling samarium-cobalt (Sm-Co) scrap (swarf) generated during the magnet manufacturing process and a liquid metal extraction process to separate REEs from old electronics (Ames Laboratory, 2015a, b).

The DOE was funding research to find cost-effective methods to separate rare earths from coal and coal byproducts. In 2015, DOE's National Energy Technology Laboratory selected 10 projects from industry and academia for the first phase of the program. Phase I projects were targeted at identifying suitable material for recovery of REEs, designing recovery technology, and examining the technical and economic feasibility of recovering REEs. In total, the 10 projects represented \$10.6 million in cost-shared funding support for bench- and pilot-scale projects, with 78% of the funding provided by the DOE (National Energy Technology Laboratory, 2015).

Production

In the third quarter, the sole U.S. producer of rare-earth mineral concentrates, Molycorp, Inc. (Greenwood Village, CO), idled its mining and separation operations at Mountain Pass, CA. Molycorp's mineral concentrate production for 2015 was estimated to be 5,900 t of REO equivalent compared with 5,400 t of REO equivalent in 2014. Production from the Mountain Pass operation included unseparated LREE concentrates, HREE concentrates, separated REOs (La, Ce, and Nd and Pr), and rare-earth-based water treatment products. Proven and probable ore reserves at Mountain Pass were estimated to be about 18 million metric tons (Mt), with an average grade of 8.1% REO (Molycorp, Inc., 2015a, p. 45). In June, owing to low prices, Molycorp filed for bankruptcy protection under Chapter 11 of the United States Bankruptcy Code. Operations outside of North America were excluded from the filings. By the third quarter, Molycorp had suspended production at Mountain Pass and, in November, filed for court approval of its reorganization plan (Molycorp, Inc., 2015b, c).

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

Chemicals & Oxides, Inc., 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 (Troy, MI), Hitachi Metals America, Ltd. (China Grove, NC), and Molycorp Metals and Alloys, Inc. (Tolleson, AZ). ETREMA Products (Ames, IA) produced the magneto-restrictive alloy Terfenol-D® containing dysprosium, iron (Fe), 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 and Russia.

The U.S. Forest Service was the lead agency preparing an environmental impact study (EIS) on Rare Element Resources Ltd.'s proposed development of the Bear Lodge deposit in Wyoming. In December, Rare Element Resources reported that, owing to market conditions and uncertainty related to the EIS, it was implementing significant cost-cutting measures that included staff reductions, consolidation of facilities, sale of nonessential equipment and assets, as well as delisting its common shares from the Toronto Stock Exchange (U.S. Department of Agriculture, 2014; Rare Element Resources Ltd., 2015).

Ucore Rare Metals, Inc. reported it had separated REEs across the lanthanide suite at purity levels of more than 99% using IBC Advanced Technologies' proprietary hydrometallurgical process technology. In March, Ucore agreed to acquire rights to IBC's molecular recognition technology (MRT) for rare-earth separation and contracted IBC to design and construct a pilot plant to be completed in 2016. Ucore revised its Bokan-Dotson resource estimate using data from a drilling program in 2014. Indicated resources were increased to 4.79 Mt containing 0.602% REO (28,800 t) using a 0.4%-REO cutoff. At yearend, a feasibility study was in progress using the revised resource data (Ucore Rare Metals, Inc., 2015).

In 2015, publicly traded companies developing domestic resources of rare earths included AusROC Metals Ltd., La Paz project in Arizona; Rare Element Resources Ltd., Bear Lodge project in Wyoming; NioCorp Developments Ltd., Elk Creek project in Nebraska; Texas Rare Earth Resources Corp., Round Top project in Texas; and Ucore Rare Metals Inc., Bokan Mountain project in Alaska. Developers of domestic deposits that were considering scandium recovery in their project plans, included NioCorp Developments Ltd., Texas Rare Earth Resources Corp., and Ucore Rare Metals Inc.

Consumption

In 2015, owing to limited data transparency, industry estimates of global consumption of rare earths varied significantly and generally ranged from about 120,000 to 150,000 t (Adamas Intelligence, 2016, p. 105; Kingsnorth, 2016, p. 6; Roskill Information Services Ltd., 2016, p. 2). Global consumption was led, in descending order, by catalysts, magnets, polishing, and metallurgical applications. Other end uses included ceramics, glass, phosphors, pigments, and miscellaneous other uses.

Based on trade data and excluding stock changes, U.S. apparent consumption of rare earths was estimated to be 9,500 t of REO in 2015. The estimated domestic use of rare earths in 2015 was primarily in catalysts (60%), with the remainder in metallurgical applications and alloys, polishing, ceramics and glass, and other uses (10% each). The United States primarily consumed LREEs. Because the United States has limited capabilities to produce battery alloys, magnet alloys, and phosphors, most LREE consumption is in the form of cerium and lanthanum compounds used to produce catalysts, ceramics, glass, and polishing compounds. Most HREE consumption is in the form of yttrium compounds. Together, the remaining HREEs (Tb, Dy, Ho, Er, Tm, Yb, and Lu) were estimated to contribute less than 2% of domestic consumption.

The amount and specific REEs used varies significantly by market sector and application. In the catalysts sector, the primary REEs being consumed are lanthanum and cerium, with lesser amounts of neodymium. Consumption in the magnet sector varies by the type of permanent magnet. Neodymium-iron-boron magnets primarily use neodymium and praseodymium with lesser amounts of dysprosium, gadolinium, and terbium; Sm-Co magnets use samarium and lesser amounts of gadolinium. Lanthanum is known to have limited use in certain ferrite magnets. Polishing compounds use primarily cerium with lesser amounts of lanthanum. Batteries primarily use lanthanum and lesser amounts of cerium as well as other REEs. Ceramics are dominated by yttrium consumption with lesser amounts of cerium and other REEs. Metallurgical applications vary by the application. For example, battery alloys use primarily lanthanum and lesser amounts of cerium and other REEs. Europium, yttrium, and terbium are the three REEs commonly associated with the phosphors sector, but other REEs are also used by this sector. The glass sector uses lanthanum, cerium, and erbium, in descending order of consumption, as well as other REEs. The HREEs are often used in high-unit-value applications. For example, laser crystals are commonly based on neodymium and yttrium and are doped with the HREEs (particularly dysprosium, erbium, thulium, and ytterbium). Among its other uses, lutetium is used in positron emission tomography.

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). Globally, the leading end uses for scandium were aluminum-scandium alloys, fuel cells, and lasers.

Prices

Prices for most rare-earth products declined significantly compared with those in 2014 and continued downward trends that began after the price spikes in 2011. On a percentage basis, the largest declines in REO prices were led by europium (-59%), samarium (-57%), and yttrium (-50%). Globally, prices for REOs were depressed by excessive capacity and illegal production within China (Chang, 2015). In the United States, based on information collected by the U.S. Census Bureau

on imports, the unit values in many trade categories declined significantly with some exceptions that may have been caused by variations in the purity or mix of specific compounds being imported from year to year. Domestic prices for scandium materials quoted by a domestic supplier were more stable.

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 6,250 t of REO equivalent, a slight increase compared with those of 2014 (table 4). Most of these exports were in the form of compounds. Exports of rare-earth compounds were about 4,980 t of REO equivalent with China and Germany as the leading export destinations. Rare-earth metal exports under HTS code 2805.30, including unalloyed and alloyed metals but excluding ferrocium, decreased by 59% compared with 2014. The leading export destinations of rare-earth metals (excluding ferrocium) were, in descending order, Spain, Australia, India, and China. Exports of ferrocium and other pyrophoric alloys under HTS code 3606.90 decreased by 25% compared with those of 2014 (table 4).

U.S. imports totaled 9,900 t of REO equivalent, a 13% decrease compared with those of 2014 (table 5). About 93% of REO equivalent imports were in the compound form and 7% were metals. China continued to dominate most import HTS categories, and most of the rare-earth metals and compounds imported from other countries were ultimately derived from China's mineral feedstocks. Unalloyed cerium metal and compounds were estimated to be 16% of total REO equivalent imports. Imports of unalloyed lanthanum metal and compounds were estimated to be 36% of total REO equivalent imports. Scandium and yttrium compounds were estimated to be less than 1% of total REO equivalent imports.

World Review

Australia.—In the Northern Territory, Arafura Resources Ltd. continued to work on its Nolans Bore project with planned production of rare-earth, phosphate, and uranium products. In October, the company announced revised resource estimates and neared completion of an environmental impact statement. Measured resources increased 10% to 4.9 Mt containing 3.2% (158,000 t) REO and indicated resources increased 45% to 30 Mt containing 2.7% (816,000 t) REO, using a 1%-REO cutoff grade. The mineralization was reported to include monazite, allanite, and thorite, as well as other carbonate, phosphate, and silicate minerals. In 2015, the company was seeking an equity partner in order to complete definitive feasibility studies (Arafura Resources Ltd., 2015a, p. 1, 4; 2015b, p. 4).

Alkane Resources Ltd. continued to develop its polymetallic Dubbo Zirconia project in New South Wales with planned production of hafnium, niobium, rare-earth, tantalum, and zirconium products. In 2015, Alkane continued to operate its demonstration plant and worked on processing improvements. In August, Alkane reported it had completed its front-end engineering design. In December, the New South Wales Department of Industry granted a mining lease to Alkane.

At yearend, Alkane awaited the approval of an environment protection license and project financing. The project was expected to produce about 25,200 metric tons per year (t/yr) of various products including about 6,660 t/yr of REO equivalent compounds as soon as 2018. Reserves were 35.9 Mt of polymetallic ore containing 0.88% REO (including yttrium oxide), based on a 1.5% [combined niobium oxide, REO, and zirconium oxide (ZrO₂)] cutoff grade (Alkane Resources Ltd., 2015a, p. 16; 2015b).

