



# 2011 Minerals Yearbook

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## RARE EARTHS

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# RARE EARTHS

By Joseph Gambogi

**Domestic survey data and tables were prepared by Martha L. Jackson, statistical assistant, and the world production tables were prepared by Lisa D. Miller, international data coordinator.**

In 2011, world rare-earth production was primarily from the minerals bastnäsite and monazite. Rare-earth ores were primarily mined in China, with smaller amounts mined in India, Australia, Malaysia, and Brazil, listed in order of decreasing production (tables 6, 7). Processing of intermediate rare-earth concentrates took place at the Mountain Pass Mine in California. At yearend, plans were underway to resume mining at Mountain Pass for the first time since 2002.

Domestic use of scandium remained limited in 2011. Demand was primarily for aluminum alloys used in baseball and softball bats. Scandium alloys, compounds, and metals were also used in analytical standards, metallurgical research, and other sports equipment. Minor amounts of high-purity scandium were used in semiconductors and specialty lighting.

Based on import data from the Port Import Export Reporting Service (PIERS) database of Commonwealth Business Media, Inc. (undated), domestic yttrium imports for consumption decreased by 18% in 2011 compared with those of 2010. Yttrium was used primarily in linear fluorescent lamp and cathode-ray tube phosphors; lesser amounts were used in structural ceramics and oxygen sensors. Because yttrium stocks are replenished sporadically, year on year changes do not necessarily reflect trends in consumption.

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 that include the following in order of atomic number: lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium. At an average concentration in the Earth's crust of 60 parts per million (ppm), cerium is more abundant than copper, followed in decreasing order, by yttrium at 33 ppm, lanthanum at 30 ppm, and neodymium at 28 ppm. Thulium and lutetium, the least abundant of the lanthanides at 0.5 ppm, occur in the Earth's crust in higher concentrations than antimony, bismuth, cadmium, and thallium. 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).

Rare earths can be classified as either light rare-earth elements (LREE) or heavy rare-earth elements (HREE). The LREE include the lanthanide elements from atomic number 57 (lanthanum) through atomic number 64 (gadolinium), and the HREE include the lanthanide elements from atomic number 65 (terbium) through atomic number 71 (lutetium). The division is based on the LREE having unpaired electrons in the 4f electron shell, and HREE having paired electrons in the 4f electron shell. Gadolinium has a very stable half-filled 4f electron shell with seven unpaired electrons. Proceeding with terbium and

continuing along the series through lutetium, paired electrons are progressively added to the 4f electron shell for each respective element in the HREE lanthanide series until there is a full complement of 14 electrons in the 4f electron shell of lutetium. Yttrium is included as a HREE even though it is not part of the lanthanide contraction series.

Scandium (atomic number 21), a transition metal, is the lightest REE but it is not classified as one of the group of LREE nor one of the HREE. It is the 31st most abundant element in the Earth's crust, with an average crustal abundance of 22 ppm. 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 often occurs in the same minerals as a result of its similar ionic radius. Its atomic radius of 104 picometers in the trivalent state places it in relative size between the ionic radii of holmium and erbium (104.1 and 103 picometers, respectively) and it is included as one of the HREE. Yttrium is the second most abundant rare earth in the Earth's crust. Yttrium is a bright silvery metal that is soft and malleable, similar in density to titanium.

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, and phosphors. The principal economic ores of the rare earths are the minerals bastnäsite, loparite, and monazite and the lateritic ion-adsorption clays (table 2).

## Production

In 2011, rare earths were not mined in the United States (table 1). Molycorp, Inc. resumed mining at its Mountain Pass operation at yearend, but production of rare-earth oxide (REO) products during the year was from stockpiled concentrates. In 2011, Molycorp sales from Mountain Pass increased to 3,050 metric tons (t) of REO equivalent, a 67% increase compared with sales in 2010. The first phase of the company's Project Phoenix was expected to add 19,100 t of annual REO capacity and was scheduled for completion by yearend 2012 (Molycorp, Inc., 2012b).

U.S. processors of rare-earth permanent magnets and permanent magnet materials included Arnold Magnetic Technologies Corp., Electron Energy Corp., Great Western Technologies, Inc., and Santoku America, Inc. Sigma-Aldrich

Co. LLC produced a variety of scandium compounds from imported materials. All domestic, commercially produced, purified yttrium products were derived from imported compounds. The principal source of these compounds was China.

In April, Molycorp acquired Santoku America which produced rare-earth metals and magnet alloys at its operations in Tolleson, AZ. Santoku America produced both neodymium-iron-boron and samarium-cobalt permanent magnets (Molycorp, Inc., 2012a, p. 13).

Owing to market conditions, several mineral exploration and development projects were underway. Drilling and prefeasibility studies were underway in Alaska, Nebraska, and Wyoming.

At yearend, Rare Element Resources Ltd. neared completion of an updated National Instrument (NI) 43–101 compliant mineral resource estimate at its Bear Lodge project near Sundance, WY. The updated estimate of the Bull Hill deposit consisted of 6.8 million metric tons (Mt) averaging 3.75% REO in measured and indicated mineral resources, using a 1.5% REO cutoff grade. At yearend, a preliminary feasibility study was underway and was scheduled to be completed in 2012 (Rare Element Resources Ltd., 2012).

In 2011, Ucore Rare Metals Inc. announced the results of a NI 43–101 report for its Bokan Mountain project in Alaska. Using a 0.5% REO cutoff, inferred resources were estimated to be 27,400 t of REO with 45% reported to be heavy REO. The resource was classified as inferred owing to the limited sample data available within the deposit area. A preliminary economic assessment was expected to be completed in 2012 (Ucore Rare Metals Inc., 2011).

## Consumption

Data on domestic rare-earth consumption were developed by surveying known processors and manufacturers and evaluating import and export data. Domestic apparent consumption of rare earths was not calculated in 2011 because data were withheld to avoid disclosing company proprietary data.

