2007 Minerals Yearbook

RARE EARTHS [ADVANCE RELEASE]

U.S. Department of the Interior
U.S. Geological Survey

September 2009

RARE EARTHS

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In 2007, world rare-earth production was primarily from the mineral bastnäsite. Rare earths were not mined in the United States in 2007; however, Chevron Mining Inc. (previously Molycorp, Inc.) restarted processing intermediate rare-earth concentrates at its Mountain Pass Mine in California in September. Rare-earth ores were primarily mined by China, with smaller amounts mined in Brazil, India, and Russia. Domestic stocks of previously produced bastnäsite concentrates, intermediate rare-earth concentrates, and separated products were available for purchase from Chevron Mining at Mountain Pass. Rare-earth consumption was estimated to have decreased in 2007. Although U.S. imports of cerium compounds and mixtures of rare-earth oxides excluding cerium oxide increased, exports of all other trade categories of rare earths declined (table 1).

Domestic use of scandium decreased slightly in 2007. Overall consumption of the commodity remained small. Demand was primarily for aluminum alloys used in baseball and softball bats. Scandium alloys, compounds, and metals were used in analytical standards, metallurgical research, and 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 consumption decreased by 8.9% in 2007 compared with that of 2006. Yttrium was used primarily in fluorescent lamp and cathode-ray tube (CRT) phosphors; smaller amounts were used in structural ceramics and oxygen sensors.

The rare earths are a moderately abundant group of 17 elements comprising the 15 lanthanides, scandium, and yttrium. The elements range in crustal abundance from cerium, the 25th most abundant element of the 78 common elements in the Earth's crust at 60 parts per million (ppm), to thulium and lutetium, the least abundant rare-earth elements (REE) at about 0.5 ppm (Mason and Moore, 1982, p. 46). In rock-forming minerals, rare earths typically occur in compounds as trivalent cations in carbonates, oxides, phosphates, and silicates.

The lanthanides comprise a group of 15 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. Cerium, which is more abundant than copper (average concentration in the Earth's crust 50 ppm), is the most abundant member of the group at 60 ppm, 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.

Scandium, atomic number 21, is the lightest REE. 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. It is represented by the chemical symbol Sc and has one naturally occurring isotope. Although its occurrence in crustal rocks is greater than 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, is chemically similar to the lanthanides and often occurs in the same minerals as a result of its similar ionic radius. It is represented by the chemical symbol Y and has one naturally occurring isotope. 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 are used in a wide variety of applications. 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 2007, Chevron Mining (a wholly owned subsidiary of Chevron Corp.), remained open on a care-and-maintenance basis. Although Chevron Mining did not actively mine rare earths in 2007, the sales operation at the mine site remained open and sold from its stockpile of bastnäsite concentrates, intermediate concentrates, and separated compounds previously processed at its open pit operations at Mountain Pass. Substantial stocks of lanthanide concentrates and intermediate and refined compounds were available. Lanthanide products available in 2007 from the former Molycorp and from Chevron Mining were bastnäsite concentrate, cerium nitrate, lanthanum chloride, lanthanum hydrate, lanthanum-rich nitrate, and the oxides of cerium, erbium, europium, gadolinium, praseodymium, samarium, and yttrium.

Three companies processed intermediate rare-earth compounds to lanthanides in 2007. Grace Davison (a subsidiary of W.R. Grace & Co.) processed intermediate rare-earth compounds to produce cerium- and lanthanum-rich compounds used in making fluid-cracking catalysts for the petroleum refining industry; the company also processed zirconia-stabilized ceria compounds for supports for automotive catalysts, fluid catalytic cracking additives, and oxidation of organic compounds in wastewater. Grace Davison also produced several grades of Vitrox and Rareox cerium oxide polishing compounds. At yearend 2007, Grace Davison reported sales revenues increased $130 million, or 9.5%, compared with those of 2006 (W.R. Grace & Co., 2008).