Clean TeQ Holdings Ltd. was conducting pilot-plant studies and a drilling program at its Syerston Scandium project in New South Wales. Using a continuous ion exchange separation process, the pilot plant was reported to have processed 12 t of ore and produced samples of scandium oxide at 99.9% purity. Using a cutoff grade of 600 parts per million (ppm) scandium, the measured and indicated resources of the Syerston project were reported to be 1.2 Mt, containing about 763 t of scandium (1,170 t of scandium oxide equivalent). Clean TeQ feasibility studies were based on production of up to 42.5 t/yr of 99.9% purity scandium oxide over a 20-year mine life (Clean TeQ Holdings Ltd., 2015, p. 20, 22).

Hastings Rare Metals Ltd. changed its name to Hastings Technology Metals Ltd. In 2015, prefeasibility studies were ongoing at the Yangibana project in Western Australia jointly held by Hastings Technology Metals (70%) and Rare Earth Minerals plc (30%) (Hastings Technology Metals Ltd., 2015a, p. 17). In October, indicated resources for the project were revised to 8.1 Mt containing 1.07% (86,700 t) REO, with no cutoff grade (Hastings Technology Metals Ltd., 2015b, p. 1).

Lynas Corp. Ltd. continued to operate its Mt Weld mining operations in New South Wales to support the rampup of its processing operations in Malaysia. In October, Lynas announced updated resource and reserves estimates for deposits at Mt Weld. Reserves for the Central Lanthanide deposit (CLD) were estimated to be 9.9 Mt containing 10.8% (1.07 Mt) REO, using a 4%-REO cutoff grade. Reserves from the Central Lanthanide deposit were expected to provide a 25-year mine life and support the production of 22,000 t/yr of REO equivalent products. Measured, indicated, and inferred resources for the CLD were 15 Mt containing 8.8% (1.4 Mt) REO. Resources for the Duncan deposit were 8.2 Mt containing 4.7% (0.39 Mt) REO. Both resource estimates used a 2.5% REO cutoff grade (Lynas Corp. Ltd., 2015a; 2015b, p. 94–95).

Metallica Minerals Ltd. was seeking joint-venture partners to continue the development of the multimetallic SCONI project in northern Queensland. The company planned to develop laterite mineralization rich in cobalt, nickel, and scandium. In 2013, the measured and indicated resources of the SCONI project were reported to be about 10.8 Mt containing 1,790 t of scandium using a 100-ppm-Sc cutoff grade. The project's prefeasibility studies were based on an operation producing up to 50 t/yr of scandium oxide (Metallica Minerals Ltd., 2013, 2015).

In February, Northern Minerals Ltd. updated the reserve and resource estimates for the Brown's Range project in Western Australia. For the reserve estimates, xenotime was the dominant REE mineralization. Indicated resources were revised to 4.69 Mt containing about 0.7% (32,800 t) REO, using a cutoff grade of 0.15% REO. Probable reserves were 3.75 Mt containing about

0.7% (26,400 t) REO. Northern Minerals completed definitive feasibility studies (DFSs) in 2015. In the DFS completed in March, the company planned to produce 3,100 t/yr of REO equivalent (Northern Minerals Ltd., 2015a, p. 13; 2015b).

Platina Resources Ltd. determined a scoping study completed in 2015 on its Owendale project in New South Wales supported the continued development of the project. The indicated resource of the Owendale Project was reported to be 4.2 Mt containing 400 ppm (1,700 t) of scandium, using a cutoff of 300 ppm Sc. The estimate also reported indicated resources of nickel, cobalt, palladium, magnesium, and platinum. The study was based on production of 30 t/yr of scandium oxide with a 70-year mine life (Platina Resources Ltd., 2015, p. 3–4).

Scandium International Mining Corp. was conducting definitive feasibility and economic assessment studies of the Nyngan Scandium project in New South Wales. Using a 100-ppm-Sc cutoff grade, measured and indicated resources were 12 Mt containing about 261 ppm (3,100 t) of scandium. Scandium International Mining expected to pursue project financing in 2016. If completed, the project was expected to produce as much as 36 t/yr of scandium oxide (Scandium International Mining Corp., 2016, p. 22–23).

Brazil.—After an unexplained hiatus in 2014, Brazil exported an estimated 1,600 t of REE-bearing monazite concentrate to China in 2015 (Global Trade Information Services Inc., 2016). Although no data were available for 2015, according to the Departamento Nacional de Produção Mineral (DNPM), Brazil's prior shipments were derived from Indústrias Nucleares do Brasil (INB) inventories in Sao Francisco do Itabapoana (Andrade, 2016, p. 108, 109). INB reported that it produced monazite concentrate from previously mined ore and mixed concentrates at its Buena operations in Sao Francisco de Itabapoana, Rio de Janeiro State (Indústrias Nucleares do Brasil S.A., undated).

Companhia Brasileira de Metalurgia e Mineração (CBMM) continued to pursue the commercial recovery of rare earths from monazite found in its Araxá mine tailings. The Araxá mining and processing operation in Minas Gerais was a leading global source of niobium metal and compounds. The company was reported to be operating a pilot plant recovering up to 1,000 t/yr of REE hydroxides and sulfates. CBMM ultimately planned to produce REE alloys and permanent magnets (Senado Federal, 2013; Villela, 2016).

Canada.—Avalon Rare Metals Inc. revised feasibility study designs for its Nechalacho project at Thor Lake, Northwest Territories. The company reported that it expected significantly improved recovery rates of HREEs and reduced consumption of reagents. In 2015, Avalon Rare Metals was also engaged in testing process improvements for the recovery of zirconium concentrate and the production of commercial-grade zirconium sulfate and zirconium oxychloride. 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; 2016, p. 4–5).

Commerce Resources Corp. announced the completion of a revised preliminary economic assessment for the development of its Ashram project in northern Quebec. Measured and indicated resources were estimated to be 29.3 Mt containing 1.9% REO, using a 1.25%-REO cutoff grade. The project was based on a proposed production of 16,900 t/yr of REO primarily derived from monazite and to a lesser degree bastnäsite and xenotime using conventional processing methods. In 2015, prefeasibility, drilling, and pilot-plant studies were ongoing (Commerce Resources Corp., 2015, p. 12–13, 135; 2016, p. 2–4).

Matamec Explorations Inc. continued metallurgical testing as well as environmental and social impact studies at its Kipawa project in Quebec. In January, the government of Quebec through Ressources Québec Inc. (RQ) invested Can\$3 million in the Kipawa property, gaining a 28% interest in the joint-venture project. Toyota Tsusho Corp. (Nagoya, Japan) held a 10% royalty on net profits. Proven and probable mineral reserves were previously estimated to be 20 Mt containing 0.41% (82,000 t) REO using a cutoff value of \$48.96 per ton of ore. The dominant REE mineralization was reported to be the silicate minerals eudialyte and mosandrite. Matamec's plans through 2017 included updating feasibility studies and continuing environmental studies (Matamec Explorations Inc., 2013, p. 12; 2016, p. 9–11; undated).

Medallion Resources Ltd. continued to pursue plans to develop a processing facility for the production of mixed rare-earth compounds from monazite. Medallion's proposed facility would purchase monazite byproduct from heavy-mineral-sands operations and produce rare-earth compounds. In 2015, the company was conducting lab-scale metallurgical testing, refining plans for a pilot-plant facility, and testing samples from heavy-mineral sands producers, to locate suitable monazite feed. The company also reported it had produced lab-scale quantities of mixed rare-earth chemical concentrates for evaluation by commercial consumers (Medallion Resources Ltd., 2016).

Orbite Technologies Inc. was developing technology to recover scandium and high-purity alumina from red mud (a residue generated during the production of alumina, fly ash, and mine tailings). In 2015, the company was commissioning a high-purity alumina plant and planned to add a scandium pilot plant in 2016. Feedstock for the plant was from the Grande-Vallée clay deposit in Quebec (Orbite Technologies Inc., 2015, p. 24).

Based on a revised business plan, Pele Mountain Resources Inc. pursued the development of a project to construct a monazite processing operation at Elliot Lake, Ontario, that would produce rare-earth compounds and source its feedstock from mineral sands mine tailings in other countries. In March, Pele formed an understanding with Sheng Kang Ning Mining Investment Co. Ltd. (SKN) to establish a joint-venture operation at Pele's Eco Ridge property in Elliot Lake; however, one of the preconditions of the understanding was the receipt of Chinese Government approval for SKN to use its proprietary separation technology in Elliot Lake. In September, the understanding expired because SKN had yet to receive the necessary approvals. At yearend, Pele continued to pursue collaborative work with SKN and other interested parties (Pele Mountain Resources Inc., 2015a, b).

In April, RQ supported the development of the Strange Lake project in northeastern Quebec through a private placement of Can\$595,000 in Quest Rare Minerals Ltd. In July, Quest announced it had been awarded a Can\$5 million grant from Sustainable Development Technology Canada to support Quest's operation of a pilot plant to produce mixed REOs. The objective was to validate the potential scale up of Quest's Selective Thermal Sulphation process (STS). The STS process was expected to aid in the production of REOs from mineral concentrate or phosphor powder recovered from fluorescent light bulbs (Quest Rare Minerals Ltd., 2015a, b). 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 Rare Minerals Ltd., 2013, p. 122).

China.—China dominated the global production of rare-earth minerals, separated compounds, and metals. Based on China's production quota, China accounted for more than 80% of global mine production in 2015. According to various industry analysts, about 20% to 40% of China's REO was produced illegally and production was well beyond the production quota (Adamas Intelligence, 2016, p. 47; Kingsnorth, 2016, p. 6; Roskill Information Services Ltd., 2016, p. 53). Because of increased production from the rest of the world, China's global share of production decreased compared with that in 2014.

China's Ministry of Land and Resources production quotas for rare-earth mine production were unchanged compared with 2014 at 105,000 t of REO equivalent, of which 87,100 t was for light rare earths and 17,900 t was for medium and heavy rare earths. The quotas for light rare earths by Province or Autonomous Region were Nei Mongol (59,500 t), Sichuan (25,000 t), and Shandong (2,600 t). The quotas for heavy rare earths by Province or Autonomous Region were Fujian (2,000 t), Jiangxi (9,000 t), Guangxi Zhuang (2,500 t), Guangdong (2,200 t), Hunan (2,000), and Yunnan (200 t).