In 2011, yttrium consumption was estimated to have decreased to 550 t from 670 t in 2010. Yttrium information was based on data retrieved from the PIERS database. The leading source of yttrium compounds and metal in 2011 was China (94%). The estimated use of yttrium, based on imports, was primarily in phosphors, ceramics, metal casting, and specialty alloys.

## Prices

There was much speculation concerning China's ability to restrict the supply of REO through quotas, licensing, and taxes; prices of rare-earth products fluctuated significantly in 2011. According to Metal-Prices, most rare-earth metal and oxide prices spiked in mid-2011, fell toward yearend, but finished the year significantly higher than yearend 2010. Prices for dysprosium, europium, and terbium metals and oxides were among the most volatile.

The yearend prices of most rare-earth materials, provided by Rhodia Inc., were higher in 2011 compared with those of 2010 (table 3). On average, REO yearend prices increased by 182%

from those in 2010. Scandium oxide prices were moderately higher than those in 2010.

## Foreign Trade

Data in this section are based on gross weight, although data in the tables are also converted to REO content. U.S. exports totaled 10,050 t valued at \$249 million, a 24% increase in quantity and a 183% increase in value compared with those of 2010. On a gross-weight basis, rare-earth compounds (excluding cerium) was the largest export category, accounting for 36% of total exports (table 4).

U.S. rare-earth imports totaled 10,000 t valued at \$802 million, approximately a 38% decrease in quantity and a 324% increase in value compared with those of 2010 (table 5). Elevated prices caused U.S. imports to fall to the lowest level since 1994. China continued to dominate most import markets, especially for mixed and individual rare-earth compounds. France was the leading source of ferrocenium and other pyrophoric alloys.

## World Review

**Australia.**—In New South Wales, Alkane Resources Ltd. continued to develop its Dubbo Zirconia project with planned production of hafnium, niobium, rare earths, tantalum, and zirconium products. In September, a definitive feasibility study was completed based on a 20-year operation with a potential production of 4,170 metric tons per year (t/yr) of REOs. Proven and probable reserves of REO, including yttrium oxide, were estimated to contain 316,000 t of REO, based on a 1.5% cutoff grade (combined ZrO<sub>2</sub>, Nb<sub>2</sub>O<sub>5</sub>, and REO). Alkane expected to begin mine production in 2014 (Alkane Resources Ltd., 2011).

Arafura Resources Ltd. continued to develop its Nolans Bore mining and beneficiation project in the Northern Territory and its Whayalla processing operation in South Australia. In 2011, Arafura continued a demonstration project that began in 2010. In the fourth quarter of 2011, a mineral concentrate was produced from 1,500 t of ore and further pilot-scale processing into REO was planned to be completed in 2012. A bankable feasibility study was scheduled to be completed in 2012 (Arafura Resources Ltd., 2011).

In May, Lynas Corp. Ltd. began production of rare-earth concentrate from its Mount Weld mining and processing operations in Western Australia. At yearend, 6,060 t of concentrate containing 2,190 t of REO was bagged and ready for shipment pending the commissioning of processing operations in Malaysia (Lynas Corp. Ltd., 2011).

**Canada.**—In the Northwest Territories, Avalon Rare Metals Inc. completed an updated prefeasibility study on its Thor Lake (Nechalco) project. The study was based on an annual production output of 8,240 t/yr of REO and probable mineral reserves of 222,000 t REO. The updated study did not include a separation plant. Construction of a separation plant and refinery was to be included in a bankable feasibility study scheduled for 2012 (Avalon Rare Metals Inc., 2011).

In Quebec, Matamec Explorations Inc. contracted with SGS Geostat Inc. to complete a preliminary economic assessment on its Kipawa project. At yearend, the study neared completion

(Matamec Explorations Inc., 2011b). Matamec also signed a nonbinding memorandum of understanding (MOU) with Toyota Tsusho Corp. The MOU could facilitate Toyota support for feasibility study expenditures and set up offtake agreements for the Kipawa project (Matamec Explorations Inc., 2011c). In 2012, the company planned to proceed with processing and hydrometallurgical pilot-plant studies for the Kipawa project (Matamec Explorations Inc., 2011a).

In Quebec and Newfoundland and Labrador, Quest Rare Minerals Ltd. continued drilling and updated its resource estimate on its Strange Lake B-zone deposit. According to its NI 43-101 report, at a cutoff grade of 0.579% REO, the indicated resource estimate was 140.3 Mt grading 0.93% REO. In 2012, the company planned a parallel path for work required to complete prefeasibility and bankable feasibility studies (Quest Rare Minerals Ltd., 2012, p. 5–10).

**China.**—China continued to dominate the supply of REE, accounting for 95% of global mine production in 2011. Mine production was primarily from bastnäsite and other rare-earth minerals in Nei Mongol Autonomous Region and Sichuan Province and from ion adsorption ores in Fujian, Guangdong, and Jiangxi Provinces in southeastern China.

Citing domestic requirements and environmental concerns, China restricted supply of REE through quotas, licenses, and taxes. The Ministry of Land and Resources increased the quota for China's REO production in 2011 to 93,800 t compared with 89,200 t in 2010. The production quota included 80,400 t of light REOs and 13,400 t of heavy REOs. Ninety-three percent of the light REO quota was allocated to Nei Mongol Autonomous Region and Sichuan Province, and 99% of the heavy REO quota was allocated to the Fujian, Guangdong, and Jiangxi Provinces (Ministry of Land and Resources of the People's Republic of China, 2011). In December, China's Ministry of Commerce announced a first-batch rare-earth export quota of 24,900 t for 2012. Unlike prior years, the Government specified quantities for light or middle and heavy rare earths allocated to each company. The Government also withheld export quotas for companies that did not meet the environmental protection guidelines (Reuters, 2011).

**Estonia.**—Molycorp acquired AS Silmet. Silmet's operations in Sillamäe produced rare-earth compounds and metals from rare-earth concentrates. The acquisition was renamed Molycorp Sillamäe and increased Molycorp's REO separation capacity by 3,000 t/yr (Molycorp, Inc., 2012a, p. 4).