Santoku America, Inc. (a subsidiary of Santoku Corporation of Japan) produced rare-earth metals and magnet alloys at its operations in Tolleson, AZ. Santoku America produced two types of alloys used in high-strength permanent magnets—neodymium-iron-boron (NIB) and samarium-cobalt (SmCo). Santoku previously produced rare-earth nickel-metal hydride (NiMH) alloys that incorporate specialty rare-earth mischmetals. The plant also produced a full range of high-purity rare-earth metals, including scandium and yttrium, in cast and distilled forms, as foils, and as sputtering targets. The sole domestic producer of NIB magnet alloys was Santuko America.

The only U.S. producer of rare-earth permanent magnets was Electron Energy Corp. (EEC) of Landisville, PA. EEC produced SmCo permanent magnets and designed and manufactured magnet assemblies, including actuators, Halbach arrays (magnetic field focusing assemblies), high-speed rotors, and other components.

Demand for rare earths used in NiMH batteries increased in 2007, as did overall demand for rechargeable batteries. Rechargeable batteries are used in camcorders, cellular telephones, PDAs, portable computers, and other portable devices. The principal world markets for rechargeable batteries are laptop computers and cellular telephones.

One scandium processor operated in 2007. High-purity products were available in various grades, with scandium oxide having up to 99.999% purity. Boulder Scientific Co. had scandium facilities on standby at its Mead, CO, operations. Boulder Scientific previously refined scandium primarily from imported oxides and domestic ores to produce high-purity scandium compounds, including carbide, chloride, diboride, fluoride, hydride, nitride, oxalate, and tungstate.

Scandium was purified and processed from imported oxides at Aldrich-APL, LLC in Urbana, IL, to produce high-purity scandium compounds, including anhydrous and hydrous chloride, fluoride, iodide, and oxide. The company also produced high-purity scandium metal.

All commercially produced purified yttrium products were derived from imported compounds. The principal source was China.

Mineral reserves and resources of the United States on a regional basis are summarized for the following areas—Colorado, Idaho and Montana, Missouri, Utah, and Wyoming.

Colorado.—The U.S. Geological Survey (USGS) investigated the Iron Hill or Powderhorn carbonatite, located 35 kilometers (km) south-southwest of Gunnison, CO (Olson and Hedlund, 1981; Van Gosen, 2008). Various companies and government agencies have studied the deposit in the past for its niobium, rare earth, titanium, and thorium content. Work on the deposit was done by Buttes Gas & Oil Co., E. I. du Pont de Nemours and Company, Teck Corp., the U.S. Bureau of Mines, and the USGS. Rare-earth minerals at the deposit are bastnäsite, rhabdophane, and synchysite, with lesser amounts of fluorapatite, monazite, and pyrochlore. Teck Corp. listed reserves at the Iron Hill carbonatite at 46 million metric tons (Mt) grading 13.2% titanium dioxide (TiO_2) and resources of 1.8 billion metric tons grading 10.9% TiO_2 (Shaver and Lunceford, 1998). USGS data listed 722.7 Mt of carbonatite containing 2.87 Mt of rare-earth oxide (REO); 31,080 t thorium dioxide ($ThO_{2;}$) and 412,000 t of niobium pentoxide (Nb_2O_5) (Staatz, 1979; Van Gosen and Lowers, 2007). The deposit is presently owned by Teck Resources Ltd.

Idaho and Montana.—Investigation of the Lemhi Pass District of Idaho and Montana by the USGS delineated a combined indicated and inferred resource of 368,000 metric tons (t) REO and 277,000 t ThO_2 (Staatz, 1979). Thorium Energy Inc. conducted new exploration, and the Idaho Geological Survey expanded research and mapping in the region to delineate and identify additional thorium and rare-earth resources. Aueralitic thorite-xenotime, monazite, and brockite are the principal thorium and rare-earth minerals in the Lemhi Pass District. The veins are relatively enriched in the middle REE such as neodymium, samarium, europium, and gadolinium, as well as the heavy REE such as terbium to ytterbium and yttrium (Reed, 2007). Based on average percentages of individual REE by recent sampling and previous analyses by Idaho Energy Reserves Co. (a subsidiary of Idaho Power Co.) the Lemhi Pass District had resources, in order of increasing atomic number, 77,345 t of yttrium; 25,780 t of lanthanum; 69,980 t of cerium; 11,050 t of praseodymium; 66,296 t of neodymium; 40,515 t of samarium; 14,735 t of europium; 40,515 t of gadolinium; 1,840 of terbium; 14,730 t of dysprosium; 1,840 t each of holmium and ytterbium; and about 929 t or less each of erbium, thulium, and lutetium. Appreciable concentrations of copper, lead, zinc, and anomalous silver and gold occur in some of the thorium and rare-earth veins in the Lemhi Pass District. As byproducts, these elements could aid the economics of the deposits (Reed and Gillerman, 2008). The Idaho Geological Survey recently reported the discovery of a Cambrian syenite intrusive and suggested that mineralization could be associated with a buried Precambrian or Cambrian alkaline intrusive complex or both. Recent and ongoing work implied the potential for a larger mineralized system at depth similar in nature to peralkaline REE-thorium or iron ore-copper-gold-REE (IOCG) models of deposition (Gillerman and others, 2008). It was estimated that about 90% of the resources of the Lemhi Pass area were held by Thorium Energy.