China continued to implement plans to integrate its rare-earth industry into six largely Province-based state-owned enterprises. The consolidated companies were 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. At yearend, 66 rare-earth mining operations and 77 rare-earth smelting and separation operations in the country were integrated into these six enterprises (Metal-Pages, 2016).

Independent industry estimates of China's REO consumption were in the range of about 80,000 to 100,000 t (Adamas Intelligence, 2016, p. 135; Kingsnorth, 2016, p. 6; Roskill Information Services Ltd., 2016, p. 98). In September, the Association of the China Rare Earth Industry (ACREI) estimated that China's consumption of rare earths was 97,700 t of REO equivalent. ACREI also estimated that consumption of rare earths was led, in descending order, by magnets (34.6%), polishing (18.2%), catalysts (14.8%), hydrogen storage alloys (8.8%), ferrosilicon alloys (7.9%), ceramics and glass (7.5%), aluminum alloys (6.1%), phosphors (1.7%), and magnesium alloys (0.2%) (Zhanheng, 2015).

In January, China's Ministry of Commerce (MOFCOM) eliminated its export quotas for rare earths following the World Trade Organization (WTO) ruling in 2014 that rare-earth export

quotas applied by the Chinese Government were in violation of WTO rules and commitments. In May, MOFCOM canceled the export tariff on rare earths and revised domestic resource taxes to be based on sales value instead of production quantity. Resource taxes for light rare earths were set at 11.5%, 9.5%, and 7.5%, respectively, in Nei Mongol Autonomous Region, Sichuan Province, and Shandong Province, whereas those for medium and heavy rare earths were generally set at 27% (Ministry of Commerce, 2015a, b).

China's imports of rare-earth compounds under the Harmonized System (HS) code 2846 were about 10,600 t in 2015, compared with 3,500 t in 2014. Increased imports from Malaysia and the United States were primarily responsible for the significant increase. The leading import sources, in descending order, were Malaysia, the United States, Vietnam, and Burma. China's imports of rare-earth metals under HS code 2805.30 were 40 t, and nearly all imports were from Thailand (Global Trade Information Services Inc., 2016).

China's exports of rare-earth compounds (HS code 2846) were 29,200 t compared with 24,000 t in 2014. The top five destinations were, in descending order, the United States, Japan, Italy, the Netherlands, and the Republic of Korea. China's exports of rare-earth metals under HS 2805.30 were 5,600 t, and the top five destinations, in descending order, were Japan, the Netherlands, Spain, the United States, and India (Global Trade Information Services Inc., 2016).

Greenland.—Greenland Minerals and Energy Ltd. (GMEL) completed definitive feasibility, environmental, and social impact studies for its polymetallic (REE-uranium-zinc) Kvanefjeld project located in southern Greenland. Steenstrupine, a complex silicate mineral, is the primary mineral host to both REEs and uranium. GMEL also reported pilot-plant studies were completed in Finland with the support of EURARE, a program funded by the European Commission for the development of Europe's rare-earth deposits. In November, GMEL submitted a mining license application including the feasibility and impact studies to the government of Greenland. The project plans included mining and through the production of mixed rare-earth carbonate. In 2015, GMEL announced proven and probable reserves were 108 Mt containing 1.43% (1.54 Mt) REO and were expected to support a mine life of 37 years. Measured and indicated resources were 1,010 Mt containing 1.1% REO (11.1 Mt) (Greenland Minerals and Energy Ltd., 2016, p. 8–16).

India.—In 2015, India's imports of rare-earth compounds were 61 t and exports were 762 t. Imports of rare-earth metals and alloys were 449 t. According to India's Department of Atomic Energy in Mumbai, India's monazite resources in heavy-mineral sands were 12 Mt and included indicated, inferred, and speculative categories. 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 by the Indian Bureau of Mines to be 6,240 t/yr. IREL's Aluva Rare Earth Division (RED) in the Ernakulam district, Kerala, had 144 t/yr of capacity to produce rare-earth fluoride. In Odisha, IREL was commissioning a processing plant that consumed monazite and could produce up to 11,000 t/yr of mixed rare-earth chloride. IREL had an agreement with Toyoto Tshusho Corp. (Japan)

for supplying more than 50% of the mixed chloride production (Global Trade Information Services Inc., 2016; Indian Bureau of Mines, 2016; Singh, 2016).

Saraf Titanium Industry planned to recover 2.5 t/yr of scandium oxide from the process streams of a titanium slag operation being constructed in Odisha. Scandium is contained in ilmenite mineral concentrates that are expected to be used as a feedstock for the titanium slag operation. Although construction of the titanium operation began in 2014, the recovery of scandium was not expected for several years (Beijing Ruidow Information Technology Co. Ltd., 2016).

Japan.—Japan's Society of Newer Metals estimated the 2014 consumption of rare earths in Japan to be 15,412 t, an 8% increase compared with 14,255 t in 2014. The breakdown of consumption included cerium (5,100 t), europium (14 t), lanthanum (2,240 t), mixed rare-earth metals (3,250 t), neodymium and praseodymium (3,500 t), samarium (80 t), yttrium (770 t), and other rare-earth compounds (558 t) (Japan Society of Newer Metals, 2016).

Kazakhstan.—Summit Atom Rare Earth Co. (SARECO), a joint venture between Japan's Sumitomo Corp. and Kazakhstan's Kazatomprom National Atomic Co., idled its newly commissioned plant in Stepnogorsk designed to recover rare earths from uranium-ore residue. The SARECO plant's design capacity was 1,500 t/yr of REO equivalent, and production of bulk concentrate in the first and second quarters of 2015 was 67 t and 1.4 t, respectively. In August, operations were suspended, and by yearend Sumitomo planned to sell its 49% share in the venture (Kazatomprom National Atomic Co., 2015a, b; 2016, p. 70).

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 2015 was about 10,900 t, a 52% increase compared with production in 2014 (Lynas Corp. Ltd., 2015b, c, 2016). In 2015, Lynas pursued the development of commercial products in soil additives, fertilizers, and road base material from its process residue (Lynas Corp. Ltd., 2015a, p. 10).

Philippines.—Japan's Sumitomo Metal Mining Co., Ltd. was operating a 10-kilogram-per-month pilot plant that was recovering scandium at its subsidiary Coral Bay Nickel Corp. on Palawan Island. Scandium was recovered from a process stream following the leaching of nickel laterite for nickel-cobalt sulfide. At yearend, a decision to construct a commercial-scale plant had not been reached (Sumitomo Metal Mining Co., Ltd., 2013; 2015, p. 20).

Russia.—Russian imports of rare-earth compounds were about 1,860 t in 2015, and exports were 6,220 t. Rare-earth-metal imports and exports were 55 t and less than 1 t, respectively. China, Estonia, and Kazakhstan were Russia's leading trading partners for both imports and exports (Global Trade Information Services Inc., 2016).

In 2015, JSC Solikamsk Magnesium Works (SMW) in Perm Krai reported consumption of about 8,500 t of loparite concentrates (containing 28% to 30% REO) sourced from the Lovozero GOK mining operations near Revda, Murmansk Oblast. Loparite concentrate consumption increased by 11% compared with that in 2014, continuing a positive trend that began in 2010. SMW's production

of REO equivalent compounds increased to about 2,310 t in 2015, an 8% increase compared with its production in 2014. SMW was reported to be capable of processing up to 13,000 t/yr of loparite concentrate and producing up to 3,600 t/yr of REO equivalent compounds (JSC Solikamsk Magnesium Works, 2016, p. 5–17).

ARMZ Uranium Holding Co. was conducting pilot-plant studies at the JSC Dalur in situ uranium mining and processing operation in the Kurgan Region. A pilot plant for recovery of scandium from process streams was underway and was reported to be able to produce up to 400 kilograms per year (kg/yr) of scandium oxide-equivalent in a concentrate. Concentrates at Dalur were expected to be supplied to JSC TVEL for use in the nuclear industry (ARMZ Uranium Holding Co., 2015).

United Company RUSAL Plc, one of the world's leading aluminum producers, was conducting pilot-plant studies in the Ural Mountains to recover scandium concentrate from red mud. In 2015, Rusal's pilot plant was reported to have increased the production capacity to 100 kg/yr of concentrate containing up to 43% scandium oxide (United Company RUSAL Plc, 2017, p. 49–50).

South Africa.—Frontier Rare Earths Ltd. completed a prefeasibility study (PFS) on the Zandkopsdrift project with planned production of rare-earth and manganese products. In the PFS, proven and probable reserves were 41.1 Mt containing 1.92% (789,000 t) REO, using a 0.9%-REO cutoff grade. Monazite and altered monazite were the main REE mineralization within a carbonatite intrusion. The PFS proposed mining through and initial production of 8,000 t/yr of separated REO at an operation to be located in Saldanha. A second phase was planned to double the production capacity. According to the PFS, because of low concentrations of uranium and thorium, no special permitting would be required for the transportation and storage of the material arising from the mining and processing operations. Korea Resources Corp. (KORES) held 10% interest in the project as well as commensurate offtake agreements (Frontier Rare Earths Ltd., 2015, p. i–xv).

Steenkampskraal Thorium Ltd. (STL) acquired the Steenkampskraal Mine (SKK) in the Western Cape Province from the bankrupt Great Western Minerals Group Ltd. STL planned to continue the refurbishment of the Steenkampskraal monazite mine for the production of rare-earth minerals and thorium compounds for the production of thorium-based fuel for nuclear reactors (Steenkampskraal Thorium Ltd., 2015). According to a NI 43–101-compliant study completed in 2013, using a 1%-REO cutoff grade, SKK's in situ measured resource was 85,000 t and contained about 19.5% (16,600 t) REO. Using the same cutoff basis, indicated resources were estimated at 474,000 t and contained about 14.1% (66,800 t) REO (Great Western Minerals Group Ltd., 2014).