**India.**—In July, Toyota Tsusho Corp.'s Indian subsidiary, Toyotsu Rare Earths Orissa Pvt. Ltd., started construction of a REO processing plant in Orissa. The plant was scheduled to be completed in 2012 and was expected to produce as much as 2,500 t/yr of REO derived from monazite produced at Indian Rare Earth Ltd.'s heavy-mineral sands operation (Toyota Tsusho Corp., 2012, p. 23).

**Japan.**—Sojitz Corp. and Japan Oil, Gas and Metals National Corp. (JOGMEC) agreed to provide Lynas with \$250 million in financial assistance through a loan and equity. The companies also agreed that Lynas would provide an 8,500-t allocation of rare-earth products for the Japanese market during a 10-year period. The assistance was expected to allow Lynas Corp. to

expand its production capacity in Australia and Malaysia (Lynas Corp. Ltd., 2012, p. 12).

**Malaysia.**—Lynas neared completion of its processing plant near Kuantan with an initial capacity of 11,000 t/yr of REO. Mineral concentrate from Australia was expected to supply the cracking and separation operation. The company commenced work on expanding REO capacity at Kuantan to 22,000 t/yr (Lynas Corp. Ltd., 2012, p. 12).

**South Africa.**—Great Western Minerals Group Ltd. (GWMG) was moving ahead with a project to recommission the abandoned Steenkampskraal (SKK) Mine in the Western Cape owned by Steenkampskraal Monazite Mine Ltd. (SMM). In July, GWMG received approval for a work program from the South African National Nuclear Regulator. The approval was expected to enable SMM to begin refurbishing the mine site and conduct a drilling program to confirm and expand resources. GWMG and China's Ganzhou Qiangdong Rare Earth Group Ltd. agreed to form a joint venture to build a rare-earth separation plant near the SKK Mine. A detailed design for a processing plant in which ore is converted into rare-earth chlorides was expected by yearend (Great Western Minerals Group Ltd., 2012, p. 5–6).

## Outlook

Rare-earth use in catalysts, magnets, phosphors, and rechargeable batteries is expected to continue to increase to keep up with future global demand for automobiles, consumer electronics, energy efficient lighting, and alternative energy sources. Demand for cerium and lanthanum for use in automotive catalytic converters and catalysts for petroleum refining is expected to follow refinery and automotive production.

REE magnet production was projected to increase to 150,000 t by 2014 from 92,000 t in 2011. Future growth was expected for rare earths in rechargeable NiMH batteries, especially those used in hybrid vehicles, increasing to 62,000 t REO by 2014 (BCC Research, 2010). NiMH demand was expected to be moderated by increasing demand for lithium-ion batteries. Increased rare-earth use was expected in fiber optics, medical applications that include dental and surgical lasers, magnetic resonance imaging, medical contrast agents, medical isotopes, and positron emission tomography scintillation detectors.

Rare-earth content of world reserves is greater than cumulative world consumption expected into the 21st century; however, recent shortages of rare earths for alloys, magnets, and phosphors have compelled companies to explore and develop rare-earth deposits throughout the world. Although the industry had shifted away from using naturally occurring radioactive rare-earth ores, several new projects are based on monazite ores. Long-term demand for monazite is expected to increase because of the mineral's abundant supply and low-cost byproduct recovery. Thorium's use as a nuclear material is a possible substitute for uranium in the future. If consumption of thorium increases, monazite could resume its role as a major source of rare earths.

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TABLE 1  
SALIENT U.S. RARE EARTH STATISTICS<sup>1</sup>

|  | 2007                 | 2008      | 2009      | 2010        | 2011        |
|--|----------------------|-----------|-----------|-------------|-------------|
| Production of rare-earth concentrates, rare-earth oxide (REO) basis <sup>e,2</sup>   |                      |           |           |             |             |
| Exports, REO basis:  |                      |           |           |             |             |
|  | metric tons          |           |           |             |             |
| Cerium compounds   | 1,470                | 1,380     | 840       | 1,350       | 1,640       |
| Ferrocium and pyrophoric alloys  | 3,210                | 4,490     | 2,970     | 3,460       | 2,010       |
| Rare-earth metals, scandium, yttrium   | 1,470                | 1,390     | 4,930     | 1,380       | 3,030       |
| Rare-earth compounds, organic or inorganic   | 1,300                | 663       | 455       | 1,690       | 3,620       |
| Imports for consumption, REO basis: <sup>e</sup>                                     |                      |           |           |             |             |
|  | do.                  |           |           |             |             |
| Cerium compounds   | 2,680                | 2,080     | 1,500     | 1,770       | 1,120       |
| Ferrocium and pyrophoric alloys  | 123                  | 125       | 102       | 131         | 186         |
| Mixtures of rare-earth chlorides except cerium chloride                              | 1,610                | 1,310     | 411       | 956         | 382         |
| Mixtures of REOs except cerium oxide   | 2,570                | 2,400     | 4,750     | 5,480       | 1,830       |
| Rare-earth compounds, oxides, hydroxides, nitrates, other compounds except chlorides | 9,900                | 8,820     | 5,080     | 3,980       | 3,770       |
| Rare-earth metals, whether intermixed or alloyed                                     | 784                  | 679       | 226       | 525         | 468         |
| Yttrium compounds  | 21                   | 10        | 7         | 73          | 35          |
| Prices, yearend:   |                      |           |           |             |             |
|  | dollars per kilogram |           |           |             |             |
| Bastnäsite concentrate, REO basis  | 6.61                 | 8.82      | 5.73      | 6.87        | NA          |
| Monazite concentrate, REO basis  | 0.73                 | 0.48      | 0.87      | 0.87        | 2.70        |
| Mischmetal, metal basis <sup>3</sup>   | 7.00-8.00            | 8.00-9.00 | 8.00-9.00 | 45.00-55.00 | 47.00-50.00 |

<sup>e</sup> Estimated. NA Not available. do. Ditto. -- Zero.