Sweden.—Tasman Metals Ltd. filed a NI 43–101-compliant PFS report on its Norra Karr project in southern Sweden. In the PFS, probable reserves were reported to be about 23.6 Mt containing 0.592% (140,000 t) REO. Using a 0.4%-REO cutoff grade, indicated resources were 31.1 Mt containing 0.61% (190,000 t) REO. Nearly all of the REE mineralization was eudialyte. The PFS was based on a proposed production

of about 5,000 t/yr of mixed REO and a 20-year mine life (Tasman Metals Ltd., 2015, p. 42–43).

Vietnam.—In Hai Phong Province, Shin-Etsu Chemical Co., Ltd. completed construction of 2,000-t/yr sintered rare-earth magnet capacity. An additional 2,000-t/yr of magnet capacity was scheduled to be completed in 2016. Shin-Etsu owned and operated alloy, separation, and magnet production operations in China, Japan, Malaysia, and Vietnam (Shin-Etsu Chemical Co., Ltd., 2016, p. 11, 42).

Rare-earth reserves in Vietnam were reported to be 22 Mt with resources 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. Limited production of rare-earth minerals was reported from artisanal mining. According to news reports, thousands of tons of monazite concentrate from heavy-mineral sands were stored in warehouses (Vietnam National Coal Mineral Industries Holding Co. Ltd., 2016).

Outlook

Globally, the annual average growth of REE consumption was expected to exceed 5% through 2020. Some market sectors are expected to have much higher average growth. As the leading producer and consumer of rare-earth minerals and most downstream products, China is expected to continue to dominate the global markets for rare-earth compounds and metal alloys. Excess inventory and production capacity in China are expected to limit increased prices and the expansion of mine production outside of China through 2020. Beyond 2020, increased demand, industry consolidation in China, tighter enforcement of environmental compliance, and reductions in illegal mining are expected to result in higher prices for some REE materials. This scenario may accelerate the development of mining and processing projects outside of China (BCC Research, 2015, p. 11; Roskill Information Services Ltd., 2016, p. 103).

Global production of automotive catalysts and transportation fuel from crude oil is expected to increase consumption of LREEs in the catalysts sector by about 5% per year. Production of fuels from heavy crude oil, overall fuel production, and the global adoption of catalytic converters are expected to drive the consumption of REEs for the catalyst sector (BCC Research, 2015, p. 171–178; Roskill Information Services Ltd., 2016, p. 118–131).

The global magnet sector consumes, in descending order of weight, neodymium, praseodymium, samarium, dysprosium, terbium, and an unquantified amount of lanthanum used in ferrite magnets. The magnet sector is expected to become the leading user of REEs, based on mass, by 2020. Global annual growth in REE consumption in this sector is expected to exceed 5% through 2020. The consumption of magnets is expected to dominate the overall availability of REEs. Increased demand for magnets may cause an oversupply of some REEs not used in magnets (BCC Research, 2015, p. 140–144; Roskill Information Services Ltd., 2016, p. 133–170).

The phosphor sector consumes europium, terbium, yttrium, and other rare earths, and the average annual consumption of REEs in the sector is expected to decrease by 5% or less through

2020. Although REEs are used in light-emitting diode (LED) lighting and the use of LED lighting is expected to increase, the consumption of REE per lumen is significantly less than in compact fluorescent lighting and other fluorescent tube lighting (BCC Research, 2015, p. 161–171; Roskill Information Services Ltd., 2016, p. 226–245).

REEs are used in a multitude of metallurgical applications including but not limited to alloys for hydrogen storage and nickel-metal-hydride batteries, aluminum alloys, ductile irons, ferrosilicon alloys, magnesium alloys, magnetostrictive alloys, mischmetal, silicides, specialty steel, superalloys, and zinc alloys. The overall annual growth in consumption of REEs for the metallurgical sector through 2020 is expected to exceed 5% and for some specific applications areas may exceed 15% (BCC Research, 2015, p. 144–151; Roskill Information Services Ltd., 2016, p. 178–199).

Consumption of REEs used in glass and ceramics is expected to continue historical annual growth rates of about 5% or less. New applications for REEs are found in agriculture, plastic additives, and water treatment and may be stimulated by a potential oversupply of some REEs. Flat prices for cerium compounds, increased demand for mobile devices, and an overall trend to larger displays are expected to increase demand for REEs in polishing compounds by not more than 5% (BCC Research, 2015, p. 152–155; Roskill Information Services Ltd., 2016, p. 201–225).

References Cited

Adamas Intelligence, 2016, Rare earth market outlook—Supply, demand, and pricing from 2016 through 2025: Sudbury, Ontario, Canada, Adamas Intelligence, December 1, 822 p.

Alkane Resources Ltd., 2015a, Annual report 2015: Burswood, Western Australia, Australia, Alkane Resources Ltd., August 25, 92 p. (Accessed March 14, 2017, at http://alkane.com.au/images/pdf/annual-reports/Alksxann_151016_Alkane_AR_2015.pdf.)

Alkane Resources Ltd., 2015b, Dubbo Zirconia Project mining lease granted: Burswood, Western Australia, Australia, Alkane Resources Ltd. media release, December 21, 2 p. (Accessed March 14, 2017, at <http://alkane.com.au/images/pdf/asx/2015/20151221.pdf>.)

Ames Laboratory, 2015a, New CMI process recycles magnets from factory floor: Ames, IA, Ames Laboratory news release, June 30. (Accessed March 2, 2017, at <https://www.ameslab.gov/news/news-releases/new-cmi-process-recycles-magnets-factory-floor>.)

Ames Laboratory, 2015b, New CMI process recycles valuable rare earth metals from old electronics: Ames, IA, Ames Laboratory news release, February 26. (Accessed March 2, 2017, at <https://www.ameslab.gov/news/news-releases/new-cmi-process-recycles-valuable-rare-earth-metals-old-electronics>.)

Andrade, R.H.P., 2016, Terras raras, in Sumário mineral 2015: Brasília, Brazil, Departamento Nacional de Produção Mineral, p. 108–109. (Accessed June 2, 2016, at <http://www.dnpm.gov.br/dnpm/sumarios/sumario-mineral-2015/>.)

Arafura Resources Ltd., 2015a, 2015 annual report: Perth, Western Australia, Australia, Arafura Resources Ltd., September 17, 85 p. (Accessed March 14, 2017, at http://www.arultd.com/images/files/Reports/Arafura_AR_2015_FINAL.pdf.)

Arafura Resources Ltd., 2015b, Large increase in minerals resources for Nolans project: Perth, Western Australia, Australia, Arafura Resources Ltd., October 30, 29 p. (Accessed March 17, 2017, at <http://clients.weblink.com.au/news/pdf2/01679120.pdf>.)

ARMZ Uranium Holding Co., 2015, The pilot unit for scandium extraction from pregnant solutions and subsequent concentrate refining was launched at JSC Dalur: Moscow, Russia, ARMZ Uranium Holding Co. press release, November 2. (Accessed April 6, 2017, at <http://www.armz.ru/eng/press/news/?id=817&p=1>.)

Avalon Rare Metals Inc., 2013, Technical report disclosing the results of the feasibility study on the Nechalacho rare earth elements project: Toronto, Ontario, Canada, Avalon Rare Metals Inc., May 31. (Accessed June 9, 2016, at http://avalonraremetals.com/_resources/projects/may_2013_ni43_report.pdf.)

Avalon Rare Metals Inc., 2016, Management's discussion and analysis of financial statements for the three months ended November 30, 2015: Toronto, Ontario, Canada, Avalon Rare Metals Inc., January 14. (Accessed March 23, 2017, at <http://www.sedar.com/GetFile.do?lang=EN&docClass=7&issuerNo=00007482&issuerType=03&projectNo=02436200&docId=3852690>.)

Beijing Ruidow Information Technology Co. Ltd., 2016, Indian Odisha's government plans to build the plant of scandium oxide: Beijing, China, Ruidow Rare Earth Monthly, June, p. 5.

BCC Research, 2015, Rare earths—Worldwide markets, applications, technologies (Market Research Report AVM018H): Wellesley, MA, BCC Research, January, 244 p. plus appendixes.

Chang, Lyu, 2015, Rare earth mining firms slip into the red: Beijing, China, China Daily Information Co., August 11. (Accessed February 28, 2017, at http://usa.chinadaily.com.cn/epaper/2015-08/11/content_21565705.htm.)

China Industrial Information Network, 2016, 2016 China's rare earth industry status analysis and price trend forecast: China Industrial Information Network, June 2. (Accessed March 30, 2017, at <http://www.chyxx.com/industry/201606/421801.html>.)

Clean TeQ Holdings Ltd., 2015, Clean TeQ Holdings Limited (ASX: CLQ) corporate overview: Notting Hill, Victoria, Australia, Clean TeQ Holdings Ltd., November, 29 p. (Accessed April 6, 2017, at http://www.cleanteq.com/wp-content/uploads/2016/12/201511_Clean-TeQ-Presentation3.pdf.)

Commerce Resources Corp., 2015, NI 43–101 technical report preliminary economic assessment Ashram rare earth deposit for Commerce Resources Corp.: Vancouver, British Columbia, Canada, Commerce Resources Corp., January 7, 202 p. plus appendixes. (Accessed March 14, 2017, at https://www.commerceresources.com/assets/docs/reports/2015-01-07_GG-PEA-Report.pdf.)

Commerce Resources Corp., 2016, Management discussion & analysis for the year ended October 31, 2015: Vancouver, British Columbia, Canada, Commerce Resources Corp., February 26, 17 p. (Accessed March 14, 2017, at <https://www.commerceresources.com/assets/docs/cce-mda-q4-october-31-2015.pdf>.)

Critical Materials Institute, [undated], Complete project list: Ames, IA, Critical Materials Institute. (Accessed June 11, 2016, at <https://cmi.ameslab.gov/project-list>.)

Defense Logistics Agency Strategic Materials, 2015a, Annual Materials Plan for FY 2016—For possible acquisition of new NDS stocks: Fort Belvoir, VA, Defense National Stockpile Center news release DLA–SM–16–3102, October 1, 1 p. (Accessed February 8, 2017, at http://www.dla.mil/Portals/104/Documents/StrategicMaterials/Announcements/3102%20FY16%20AMP_ACQ.pdf.)