<sup>1</sup> Data are rounded to no more than three significant digits.

<sup>2</sup> Includes only the rare earths derived from bastnäsite as obtained from Molycorp, Inc.

<sup>3</sup> Source: Hefa Rare Earths Canada Co. Ltd., Vancouver, British Columbia, Canada.

TABLE 2  
RARE EARTH CONTENTS OF MAJOR AND POTENTIAL SOURCE MINERALS<sup>1,2</sup>

(Percentage of total rare-earth oxide)

| Rare earth   | Bastnäsité                                       |  | Monazite                                       |  |   |   |  |
|--------------|--|--|--|--|---|---|--|
|              | Mountain Pass,<br>CA, United States <sup>3</sup> | Bayan Obo, Inner<br>Mongolia, China <sup>4</sup> | North Capel,<br>Western Australia <sup>5</sup> | North Stradbroke Island,<br>Queensland, Australia <sup>6</sup> | Green Cove Springs,<br>FL, United States <sup>7</sup> | Nangang,<br>Guangdong, China <sup>8</sup>         |  |
| Yttrium      | 0.10   | trace  | 2.40   | 2.50   | 3.20  | 2.40  |  |
| Lanthanum    | 33.20  | 23.00  | 23.90  | 21.50  | 17.50   | 23.00   |  |
| Cerium       | 49.10  | 50.00  | 46.00  | 45.80  | 43.70   | 42.70   |  |
| Praseodymium | 4.34   | 6.20   | 5.00   | 5.30   | 5.00  | 4.10  |  |
| Neodymium    | 12.00  | 18.50  | 17.40  | 18.60  | 17.50   | 17.00   |  |
| Samarium     | 0.8  | 0.8  | 2.53   | 3.10   | 4.90  | 3.00  |  |
| Europium     | 0.1  | 0.2  | 0.053  | 0.8  | 0.16  | 0.1   |  |
| Gadolinium   | 0.2  | 0.7  | 1.49   | 1.80   | 6.60  | 2.00  |  |
| Terbium      | trace  | 0.1  | 0.035  | 0.3  | 0.26  | 0.7   |  |
| Dysprosium   | trace  | 0.1  | 0.7  | 0.60   | 0.9   | 0.8   |  |
| Holmium      | trace  | trace  | 0.053  | 0.1  | 0.11  | 0.12  |  |
| Erbium       | trace  | trace  | 0.2  | 0.2  | trace   | 0.3   |  |
| Thulium      | trace  | trace  | trace  | trace  | trace   | trace   |  |
| Ytterbium    | trace  | trace  | 0.1  | 0.1  | 0.21  | 2.40  |  |
| Lutetium     | trace  | trace  | trace  | 0.01   | trace   | 0.14  |  |
| Total        | 100  | 100  | 100  | 100  | 100   | 100   |  |
| Rare earth   | Monazite—Continued                               |  | Xenotime                                       |  | Rare earth laterite                                   |   |  |
|              | Eastern coast,<br>Brazil <sup>9</sup>            | Mount Weld,<br>Australia <sup>10</sup>           | Lahat, Perak,<br>Malaysia <sup>3</sup>         | Southeast<br>Guangdong, China <sup>11</sup>                    | Xunwu, Jiangxi<br>Province, China <sup>12</sup>       | Longnan, Jiangxi<br>Province, China <sup>12</sup> |  |
| Yttrium      | 1.40   | trace  | 61.00  | 59.30  | 8.00  | 65.00   |  |
| Lanthanum    | 24.00  | 26.00  | 1.24   | 1.20   | 43.4  | 1.82  |  |
| Cerium       | 47.00  | 51.00  | 3.13   | 3.00   | 2.40  | 0.4   |  |
| Praseodymium | 4.50   | 4.00   | 0.5  | 0.6  | 9.00  | 0.7   |  |
| Neodymium    | 18.50  | 15.00  | 1.60   | 3.50   | 31.70   | 3.00  |  |
| Samarium     | 3.00   | 1.80   | 1.10   | 2.20   | 3.90  | 2.80  |  |
| Europium     | 0.1  | 0.4  | trace  | 0.2  | 0.5   | 0.10  |  |
| Gadolinium   | 1.00   | 1.00   | 3.50   | 5.00   | 3.00  | 6.90  |  |
| Terbium      | 0.1  | 0.1  | 0.9  | 1.20   | trace   | 1.30  |  |
| Dysprosium   | 0.4  | 0.2  | 8.30   | 9.10   | trace   | 6.70  |  |
| Holmium      | trace  | 0.1  | 2.00   | 2.60   | trace   | 1.60  |  |
| Erbium       | 0.1  | 0.2  | 6.40   | 5.60   | trace   | 4.90  |  |
| Thulium      | trace  | trace  | 1.10   | 1.30   | trace   | 0.7   |  |
| Ytterbium    | 0.02   | 0.1  | 6.80   | 6.00   | 0.3   | 2.50  |  |
| Lutetium     | not determined                                   | trace  | 1.00   | 1.80   | 0.1   | 0.4   |  |
| Total        | 100  | 100  | 100  | 100  | 100   | 100   |  |

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

<sup>2</sup>This table is in atomic numerical order.

<sup>3</sup>Johnson, G.W., and Sisneros, T.E., 1981, Analysis of rare-earth elements in ore concentrate samples using direct current plasma spectrometry—Proceedings of the 15th Rare Earth Research Conference, Rolla, MO, June 15–18, 1981: New York, NY, Plenum Press, v. 3, p. 525–529.

<sup>4</sup>Zang, 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.

<sup>5</sup>Westralian Sands Ltd., 1979, Product specifications, effective January 1980: Capel, Australia, Westralian Sands Ltd. brochure, 8 p.

<sup>6</sup>Analysis from Consolidated Rutile Ltd.

<sup>7</sup>Analysis from RGC Minerals (USA), Green Cove Springs, FL.