Defense Logistics Agency Strategic Materials, 2015b, Economically recovering rare earth materials: Fort Belvoir, VA, Defense Logistics Agency Strategic Materials, December 28. (Accessed March 1, 2017, at <http://www.acq.osd.mil/osbp/sbir/solicitations/sbir20161/dla161.pdf>.)

Frontier Rare Earths Ltd., 2015, National Instrument 43–101 independent technical report on the results of a preliminary feasibility study on the Zandkopsdrift rare earth element and manganese by-product project in the Northern Cape Province of South Africa for Frontier Rare Earths Limited: Luxembourg, Luxembourg, Frontier Rare Earths Ltd., June 2, 245 p. (Accessed March 29, 2017, at <http://sedar.com/GetFile.do?lang=EN&docClass=24&issuerNo=00030507&issuerType=03&projectNo=02362022&docId=3754243>.)

Global Trade Information Services Inc., 2016, Global trade atlas: Global Trade Information Services Inc. (Accessed January 19, 2017, via <https://www.gtis.com/gta/>.)

Great Western Minerals Group Ltd., 2014, National Instrument 43–101 independent technical report on the results of a feasibility study for the Steenkampskraal rare earth element project in the Western Cape, South Africa for Great Western Minerals Group Ltd.: Saskatoon, Saskatchewan, Canada, Great Western Minerals Group Ltd., June 20, 264 p. (Accessed January 17, 2017, via <http://www.sedar.com/>.)

Greenland Minerals and Energy Ltd., 2016, 2015 annual report: Subiaco, Western Australia, Australia, Greenland Minerals and Energy Ltd., March 30. (Accessed March 24, 2017, at <http://www.ggg.gl/docs/annual-reports/2015-Annual-Report.pdf>.)

Hastings Technology Metals Ltd., 2015a, September 2015 quarterly activities report: Sydney, New South Wales, Australia, Hastings Technology Metals Ltd., October, 28, 19 p. (Accessed March 15, 2017, at http://www.hastingsstechmetals.com/images/rpt_quarter/2QuarterlyReportsSeptember15.pdf.)

- Hastings Technology Metals Ltd., 2015b, Yangibana project confirmed as a significant neodymium project following major increase in JORC resources: Sydney, New South Wales, Australia, Hastings Technology Metals Ltd. news release, October, 6, 39 p. (Accessed March 15, 2017, at http://www.hastingstechmetals.com/images/asx_all/29-SEPT-ASX-RELEASE-RESOURCES-RELEASE-AB-VERSION-10-00-on-29th-TH-6-October-2015FINAL.pdf.)
- Indian Bureau of Mines, 2016, Rare earths, *in* Part III—Mineral reviews (54th ed.) (advance release): Nagpur, India, Indian Minerals Yearbook 2015, v. III, December, p. 43–1 to 43–9. (Accessed March 24, 2017, at http://ibm.gov.in/writereaddata/files/12272016154439IMYB2015_Rare%20Earth_27122016_Adv.pdf.)
- Indústrias Nucleares do Brasil S.A., [undated], INB Buena—Heavy minerals unit: Sao Francisco de Itabapoana, Brazil, Indústrias Nucleares do Brasil S.A. (Accessed March 16, 2017, at <http://www.inb.gov.br/en-us/INB/Where-we-are/Buena>.)
- Japan Society of Newer Metals, 2016, Aggregate the actual demand of rare earth group 2015: Tokyo, Japan, Japan Society of Newer Metals, March 18. (Accessed March 10, 2017, at <http://www.jsnm.or.jp/news/?p=1033>.)
- JSC Solikamsk Magnesium Works, 2016, Solikamsk Magnesium Works annual report 2015: Solikamsk, Russia, JSC Solikamsk Magnesium Works, May 20, 46 p. plus 3 annexes. (Accessed March 27, 2017, at http://xn--g1ajo.xn--p1ai/raport/2016/2015_Solikamsk_Magnesium_Works_Annual_Report_web_v.pdf.)
- Kazatomprom National Atomic Co., 2015a, Press release on the results of Kazatomprom's Q1 production 2015: Almaty, Kazakhstan, Kazatomprom National Atomic Co. press release, April 20. (Accessed March 24, 2017, at <http://www.nuclear.kz/news/press-release-on-the-results-of-kazatomproms-q1-production-2015.html?lang=en>.)
- Kazatomprom National Atomic Co., 2015b, Press release on the results of Kazatomprom's Q2 production 2015: Almaty, Kazakhstan, Kazatomprom National Atomic Co. press release, April 20. (Accessed March 24, 2017, at <http://www.nuclear.kz/news/press-release-kazatomproms-operating-results-for-q2-2015.html?lang=en>.)
- Kazatomprom National Atomic Co., 2016, Integrated annual report for 2015: Astana, Kazakhstan, Kazatomprom JSC, 115 p. (Accessed January 23, 2017, at http://www.kazatomprom.kz/sites/default/files/corpfiles/integrated_annual_report_for_2015.pdf.)
- Kingsnorth, Dudley, 2016, Rare earths—The China conundrum: Metal Events, Ltd. 12th International Rare Earths Conference, Hong Kong, November 8–10, 28 p.
- Lawrence Livermore National Laboratory, 2015, Better fluorescent lighting through physics: Livermore, CA, Lawrence Livermore National Laboratory news release, October 7. (Accessed March 2, 2017, at <https://www.llnl.gov/news/better-fluorescent-lighting-through-physics>.)
- Lynas Corp. Ltd., 2015a, 2015 annual report and appendix 4G: East Perth, Western Australia, Australia, Lynas Corp. Ltd., October 5, 100 p. (Accessed March 27, 2017, at <https://www.lynascorp.com/Shared%20Documents/Investors%20and%20media/Reporting%20Centre/Annual%20reports/2015/151005%20Annual%20Report%201481137.pdf>.)
- Lynas Corp. Ltd., 2015b, Mount Weld Mineral Resource and Ore Reserve update 2015: East Perth, Western Australia, Australia, Lynas Corp. Ltd. news release, October 15. (Accessed March 10, 2017, at <https://www.lynascorp.com/Shared%20Documents/Investors%20and%20media/Announcements%20and%20media/2015/151005%20Ore%20Reserves%20and%20Resources%201481136.pdf>.)
- Lynas Corp. Ltd., 2015c, Quarterly report for the period ending 30 September 2015: East Perth, Western Australia, Australia, Lynas Corp. Ltd., October 10, 6 p. (Accessed March 27, 2017, at <https://www.lynascorp.com/Shared%20Documents/Investors%20and%20media/Reporting%20Centre/Quarterly%20reports/2015/151014%20Lynas%20Quarterly%20Activities%20Report.pdf>.)
- Lynas Corp. Ltd., 2016, Quarterly report for the period ending 30 December 2015: East Perth, Western Australia, Australia, Lynas Corp. Ltd., January 27, 6 p. (Accessed March 27, 2017, at <https://www.lynascorp.com/Shared%20Documents/Investors%20and%20media/Reporting%20Centre/Quarterly%20reports/2015/160127%20Quarterly%20Report%20Q2%20FY16%201518438.pdf>.)
- Mason, Brian, and Moore, Carleton, 1982, Principles of geochemistry (4th ed.): New York, NY, John Wiley & Sons, 344 p.
- Matamec Explorations Inc., 2013, Kipawa JV heavy rare earths mine project—Feasibility study results: Montreal, Quebec, Canada, Matamec Explorations Inc., presentation, September 4, 25 p. (Accessed June 9, 2016, at <http://www.matamec.com/vns-site/uploads/documents/matamec-feasibilitypresentation-04092013-7h00.pdf>.)
- Matamec Explorations Inc., 2016, Management discussion and analysis December 31, 2015: Montreal, Quebec, Canada, Matamec Explorations Inc., June 10, 38 p. (Accessed March 23, 2017, at <http://www.matamec.com/vns-site/uploads/documents/matamec-mda-december31st2015-061016.pdf>.)
- Matamec Explorations Inc., [undated], Kipawa: Montreal, Quebec, Canada, Matamec Explorations Inc. (Accessed March 23, 2017, at http://www.matamec.com/vns-site/page-energy_kipawa-en.html.)
- Medallion Resources Ltd., 2016, Management discussion and analysis of financial results for the nine months ended December 31, 2015: Vancouver, British Columbia, Canada, Medallion Resources Ltd., February 23. (Accessed January 12, 2017, via <http://www.sedar.com/>.)
- Metal-Pages, 2016, China claims limited success tackling illegal RE mining: Argus Media group Metal-Pages, June 16. (Accessed February 15, 2018, via <https://metals.argusmedia.com/>.)
- Metallica Minerals Ltd., 2013, SCONI project, North Queensland and nickel-cobalt and scandium resource upgrade: Brisbane, Queensland, Australia, Metallica Minerals Ltd. ASX release, October 21, 40 p. (Accessed April 4, 2017, at <http://www.proactiveinvestors.com.au/companies/news/159020/metallica-minerals-bags-500000-from-sale-of-non-core-assets-63363.html>.)
- Metallica Minerals Ltd., 2015, Metallica Minerals bags \$500,000 from sale of non-core assets: Brisbane, Queensland, Australia, Metallica Minerals Ltd. ASX release, July 15. (Accessed April 4, 2017, at <http://www.proactiveinvestors.com.au/companies/news/159020/metallica-minerals-bags-500000-from-sale-of-non-core-assets-63363.html>.)
- Ministry of Commerce, 2015a, China reforms resource tax for rare earths: Beijing, China, Ministry of Commerce, May 4. (Accessed March 31, 2017, at <http://english.mofcom.gov.cn/article/newsrelease/counselorsoffice/westernasiaandaficareport/201505/20150500959354.shtml>.)
- Ministry of Commerce, 2015b, Official of Chinese Ministry of Commerce comments on cancelling rare earth export quotas: Beijing, China, Ministry of Commerce, January 15. (Accessed March 31, 2017, at <http://english.mofcom.gov.cn/article/newsrelease/significantnews/201501/20150100874624.shtml>.)
- Molycorp, Inc., 2015a, Form 10–K—2014: Greenwood Village, CO, Molycorp, Inc., 148 p. (Accessed June 30, 2016, at <http://www.molycorp.com/investors>.)
- Molycorp, Inc., 2015b, Molycorp, Inc. files restructuring plan: Greenwood Village, CO, Molycorp, Inc. press release, November 3. (Accessed February 13, 2017, at <https://globenewswire.com/news-release/2015/11/04/783166/0/en/Molycorp-Inc-Files-Restructuring-Plan.html>.)
- Molycorp, Inc., 2015c, Molycorp, Inc. to move its Mountain Pass rare earth facility to 'care and maintenance' mode: Greenwood Village, CO, Molycorp, Inc. press release, August 26. (Accessed February 13, 2017, at <https://cases.primeclerk.com/molycorp/Home-DownloadPDF?id1=MTc5MTMx&id2=0>)
- National Energy Technology Laboratory, 2015, DOE selects projects to enhance its research into recovery of rare earth elements from coal and coal byproducts: Morgantown, WV, National Energy Technology Laboratory news release, December 15. (Accessed February 8, 2017, at <https://netl.doe.gov/newsroom/news-releases/news-details?id=55360995-ac95-4722-8370-58d0b58fb82f>.)
- Northern Minerals Ltd., 2015a, DFS positions Browns Range project as next dysprosium supplier: West Perth, Western Australia, Australia, Northern Minerals Ltd. ASX announcement, March 2. (Accessed March 14, 2017, at <http://northernminerals.com.au/wp-content/uploads/2015/02/1503-02-DFS-positions-Browns-Range-Project-as-next-dysprosium-supplier-.pdf>.)
- Northern Minerals Ltd., 2015b, Study update on dysprosium rich Browns Range project; post DFS: West Perth, Western Australia, Australia, Northern Minerals Ltd. ASX announcement, August 27. (Accessed March 14, 2017, at <http://northernminerals.com.au/wp-content/uploads/2015/02/1508-25-Study-update-on-dysprosium-rich-Browns-Range-Project-post-DFS-final.pdf>.)
- Oak Ridge National Laboratory, 2015, Critical Materials Institute rare-earth recycling invention licensed to U.S. Rare Earths: Oak Ridge, TN, Oak Ridge National Laboratory news release, August 10. (Accessed March 2, 2017, at <https://www.ornl.gov/news/critical-materials-institute-rare-earth-recycling-invention-licensed-us-rare-earths>.)
- Orbite Technologies Inc., 2015, Orbite Technologies corporate presentation: Montreal, Quebec, Canada, Orbite Technologies Inc., July, 28 p. (Accessed April 6, 2017, at http://s2.q4cdn.com/622589029/files/doc_presentations/2015/ORT_Corp_Presentation_2015-07.pdf.)
- Pele Mountain Resources Inc., 2015a, Pele Mountain executes MOU with major Chinese rare earth player to pursue opportunities of developing rare earth processing facilities in Elliot Lake: Pele Mountain Resources Inc. news release, March 30. (Accessed January 12, 2017, at <http://www.pelemountain.com/pdfs/news-releases/2015-03-30%20Pele%20Mountain%20Executes%20MOU%20with%20Major%20Chinese%20Rare%20Earth%20Player.pdf?v=20160707>.)