<sup>8</sup>Xi, Zhang, 1986, The present status of Nd-Fe-B magnets in China—Proceedings of the Impact of Neodymium-Iron-Boron Materials on Permanent Magnet Users and Producers Conference, Clearwater, FL, March 2–4, 1986: Clearwater, FL, Gorham International Inc., 5 p.

<sup>9</sup>Krumholz, Pavel, 1991, Brazilian practice for monazite treatment: Symposium on Rare Metals, Sendai, Japan, December 12–13, 1991, Proceedings, p. 78–82.

<sup>10</sup>Kingsnorth, Dudley, 1992, Mount Weld—A new source of light rare earths—Proceedings of the TMS and Australasian Institute of Mining and Metallurgy Rare Earth Symposium, San Diego, CA, March 1–5, 1992: Sydney, Australia, Lynas Gold NL, 8 p.

<sup>11</sup>Nakamura, Shigeo, 1988, China and rare metals—Rare earth: Industrial Rare Metals, no. 94, May, p. 23–28.

<sup>12</sup>Introduction to Jiangxi rare-earths and applied products, 1985, Jiangxi Province brochure, 42 p.

TABLE 3  
RARE-EARTH OXIDE PRICES IN 2011<sup>1</sup>

| Product (oxide)           | Purity<br>(percentage) | Standard package<br>quantity<br>(kilograms) | Price<br>(dollars per<br>kilogram) |
|---------------------------|------------------------|---|------------------------------------|
| Scandium <sup>2</sup>     | 99.99                  | NA  | 3,700                              |
| Yttrium <sup>3</sup>      | 99.99                  | 20  | 165                                |
| Lanthanum <sup>3</sup>    | 99.99                  | 20  | 100                                |
| Cerium <sup>3</sup>       | 99.50                  | 20  | 100                                |
| Praseodymium <sup>3</sup> | 96.00                  | 20  | 225                                |
| Neodymium <sup>3</sup>    | 95.00                  | 20  | 270                                |
| Samarium <sup>3</sup>     | 99.90                  | 20  | 118                                |
| Europium <sup>3</sup>     | 99.99                  | 20  | 3,300                              |
| Gadolinium <sup>3</sup>   | 99.99                  | 20  | 239                                |
| Terbium <sup>3</sup>      | 99.99                  | 20  | 2,750                              |
| Dysprosium <sup>3</sup>   | 99.00                  | 20  | 1,600                              |
| Holmium <sup>3</sup>      | 99.90                  | 10  | NA                                 |
| Erbium <sup>3</sup>       | 96.00                  | 20  | 255                                |
| Thulium <sup>3</sup>      | 99.90                  | 5   | NA                                 |
| Ytterbium <sup>3</sup>    | 99.00                  | 10  | 450                                |
| Lutetium <sup>3</sup>     | 99.99                  | 1 or 10                                     | 4,000                              |

NA Not available.

<sup>1</sup>This table is in atomic numerical order.

<sup>2</sup>Source: Stanford Metals Corp.

<sup>3</sup>Source: Rhodia Electronics & Catalysis, Inc.



TABLE 4  
U.S. EXPORTS OF RARE EARTHS, BY COUNTRY<sup>1</sup>

| Category <sup>2</sup> and country                              | 2010                        |                        | 2011                        |            |
|--|-----------------------------|------------------------|-----------------------------|------------|
|  | Gross weight<br>(kilograms) | Value                  | Gross weight<br>(kilograms) | Value      |
| <b>Cerium compounds (2846.10.0000):</b>                        |                             |                        |                             |            |
| Australia  | 9                           | \$8,060                | 2,040                       | \$154,000  |
| Austria  | 122,000                     | 1,530,000              | 64,900                      | 3,780,000  |
| Belgium  | 5,000                       | 5,000                  | 9,060                       | 378,000    |
| Brazil   | 7,900                       | 133,000                | 12,400                      | 144,000    |
| Canada   | 25,300                      | 284,000                | 39,600                      | 513,000    |
| China  | 255,000                     | 2,110,000              | 139,000                     | 1,780,000  |
| Estonia  | --                          | --                     | 378,000                     | 6,380,000  |
| France   | 95,300                      | 412,000                | 69,700                      | 3,490,000  |
| Germany  | 124,000                     | 1,110,000              | 141,000                     | 1,800,000  |
| Hong Kong  | 18,100                      | 446,000                | 26,900                      | 1,330,000  |
| India  | 15,700                      | 159,000                | 27,200                      | 416,000    |
| Japan  | 180,000                     | 3,170,000              | 122,000                     | 4,140,000  |
| Korea, Republic of   | 25,900                      | 214,000                | 7,590                       | 82,000     |
| Mexico   | 241,000                     | 1,420,000              | 80,000                      | 2,130,000  |
| Netherlands  | 64,500                      | 364,000                | 102,000                     | 637,000    |
| Russia   | 11,400                      | 399,000                | 22,800                      | 3,200,000  |
| Singapore  | 181                         | 9,500                  | 4,850                       | 121,000    |
| Taiwan   | 8,490                       | 156,000                | 4,740                       | 158,000    |
| United Kingdom   | 14,400                      | 737,000                | 20,100                      | 592,000    |
| Vietnam  | --                          | --                     | 161,000                     | 14,500,000 |
| Other  | 139,000 <sup>r</sup>        | 1,680,000 <sup>r</sup> | 202,000                     | 5,210,000  |
| Total  | 1,350,000                   | 14,300,000             | 1,640,000                   | 50,900,000 |
| Total estimated equivalent rare-earth oxide (REO) content      | 1,350,000                   | XX                     | 1,640,000                   | XX         |
| <b>Ferrocerium and other pyrophoric alloys (3606.90.0000):</b> |                             |                        |                             |            |
| Argentina  | 143                         | 4,920                  | 142                         | 5,160      |
| Australia  | 12,700                      | 2,750,000              | 15,300                      | 3,660,000  |
| Canada   | 513,000                     | 2,040,000              | 462,000                     | 2,040,000  |
| China  | 100,000                     | 789,000                | 1,610                       | 18,900     |
| Egypt  | 1,260                       | 102,000                | 39                          | 18,500     |
| France   | 35,400                      | 183,000                | 13,400                      | 165,000    |
| Germany  | 7,760                       | 176,000                | 6,790                       | 250,000    |
| Greece   | 639                         | 42,200                 | 369                         | 39,600     |
| Hong Kong  | 9,450                       | 305,000                | 16,300                      | 567,000    |
| India  | 315,000                     | 182,000                | 14,300                      | 378,000    |
| Israel   | 1,210                       | 10,700                 | 77                          | 3,230      |
| Japan  | 17,100                      | 504,000                | 31,300                      | 559,000    |
| Korea, Republic of   | 1,380                       | 73,100                 | 2,580                       | 86,600     |
| Mexico   | 2,300,000                   | 4,840,000              | 1,120,000                   | 2,590,000  |
| Netherlands  | 229,000                     | 1,180,000              | 33,700                      | 114,000    |
| New Zealand  | 16,700                      | 55,600                 | --                          | --         |
| Saudi Arabia   | 268                         | 5,400                  | 1,650                       | 87,200     |
| Singapore  | 1,280                       | 40,300                 | 1,250                       | 41,800     |
| Sweden   | --                          | --                     | 12,400                      | 911,000    |
| Taiwan   | 408                         | 13,200                 | 380                         | 13,500     |
| United Arab Emirates   | --                          | --                     | 52,400                      | 111,000    |
| United Kingdom   | 168,000                     | 4,790,000              | 153,000                     | 5,540,000  |
| Other  | 163,000 <sup>r</sup>        | 941,000 <sup>r</sup>   | 333,000                     | 1,150,000  |
| Total  | 3,900,000                   | 19,000,000             | 2,270,000                   | 18,300,000 |
| Total estimated equivalent REO content                         | 3,460,000                   | XX                     | 2,010,000                   | XX         |
| <b>Rare-earth compounds<sup>3</sup> (2846.90.0000):</b>        |                             |                        |                             |            |
| Austria  | 279,000                     | 616,000                | 134,000                     | 4,150,000  |
| Brazil   | 9,450                       | 248,000                | 1,530                       | 223,000    |
| Canada   | 49,600                      | 588,000                | 88,900                      | 1,360,000  |
| China  | 47,000                      | 906,000                | 61,900                      | 3,150,000  |
| Colombia   | 9,010                       | 25,500                 | 14,300                      | 25,300     |
| Czech Republic   | --                          | --                     | 136,000                     | 2,300,000  |
| Estonia  | 77,700                      | 220,000                | 1,010,000                   | 19,100,000 |
| France   | 23,000                      | 442,000                | 123,000                     | 2,470,000  |
| Germany  | 38,200                      | 1,420,000              | 50,600                      | 2,510,000  |

See footnotes at end of table.

TABLE 4—Continued  
U.S. EXPORTS OF RARE EARTHS, BY COUNTRY<sup>1</sup>

| Category <sup>2</sup> and country                                 | 2010                        |                        | 2011                        |             |
|---|-----------------------------|------------------------|-----------------------------|-------------|
|   | Gross weight<br>(kilograms) | Value                  | Gross weight<br>(kilograms) | Value       |
| Rare-earth compounds <sup>3</sup> (2846.90.0000)—Continued:       |                             |                        |                             |             |
| Hong Kong   | 1,090                       | \$69,500               | 68,200                      | \$2,380,000 |
| India   | 18,500                      | 127,000                | 96,900                      | 2,510,000   |
| Italy   | 16,300                      | 108,000                | 2,050                       | 140,000     |
| Japan   | 379,000                     | 13,900,000             | 115,000                     | 11,700,000  |
| Korea, Republic of  | 90,100                      | 940,000                | 29,700                      | 593,000     |
| Mexico  | 79,800                      | 1,160,000              | 351,000                     | 4,570,000   |
| Netherlands   | 107,000                     | 1,560,000              | 569,000                     | 9,040,000   |
| Singapore   | 12,000                      | 204,000                | 17,900                      | 221,000     |
| Taiwan  | 1,670                       | 407,000                | 1,750                       | 242,000     |
| Thailand  | 1,140                       | 385,000                | 334,000                     | 36,700,000  |
| United Kingdom  | 77,400                      | 1,930,000              | 11,000                      | 626,000     |
| Vietnam   | 62,500                      | 682,000                | 304,000                     | 9,060,000   |
| Other   | 313,000 <sup>r</sup>        | 1,300,000 <sup>r</sup> | 100,000                     | 2,700,000   |
| Total   | 1,690,000                   | 27,200,000             | 3,620,000                   | 116,000,000 |
| Total estimated equivalent REO content                            | 1,690,000                   | XX                     | 3,620,000                   | XX          |
| Rare-earth metals, including scandium and yttrium (2805.30.0000): |                             |                        |                             |             |
| Brazil  | 84,200                      | 1,290,000              | 56,100                      | 1,330,000   |
| China   | 316,000                     | 1,230,000              | 951,000                     | 2,750,000   |
| Estonia   | 1,030 <sup>r</sup>          | 40,000 <sup>r</sup>    | 77,700                      | 352,000     |
| Germany   | 7,220                       | 317,000                | 10,400                      | 412,000     |
| Hong Kong   | 990                         | 190,000                | 56,600                      | 274,000     |
| India   | 6,780                       | 380,000                | 10,600                      | 840,000     |
| Japan   | 639,000                     | 19,800,000             | 839,000                     | 48,000,000  |
| Mexico  | 675                         | 83,700                 | 1,230                       | 160,000     |
| Philippines   | --                          | --                     | 394,000                     | 3,400,000   |
| Taiwan  | 801                         | 64,700                 | --                          | --          |
| Vietnam   | 49,000                      | 3,310,000              | 76,700                      | 1,620,000   |
| Other   | 43,300 <sup>r</sup>         | 797,000 <sup>r</sup>   | 50,600                      | 4,780,000   |
| Total   | 1,150,000                   | 27,500,000             | 2,520,000                   | 63,900,000  |
| Total estimated equivalent REO content                            | 1,380,000                   | XX                     | 3,030,000                   | XX          |

<sup>1</sup>Revised. XX Not applicable. -- Zero.