- Pele Mountain Resources Inc., 2015b, Pele Mountain provides an update on its Eco Ridge monazite processing project: Pele Mountain Resources Inc. news release, October 1. (Accessed January 12, 2017, at <http://www.pelemountain.com/pdfs/news-releases/2015-10-01%20Pele%20Mountain%20Provides%20an%20Update%20on%20its%20Eco%20Ridge%20Monazite%20Processing%20Project.pdf?v=20160707>.)
- Platina Resources Ltd., 2015, Platina Resources Ltd ABN 25 119 007 939 annual financial report for the year ended 30 June 2015: Varsity Lakes, Queensland, Australia, Platina Resources Ltd., September 21, 66 p. (Accessed April 6, 2017, at http://www.platinareources.com.au/wp-content/uploads/2016/05/20150921_-_PGM_ASX_-_Annual_Report.pdf.)
- Quest Rare Minerals Ltd., 2013, NI 43–101 technical report on the pre-feasibility study for the Strange Lake property: Montreal, Quebec, Canada, Quest Rare Minerals Ltd., December 6, 259 p. (Accessed June 10, 2015, via <http://www.sedar.com/>.)
- Quest Rare Minerals Ltd., 2015a, Quest awarded \$5m grant from Sustainable Development Technology Canada (SDTC): Montreal, Quebec, Canada, Quest Rare Minerals Ltd., July 31. (Accessed March 23, 2017, at <http://www.questrareminerals.com/QRM-PR-JUL-31-2015.php>.)
- Quest Rare Minerals Ltd., 2015b, Quest rare minerals completes private placement with Ressources Québec: Montreal, Quebec, Canada, Quest Rare Minerals Ltd., April 30. (Accessed March 23, 2017, at <http://www.questrareminerals.com/QRM-PR-APR-30-2015.php>.)
- Rare Element Resources Ltd., 2015, Rare Element Resources implements extensive cost cutting measures: Lakewood, CO, Rare Element Resources Ltd. news release, December 17. (Accessed March 1, 2017, at <http://www.rareelementresources.com/investor-information/news-releases/2015-archive/2015/12/17/rare-element-resources-implements-extensive-cost-cutting-measures#.WLbsGG8rJEY>.)
- Roskill Information Services Ltd., 2016, Rare earths: Global industry, markets & outlook to 2026 (16th ed.): London, United Kingdom, Roskill Information Services Ltd., 396 p.
- Scandium International Mining Corp., 2016, Form 10–K—2015: U.S. Securities and Exchange Commission, 54 p. plus appendixes. (Accessed April 6, 2016, at <https://www.sec.gov/Archives/edgar/data/1408146/000106299316008361/form10k.htm>.)
- Senado Federal, 2013, CBMM e a estratégia de exploração do Nióbio em Araxá [CBMM and the niobium exploration strategy in Araxá]: Tres Poderes, Brazil, Senado Federal, September. (Accessed March 23, 2017, at <http://www.senado.gov.br/noticias/Jornal/emdiscussao/terras-raras/realidade-brasileira/cbmm-e-a-estrategia-de-exploracao-do-niobio-em-araxa-mg.aspx>.)
- Shin-Etsu Chemical Co., Ltd., 2016, Annual report 2016: Tokyo, Japan, Shin-Etsu Chemical Co., Ltd., August 2, 43 p. (Accessed February 17, 2017, at <https://www.shinetsu.co.jp/en/ir/pdf/2016/annual2016.pdf>.)
- Singh, Deependra, 2016, India as a viable source of rare earths: Metal Events, Ltd. 12th International Rare Earths Conference, Hong Kong, November 8–10, presentation, 40 p.
- Steenkampskraal Thorium Ltd., 2015, The STL Group acquires the Steenkampskraal thorium and rare earth mine: Centurion, South Africa, Steenkampskraal Thorium Ltd., October 22. (Accessed January 20, 2017, at <http://www.thorium100.com/blog/the-stl-group-acquires-the-steenkampskraal-thorium-and-rare-earth-mine/>.)
- Sumitomo Metal Mining Co., Ltd., 2013, SMM to construct scandium recovery pilot-plant: Tokyo, Japan, Sumitomo Metal Mining Co., Ltd. press release, March 11. (Accessed April 6, 2017, at http://www.smm.co.jp/E/news/release/uploaded_files/130311e.pdf.)
- Sumitomo Metal Mining Co., Ltd., 2015, CSR report 2015 digest: Tokyo, Japan, Sumitomo Metal Mining Co., Ltd., November, 42 p. (Accessed April, 6, 2017, at http://www.smm.co.jp/E/csr/report/pdf/csr2015_digest.pdf.)
- Tasman Metals Ltd., 2015, Annual report on form 20–F: Vancouver, British Columbia, Canada, Tasman Metals Ltd., November 30, 116 p. (Accessed March 29, 2016, at <http://www.sedar.com/GetFile.do?lang=EN&docClass=2&issuerNo=00029095&issuerType=03&projectNo=02424798&docId=3837116>.)
- Texas Rare Earth Resources Corp., 2015a, Texas Rare Earth Resources and K-Technologies to form rare earth processing technology joint venture: Sierra Blanca, TX, Texas Rare Earth Resources Corp. press release, February 24. (Accessed March 2, 2016, at http://tmrcorp.com/news/press_releases/index.php?&content_id=110.)
- Texas Rare Earth Resources Corp., 2015b, U.S. Defense Logistics Agency awards TRER strategic materials research contract: Sierra Blanca, TX, Texas Rare Earth Resources Corp. press release, September 25. (Accessed March 2, 2016, at http://tmrcorp.com/news/press_releases/2015/index.php?&content_id=155.)
- Ucore Rare Metals, Inc., 2015, Management’s discussion and analysis for the year ended December 31, 2015: Bedford, Nova Scotia, Canada, Ucore Rare Metals, Inc., 19 p. (Accessed March 2, 2017, at http://ucore.com/documents/Ucore_Dec31_2015_MDA.pdf.)
- United Company RUSAL Plc, 2017, Rusal sustainability report 2015: Moscow, Russia, United Company RUSAL Plc, January, 124 p. (Accessed April 7, 2017, at <https://sr.rusal.com/>.)
- U.S. Department of Agriculture, 2014, Black Hills National Forest, Bearlodge Ranger District; Wyoming; Bear Lodge Project: Federal Register, v. 79, no. 60, March 28, p. 17497–17500. (Accessed March 1, 2017, at <https://www.gpo.gov/fdsys/pkg/FR-2014-03-28/pdf/2014-06916.pdf>.)
- Vietnam National Coal Mineral Industries Holding Co. Ltd., 2016, Rare earth industry developed in Vietnam: Hanoi, Vietnam, Vietnam National Coal Mineral Industries Holding Co. Ltd., April 29. (Accessed June 30, 2016, at <http://www.vinacomin.vn/home-news/rare-earth-industry-developed-in-vietnam-201604291609429008.htm>.)
- Villela, Marcelo, 2016, CBMM anuncia exploração de terras raras [CBMM announces rare earth exploration]: Vancouver, British Columbia, Canada, Mining.com, November 1. (Accessed March 23, 2017, at <http://noticiasmineracao.mining.com/2016/11/01/cbmm-surpreende-e-anuncia-exploracao-de-terras-raras/>.)
- Zhanheng, Chen, 2015, Evaluation of rare earth market and forecast of demand in China: Shanghai Pudong, China, September 15–18, 2015, Argus Rare Earths 2015, Argus Media Ltd., 46 p.