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

<sup>2</sup>Harmonized Tariff Schedule of the United States category numbers.

<sup>3</sup>Inorganic and organic.

TABLE 5  
U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY<sup>1</sup>

| Category <sup>2</sup> and country  | 2010                        |                      | 2011                        |              |
|--|-----------------------------|----------------------|-----------------------------|--------------|
|  | Gross weight<br>(kilograms) | Value                | Gross weight<br>(kilograms) | Value        |
| Cerium compounds, including oxides, hydroxides, nitrates, sulfate, chlorides, oxalates (2846.10.0000):         |                             |                      |                             |              |
| Austria  | 131,000                     | \$1,400,000          | 302,000                     | \$10,400,000 |
| China  | 2,010,000                   | 13,500,000           | 640,000                     | 38,500,000   |
| Estonia  | 200,000                     | 1,040,000            | 182,000                     | 10,600,000   |
| France   | 11,800                      | 685,000              | 48,000                      | 2,370,000    |
| Japan  | 139,000                     | 4,700,000            | 168,000                     | 8,710,000    |
| Korea, Republic of   | 32,400                      | 275,000              | 7,360                       | 298,000      |
| United Kingdom   | 60,100                      | 155,000              | 203                         | 19,400       |
| Other  | 61,500 <sup>r</sup>         | 939,000 <sup>r</sup> | 327,000                     | 16,200,000   |
| Total  | 2,640,000                   | 22,600,000           | 1,670,000                   | 87,100,000   |
| Total estimated equivalent rare-earth oxide (REO) content  | 1,770,000                   | XX                   | 1,120,000                   | XX           |
| Ferrocerium and other pyrophoric alloys (3606.90.3000):  |                             |                      |                             |              |
| Austria  | 25,400                      | 626,000              | 28,200                      | 646,000      |
| China  | 11,900                      | 184,000              | 44,100                      | 801,000      |
| France   | 110,000                     | 2,290,000            | 133,000                     | 2,440,000    |
| Germany  | --                          | --                   | 706                         | 29,500       |
| Netherlands  | --                          | --                   | 2,070                       | 8,500        |
| Taiwan   | 700                         | 9,530                | 550                         | 8,500        |
| Total  | 148,000                     | 3,110,000            | 209,000                     | 3,930,000    |
| Total estimated equivalent REO content   | 131,000                     | XX                   | 186,000                     | XX           |
| Mixtures of rare-earth chlorides, except cerium chloride (2846.90.2050):                                       |                             |                      |                             |              |
| Australia  | 1,930                       | 3,190                | --                          | --           |
| China  | 2,030,000                   | 11,100,000           | 636,000                     | 40,600,000   |
| Estonia  | 4,000                       | 126,000              | 12,000                      | 1,610,000    |
| France   | 10,300                      | 243,000              | 120,000                     | 2,010,000    |
| Germany  | 336                         | 87,000               | 10,400                      | 2,980,000    |
| Japan  | 19,500                      | 206,000              | 21,200                      | 2,360,000    |
| Korea, Republic of   | --                          | --                   | 29,300                      | 1,820,000    |
| Russia   | 138                         | 76,400               | 248                         | 186,000      |
| United Kingdom   | 15,000                      | 121,000              | --                          | --           |
| Other  | --                          | --                   | 2,120                       | 141,000      |
| Total  | 2,080,000                   | 12,000,000           | 831,000                     | 51,700,000   |
| Total estimated equivalent REO content   | 956,000                     | XX                   | 382,000                     | XX           |
| Mixtures of REOs except cerium oxide (2846.90.2010):   |                             |                      |                             |              |
| Canada   | --                          | --                   | 11,000                      | 1,080,000    |
| China  | 5,410,000                   | 33,400,000           | 1,740,000                   | 92,600,000   |
| Estonia  | --                          | --                   | 17,000                      | 2,370,000    |
| Germany  | 1,270                       | 65,400               | 615                         | 39,200       |
| Ireland  | 34,600                      | 2,830,000            | 43,600                      | 4,240,000    |
| Italy  | 18,400                      | 1,790,000            | 6,760                       | 656,000      |
| Japan  | 9,310                       | 148,000              | 12,200                      | 797,000      |
| Russia   | 63                          | 35,100               | 1,870                       | 230,000      |
| Other  | 56 <sup>r</sup>             | 22,900 <sup>r</sup>  | 2,020                       | 200,000      |
| Total  | 5,480,000                   | 38,300,000           | 1,830,000                   | 102,000,000  |
| Total estimated equivalent REO content   | 5,480,000                   | XX                   | 1,830,000                   | XX           |
| Rare-earth compounds, including oxides, hydroxides, nitrates, other compounds except chlorides (2846.90.8000): |                             |                      |                             |              |
| Austria  | 108,000                     | 4,390,000            | 171,000                     | 15,900,000   |
| Canada   | --                          | --                   | 6,090                       | 26,800,000   |
| China  | 4,080,000                   | 55,400,000           | 3,340,000                   | 279,000,000  |
| France   | 542,000                     | 16,600,000           | 425,000                     | 52,500,000   |
| Germany  | 700                         | 208,000              | 8,800                       | 1,500,000    |
| Hong Kong  | 100                         | 6,800                | 1,240                       | 127,000      |
| Japan  | 417,000                     | 17,300,000           | 701,000                     | 74,200,000   |
| Russia   | 13,200                      | 339,000              | 360                         | 208,000      |
| South Africa   | 64,100                      | 781,000              | 159,000                     | 5,940,000    |
| United Kingdom   | 43,800                      | 211,000              | 27,300                      | 465,000      |

See footnotes at end of table.