GENERAL SOURCES OF INFORMATION

U.S. Geological Survey Publications

- Historical Statistics for Mineral and Material Commodities in the United States. Data Series 140.
- Rare-Earth Elements. Ch. in United States Mineral Resources, Professional Paper 820, 1973.
- Rare-Earth Metals (Ce, Dy, Eu, Gd, La, Nd, Pr, Sm, Sc, Tb, Y). Ch. in Metal Prices in the United States Through 2010, Scientific Investigations Report 2012–5188, 2013.
- Rare-Earth Oxides. International Strategic Minerals Inventory Summary Report, Circular 930–N, 1993.
- Rare Earths. Ch. in Mineral Commodity Summaries, annual.
- Scandium. Ch. in Mineral Commodity Summaries, annual.
- Thorium. Ch. in Mineral Commodity Summaries, annual.
- Yttrium. Ch. in Mineral Commodity Summaries, annual.
- Other**
- China Rare Earth Information (newsletter), monthly.
- Economics of Rare Earths and Yttrium, The. Roskill Information Services Ltd., 2007.
- Industrial Minerals, monthly.
- Metal Bulletin, weekly.
- Rare Earth Elements and Yttrium. Ch. in Mineral Facts and Problems, U.S. Bureau of Mines Bulletin 675, 1985.
- Rare Earths. Ch. in Industrial Minerals and Rocks—Commodities, Markets, and Uses, Society for Mining, Metallurgy, and Exploration Inc., 7th ed., 2006.

TABLE 1
SALIENT U.S. RARE EARTH STATISTICS¹

	2011	2012	2013	2014	2015
Production of rare-earth concentrates, rare-earth oxide (REO) basis ^{2,3}					
Exports, REO basis: ^e					
Compounds:					
Cerium compounds	1,640	996	734	608	441
Other rare-earth compounds	3,620	1,830	5,570	3,800	4,540
Metals:					
Ferrocerium and pyrophoric alloys	2,010	960	1,420	1,640	1,220
Rare-earth metals, scandium, yttrium	3,030	2,080	1,050	140	57
Imports for consumption, REO basis: ^e					
Compounds:					
Cerium compounds	1,120	1,390	1,110	1,440	1,440
Other rare-earth compounds	6,020	3,400	7,330	9,260 ^r	7,720
Metals:					
Ferrocerium and pyrophoric alloys	186	276	313	371	356
Rare-earth metals, scandium, yttrium	468	240	393	348	383
World production, REO basis	104,000	106,000 ^r	107,000	125,000	130,000
Prices, yearend:					
Monazite concentrate, REO basis ^e	2.70	2.30	2.00	3.50	2.60
Mischmetal, 65% cerium, 35% lanthanum, metal basis ⁴	47.00–49.00	14.00–16.00	9.00–10.00	9.00–10.00	6.00–7.00

^eEstimated. Revised. do. Ditto. -- Zero.

¹Data are rounded to no more than three significant digits.

²Includes only the rare earths derived from bastnäsite.

³Source: Molycorp, Inc., 2015a, Form 10-K—2014: Greenwood Village, CO, Molycorp, Inc., 148 p. (Accessed June 30, 2016, at <http://www.molycorp.com/investors>.)

⁴Source: Metal-Pages Ltd.

TABLE 2
RARE EARTH CONTENTS OF SELECTED SOURCE MINERALS^{1,2}
(Relative distribution of total rare-earth oxide, in percent)

Primary source Bastnäsite	Country	Location	Rare-earth element symbol																	
			La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Y			
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	0.10	NA	NA	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	NA	NA	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	0.01	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	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	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	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.

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

²Rare earths are listed in order of atomic number except yttrium, which is listed after the last of the heavy rare earth lanthanide elements.

³Zang, Zhang Bao, Lu, Ke Yi, King, Kue Chu, Wei, Wei Cheng, and Wang, Wen Cheng, 1982, Rare-earth industry in China: Hydrometallurgy, v. 9, no. 2, p. 205-210.

⁴Yang, Xiaosheng, and Zhi Li, Ling, 2014, China's rare earth ore deposits and beneficiation techniques: ERES 2014—1st European Rare Earth Resources Conference, Milos, Greece, April 4-7, 11 p.

⁵Molycorp, Inc., 2015, Form 10-K—2014: Greenwood Village, CO, Molycorp, Inc., 148 p. (Accessed June 30, 2016, at <http://www.molycorp.com/investors>.)

⁶Hedrick, J.B., Sinha, S.P., and Kosynkin, V.D., 1997, Loparite, a rare-earth ore: Journal of Alloys and Compounds, v. 250, p. 467-470.

⁷Lynas Corp. Ltd., 2012, Increase in Mt Weld resource estimate for the Central Lanthanide deposit and Duncan deposit, January 18.

⁸Patra, R.N., 2014, Latest scenario in rare earth and atomic minerals in India: PDAC Convention 2014, Toronto, Ontario, Canada, March 2-4, 42 p.

⁹Nakamura, Shigeo, 1988, China and rare metals—Rare earth: Industrial Rare Metals, no. 94, May, p. 23-28.

TABLE 3
RARE-EARTH OXIDE PRICES¹
(Dollars per kilogram)

Product (oxide)	Purity (percent)	2014	2015
Scandium ²	99.990	5,000	5,100
Yttrium ³	99.999	16	8
Lanthanum ³	99.000	5	3
Cerium ³	99.000	5	3
Praseodymium ³	99.000	121	75
Neodymium ³	99.000	63	48
Samarium ³	99.000	7	3
Europium ³	99.900	822	339
Gadolinium ³	99.500 ^r	47	47
Terbium ³	99.990 ^r	713	562
Dysprosium ³	99.000	395	278

^rRevised.

¹Products are listed in order of atomic number.

²Source: Stanford Metals Corp.

³Source: Metal-Pages Ltd.

TABLE 4
U.S. EXPORTS OF RARE EARTHS, BY COUNTRY¹

Category ² and country	2014		2015	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Compounds:				
Cerium compounds (2846.10.0000):				
Austria	41,200	\$726,000	19,900	\$295,000
China	59,200	827,000	70,400	1,120,000
Egypt	76,800	669,000	76,800	793,000
Germany	119,000	1,090,000	109,000	1,180,000
Hong Kong	12,200	794,000	11,500	875,000
India	12,900	272,000	10,400	192,000
Israel	22,700	263,000	722	21,100
Japan	47,700	735,000	40,600	592,000
Korea	9,490	337,000	31,000	756,000
Mexico	119,000	979,000	10,100	235,000
Singapore	14,300	324,000	186,000	2,760,000
Taiwan	11,100	222,000	18,500	355,000
United Kingdom	11,000	229,000	17,100	350,000
Other	50,800 ^r	1,730,000 ^r	55,800	1,200,000
Total	608,000	9,200,000 ^r	658,000	10,700,000
Total estimated equivalent rare-earth oxide (REO) content	608,000 ^r	XX	440,000	XX
Scandium or yttrium oxides (2846.90.2015):				
China	XX	XX	34,100	58,800
Germany	XX	XX	1,440	276,000
Other	XX	XX	3,130	254,000
Total	XX	XX	38,700	588,000
Total estimated equivalent REO content	XX	XX	38,700	XX
Other rare-earth compounds ³ (2846.90.0000, 2846.90.2040, 2846.90.2060, 2846.90.9000):				
China	1,870,000	4,770,000	2,990,000	9,140,000
Estonia	3,330,000	8,610,000	200,000	197,000
Germany	894,000	3,250,000	3,840,000	7,850,000
Taiwan	258,000	8,940,000	20,000	30,000
Vietnam	67,200	3,560,000	170,000	7,540,000
Other	496,000	14,600,000	772,000	19,100,000
Total	6,910,000	43,700,000	7,990,000	43,800,000
Total estimated equivalent REO content	3,800,000	XX	4,500,000	XX
Metals:				
Ferrocerium and other pyrophoric alloys (3606.90.0000):				
Bahamas	18,200	37,400	27,200	113,000
Barbados	30,100	112,000	54,000	113,000
Canada	598,000	2,070,000	345,000	1,250,000
Colombia	805	9,410	37,200	95,800
Costa Rica	102,000	164,000	178,000	260,000
Dominican Republic	265,000	376,000	227,000	334,000
Hong Kong	93,600	1,660,000	48,900	1,690,000
Jamaica	40,200	87,400	61,400	107,000
Japan	212,000	1,700,000	19,100	780,000
Mexico	46,400	2,310,000	70,400	708,000
Netherlands	34,700	110,000	3,550	998,000
Panama	31,500	75,000	25,800	60,200
Trinidad and Tobago	60,700	131,000	42,900	80,600
United Kingdom	115,000	3,460,000	124,000	1,560,000
Other	193,000 ^r	5,710,000 ^r	108,000	7,660,000
Total	1,840,000	18,000,000	1,370,000	15,800,000
Total estimated equivalent REO content	1,630,000	XX	1,220,000	XX

See footnotes at end of table.

TABLE 4—Continued
U.S. EXPORTS OF RARE EARTHS, BY COUNTRY¹

Category ² and country	2014		2015	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Metals—Continued:				
Rare-earth metals and alloys (2805.30.0000):				
Australia	3,900	61,300	6,870	60,100
Brazil	2,590	56,400	2,080	14,900
Canada	1,760	517,000	1,940	103,000
China	28,700	514,000	4,880	279,000
France	6,440	\$46,300	124	\$30,300
Germany	2,760	211,000	1,570	152,000
Hungary	1,840	121,000	1,140	98,200
India	6,780	279,000	5,220	229,000
Japan	1,560	155,000	2,120	125,000
Netherlands	35,600	245,000	3,520	61,700
Spain	14,500	68,600	7,430	57,600
United Kingdom	3,870	110,000	2,140	125,000
Other	6,650 ^r	1,110,000 ^r	8,320	2,410,000
Total	117,000	3,490,000	47,300	3,750,000
Total estimated equivalent REO content	140,000	XX	56,800	XX

^rRevised. XX Not applicable.

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

²Harmonized Tariff Schedule of the United States code.

³Inorganic and organic.

Source: U.S. Census Bureau.

TABLE 5
U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY¹

Category ² and country	2014		2015	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Compounds:				
Cerium oxides (2846.10.0010):				
China	307,000	\$1,680,000	402,000	\$1,770,000
Japan	309,000	12,300,000	292,000	13,500,000
Other	73,600 ^r	897,000 ^r	35,000	656,000
Total	690,000	14,900,000	730,000	15,900,000
Total estimated equivalent rare-earth oxide (REO) content	690,000	XX	730,000	XX
Cerium compounds, other than cerium oxide (2846.10.0050):				
Austria	101,000	1,500,000	46,900	1,040,000
China	576,000	2,870,000	302,000	1,490,000
Estonia	385,000	1,860,000	658,000	2,080,000
Other	57,000	3,440,000 ^r	58,700	3,840,000
Total	1,120,000	9,670,000 ^r	1,070,000	8,450,000
Total estimated equivalent REO content	749,000	XX	713,000	XX
Other rare-earth compounds:				
Carbonates:				
Lanthanum carbonates mixtures (2846.90.8070):				
China	694,000	4,050,000	755,000	2,220,000
Other	143,000 ^r	760,000 ^r	212	26,700
Total	837,000	4,810,000	755,000	2,250,000
Total estimated equivalent REO content	573,000	XX	517,000	XX
Other rare-earth carbonates mixtures (2846.90.8075):				
Estonia	38,000	150,000	38,000	123,000
Other	4,930 ^r	491,000 ^r	2,570	167,000
Total	42,900	642,000	40,600	290,000
Total estimated equivalent REO content	23,600	XX	22,300	XX
Chlorides:				
Scandium or yttrium chloride mixtures (2846.90.2082):				
China	5,000	118,000	7	5,030
Other	15	13,500	45	17,400
Total	5,020	131,000	52	22,400
Total estimated equivalent REO content	1,860	XX	19	XX
Unspecified chlorides and chloride mixtures (2846.90.2080,³ 2846.90.2090³):				
China	131,000	1,220,000	XX	XX
France	22,100	1,010,000	XX	XX
Other	12,600	1,900,000	XX	XX
Total	165,000	4,130,000	XX	XX
Total estimated equivalent REO content	76,100	XX	XX	XX
Unspecified mixtures of chlorides (2846.90.2084):				
China	46,400	433,000	222,000	1,130,000
France	14,100	517,000	37,400	1,320,000
Malaysia	--	--	40,000	103,000
Other	12,700 ^r	804,000 ^r	20,900	980,000
Total	73,200 ^r	1,750,000	320,000	3,530,000
Total estimated equivalent REO content	40,300 ^r	XX	176,000	XX
Oxides:				
Lanthanum oxides (2846.90.2005):				
China	4,280,000 ^r	24,000,000 ^r	2,960,000	10,700,000
Other	311,000	5,250,000	36,600	723,000
Total	4,600,000	29,200,000 ^r	3,000,000	11,400,000
Total estimated equivalent REO content	4,600,000	XX	3,000,000	XX
Scandium or yttrium oxides (2846.90.2015):				
China	79	13,000	5,560	102,000
Estonia	58,100	401,000	20,000	109,000
France	5,860	662,000	4,880	512,000
Other	4,380 ^r	147,000	861	214,000

See footnotes at end of table.

TABLE 5—Continued
U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY¹

Category ² and country	2014		2015	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Compounds—Continued:				
Other rare-earth compounds—Continued:				
Oxides—Continued:				
Scandium or yttrium oxides (2846.90.2015)—Continued:				
Total	68,500	\$1,220,000	31,300	\$937,000
Total estimated equivalent REO content	68,500	XX	31,300	XX
Scandium or yttrium oxides mixtures (2846.90.8050 ³):				
China	162,000	2,150,000	XX	XX
Other	16,500 ^r	1,230,000 ^r	XX	XX
Total	178,000 ^r	3,380,000	XX	XX
Total estimated equivalent REO content	178,000 ^r	XX	XX	XX
REOs except cerium oxide (2846.90.2040):				
China	40,500	1,820,000	66,900	3,020,000
Estonia	9,970	904,000	--	--
Germany	15,300	2,620,000	16,800	2,990,000
Other	1,010	304,000	11,700	630,000
Total	66,700	5,650,000	95,400	6,650,000
Total estimated equivalent REO content	66,700	XX	95,400	XX
REOs except cerium or lanthanum oxide (2846.90.2045 ³):				
China	40,800	1,360,000	XX	XX
Estonia	191,000	1,620,000	XX	XX
Other	17,700	2,300,000	XX	XX
Total	249,000	5,280,000	XX	XX
Total estimated equivalent REO content	249,000	XX	XX	XX
Other rare-earth compounds or mixtures:				
Unspecified compounds or mixtures (2846.90.8090):				
China	4,350,000	40,000,000	4,670,000	54,700,000
Estonia	351,000	140,000	154,000	87,200
France	259,000	4,890,000	381,000	7,730,000
Germany	191,000	4,410,000	170,000	3,140,000
Malaysia	497,000	2,780,000	800,000	2,740,000
Other	313,000 ^r	17,700,000 ^r	796,000	23,800,000
Total	5,960,000	69,900,000 ^r	6,970,000	92,200,000
Total estimated equivalent REO content	3,280,000	XX	3,830,000	XX
Yttrium materials and compounds content by weight greater than 19% but less than 85% oxide equivalent (2846.90.4000):				
China	152,000	12,400,000	75,600	6,160,000
Japan	25,400	11,800,000	7,770	4,410,000
Other	2,700 ^r	897,000 ^r	649	857,000
Total	180,000	25,100,000	84,000	11,400,000
Total estimated equivalent REO content	108,000	XX	50,400	XX
Metals:				
Ferrocerium and other pyrophoric alloys (3606.90.3000):				
Austria	90,900	974,000	39,100	442,000
China	144,000	2,210,000	206,000	2,560,000
France	174,000	5,100,000	139,000	3,080,000
Other	9,120	69,400	16,500	226,000
Total	418,000	8,350,000	401,000	6,310,000
Total estimated equivalent REO content	371,000	XX	356,000	XX
Rare-earth metals and alloys:				
Cerium, unalloyed (2805.30.0010):				
China	48,500	407,000	97,300	841,000
Hong Kong	53,100	431,000	18,500	129,000
Other	10,300	109,000	1,180	73,500
Total	112,000	947,000	117,000	1,040,000
Total estimated equivalent REO content	134,000	XX	140,000	XX

See footnotes at end of table.

TABLE 5—Continued
U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY¹

Category ² and country	2014		2015	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Metals—Continued:				
Rare-earth metals and alloys—Continued:				
Lanthanum, unalloyed (2805.30.0005):				
China	48,400	\$626,000	61,900	\$464,000
Other	2,280	42,000 ^r	--	--
Total	50,700	668,000 ^r	61,900	464,000
Total estimated equivalent REO content	60,800	XX	74,200	XX
Neodymium, unalloyed (2805.30.0020):				
China	802	149,000	1,940	223,000
Thailand	1,500	720,000	1,500	69,000
United Kingdom	--	--	680	105,000
Other	--	--	617	20,400
Total	2,300	869,000	4,730	417,000
Total estimated equivalent REO content	2,760	XX	5,680	XX
Other rare-earth metals, unalloyed (2805.30.0050):				
China	24,200	616,000	59,200	857,000
Other	940	157,000	2,250	192,000
Total	25,100	772,000	61,400	1,050,000
Total estimated equivalent REO content	30,100	XX	73,700	XX
Other rare-earth metals, alloys (2805.30.0090):				
Austria	11,200	163,000	5,100	36,700
China	79,400	1,490,000	46,200	378,000
Japan	6,380	170,000	18,800	519,000
Other	3,140 ^r	523,000 ^r	4,150	443,000
Total	100,000	2,350,000	74,300	1,380,000
Total estimated equivalent REO content	120,000	XX	89,100	XX

^rRevised. XX Not applicable. -- Zero.

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

²Harmonized Tariff Schedule of the United States code.

³Code was discontinued effective July 1, 2014.

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	2011	2012	2013	2014	2015
Australia	2,188 ⁴	3,222 ⁴	3,000	8,000	12,000
Brazil	140	1,620 ^r	330	--	880
China	93,800	93,800	93,800 ⁵	105,000 ⁵	105,000 ⁵
India ⁶	1,700	1,700	1,700	1,700	1,700
Malaysia	410	100	180	240	310
Russia	2,500	2,200 ^r	2,500	2,600	2,800
Thailand ⁷	3,100	120	130	1,900	760
United States	--	3,000	5,500	5,400	5,900
Vietnam ⁷	200	200	100	--	250
Total	104,000	106,000 ^r	107,000	125,000	130,000

^rRevised. -- Zero.

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

²Includes data available through December 13, 2017.

³In addition to the countries listed, rare-earth minerals were thought to have been produced in Indonesia, Nigeria, North Korea, and some Commonwealth of Independent States countries, but information was inadequate to make reliable estimates of output.

⁴Reported figure.

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

⁶India's Department of Atomic Energy did not disclose monazite production data.

⁷Rare-earth oxide content of exports.