TABLE 5—Continued  
U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY<sup>1</sup>

| Category <sup>2</sup> and country   | 2010                        |                      | 2011                        |              |
|---|-----------------------------|----------------------|-----------------------------|--------------|
|   | Gross weight<br>(kilograms) | Value                | Gross weight<br>(kilograms) | Value        |
| Rare-earth compounds, including oxides, hydroxides, nitrates, other compounds<br>except chlorides (2846.90.8000)—Continued: |                             |                      |                             |              |
| Other   | 45,800                      | \$1,080,000          | 191,000                     | \$18,000,000 |
| Total   | 5,310,000                   | 96,300,000           | 5,030,000                   | 475,000,000  |
| Total estimated equivalent REO content  | 3,980,000                   | XX                   | 3,770,000                   | XX           |
| Rare-earth metals, whether intermixed or alloyed (2805.30.0000):  |                             |                      |                             |              |
| Austria   | 3,610                       | 223,000              | 13,400                      | 870,000      |
| Canada  | 224                         | 19,700               | 70                          | 5,240        |
| China   | 361,000                     | 12,300,000           | 282,000                     | 54,600,000   |
| Germany   | 70                          | 17,600               | 6,800                       | 620,000      |
| Hong Kong   | 46,400                      | 409,000              | 17,200                      | 1,220,000    |
| Japan   | 13,600                      | 954,000              | 31,400                      | 6,060,000    |
| Korea, Republic of  | 53                          | 51,600               | --                          | --           |
| Laos  | --                          | --                   | 16,100                      | 4,290,000    |
| Russia  | 3,620                       | 328,000              | 5,510                       | 463,000      |
| Thailand  | --                          | --                   | 14,900                      | 2,260,000    |
| United Kingdom  | 8,480                       | 413,000              | 3,070                       | 510,000      |
| Vietnam   | 219                         | 4,150                | --                          | --           |
| Total   | 437,000                     | 14,700,000           | 390,000                     | 70,800,000   |
| Total estimated equivalent REO content  | 525,000                     | XX                   | 468,000                     | XX           |
| Yttrium compounds content by weight greater than 19% but less than 85%<br>oxide equivalent (2846.90.4000):                  |                             |                      |                             |              |
| Austria   | --                          | --                   | 12,100                      | 169,000      |
| China   | 98,000                      | 586,000              | 37,000                      | 9,140,000    |
| France  | 9,100                       | 589,000              | 828                         | 14,800       |
| Germany   | 17                          | 9,610                | 4,720                       | 1,430,000    |
| Japan   | 5,100                       | 641,000              | 3,060                       | 739,000      |
| Other   | 10,200 <sup>r</sup>         | 234,000 <sup>r</sup> | 187                         | 289,000      |
| Total   | 122,000                     | 2,060,000            | 57,900                      | 11,800,000   |
| Total estimated equivalent REO content  | 73,500                      | XX                   | 34,700                      | XX           |

<sup>r</sup>Revised. XX Not applicable. -- Zero.

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

<sup>2</sup>Harmonized Tariff Schedule of the United States category numbers.

Source: U.S. Census Bureau.

TABLE 6  
RARE EARTHS: ESTIMATED WORLD MINE PRODUCTION, BY COUNTRY<sup>1, 2, 3</sup>

(Metric tons of rare earth oxide equivalent)

| Country   | 2007             | 2008             | 2009             | 2010                | 2011               |
|-----------|------------------|------------------|------------------|---------------------|--------------------|
| Australia | --               | --               | --               | --                  | 2,188 <sup>4</sup> |
| Brazil    | 645 <sup>4</sup> | 460 <sup>4</sup> | 170 <sup>4</sup> | 140 <sup>r, 4</sup> | 140 <sup>p</sup>   |
| China     | 120,000          | 125,000          | 129,000          | 120,000             | 105,000            |
| India     | 2,700            | 2,700            | 2,700            | 2,800               | 2,800              |
| Malaysia  | 380              | 120              | 13               | 310 <sup>r</sup>    | 280                |
| Total     | 124,000          | 128,000          | 132,000          | 123,000             | 110,000            |

<sup>p</sup>Preliminary. <sup>r</sup>Revised. -- Zero.

<sup>1</sup>World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

<sup>2</sup>Table includes data available through July 26, 2012.

<sup>3</sup>In addition to the countries listed, rare-earth minerals may be produced in other countries, but information is inadequate for the formulation of reliable estimates of output levels.

<sup>4</sup>Reported figure.

TABLE 7  
 MONAZITE CONCENTRATE: ESTIMATED WORLD PRODUCTION, BY COUNTRY<sup>1,2</sup>

(Metric tons, gross weight)

| Country <sup>3</sup>  | 2007                 | 2008               | 2009               | 2010               | 2011  |
|-----------------------|----------------------|--------------------|--------------------|--------------------|-------|
| Brazil                | 1,173 <sup>r,4</sup> | 834 <sup>r,4</sup> | 303 <sup>r,4</sup> | 249 <sup>4</sup>   | 250   |
| India                 | 5,000                | 5,000              | 5,000              | 5,200              | 5,200 |
| Malaysia <sup>4</sup> | 682                  | 233                | 25                 | 732 <sup>r</sup>   | 779   |
| Vietnam               | 1,400                | 1,400              | 1,200              | 310                | 360   |
| Total                 | 8,260 <sup>r</sup>   | 7,470 <sup>r</sup> | 6,530 <sup>r</sup> | 6,490 <sup>r</sup> | 6,590 |

<sup>r</sup>Revised.

<sup>1</sup>World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

<sup>2</sup>Table includes data available through May 9, 2012.

<sup>3</sup>In addition to the countries listed, other countries may produce monazite, but available information is inadequate for the formulation of reliable estimates of output levels.

<sup>4</sup>Reported figure.