The Diamond Creek region of Idaho has rare-earth and thorium resources that are exposed in a Precambrian granite intrusive. Similar to Lemhi Pass, the Diamond Creek mineralization has signatures of a peralkaline REE-thorium or iron-REE models of deposition as described by the Idaho Geological Survey. Monazite is the primary rare-earth mineral in the region with smaller amounts of bastnäsite and xenotime. Gold was also reported. Historical and recent investigations noted the potential for a larger, buried iron (Fe)-REE-thorium-apatite (FRETA) deposit, similar to the FRETA deposits in Mineville, NY, and Pea Ridge, MO. Recent analysis by Thorium

Energy corroborated earlier reported data by the USGS and the Atomic Energy Commission (AEC). Total rare earths averaged 0.80% and thorium averaged 0.12%. The USGS reported gold contents of 0.017, 0.07, and 0.348 ounces per short ton in three samples while the highest gold content reported by the AEC was 3 ounces per short ton from one vein. A preliminary estimate of the amounts of REE in the deposit are 22,400 t of cerium, 17,125 t of neodymium, 8,220 t of lanthanum, 5,480 t of samarium, 4,795 t of yttrium, 3,425 t of praseodymium, 3,425 t of gadolinium, 1,370 t of dysprosium and europium each, and a total of 685 t of the remaining heavy rare earths. The ratio of REE to thorium at Diamond Creek is approximately 8 to 1 (Rich Reed, President, Idaho Engineering & Geology, Inc., oral commun., 2008).

Missouri.—Seven major iron ore deposits are known in the southeastern Missouri iron metallogenic province. The deposit at Pea Ridge has rare-earth mineralization in four igneous breccia pipes and in apatite associated with magnetite. The principal rare-earth resources are in the breccia pipes, which contain primarily monazite and xenotime. Within the main iron ore deposit, rare earths occur as inclusions in apatite and as interstitial grains exsolved from apatite (Seeger, 2008). Other REE minerals at Pea Ridge are allanite, bastnäsite, britholite, tengerite-(Y), and synchysite-(Y). The deposit is owned by Upland Wings, Inc. and Wings Enterprises, Inc., with secured backing from Minmetals Inc. of Leonia, NJ (a subsidiary of China Minmetals Group of China) (Wings Enterprises Inc., undated).

Utah.—Great Western Minerals Group Ltd. (Saskatoon, Saskatchewan, Canada) announced it had acquired a 25% interest in the Deep Creek rare-earth bearing mineral sands deposit in Juab County, Utah, from Titan Mining Group. Great Western Minerals paid $4.3 million for the 25% share with exclusive rights to explore for REEs. The property covers 17,094 hectares near the community of Callao. The Deep Creek deposit is adjacent to power, rail, and roads (Great Western Minerals Group Ltd., 2007b).

Wyoming.—Rare Element Resources Ltd. (Vancouver, British Columbia, Canada) announced results from its initial 2007 drilling program at its Bear Lodge property in northeastern Wyoming. The first hole intersected four mineralized zones which had an aggregated thickness of 34.1 meters (m) (111.9 feet) with an average grade of 4.69% REO. The mineralized zones were within one upper oxidized iron oxide-manganese oxide-REE dike and three lower carbonatite dikes (Rare Element Resources Ltd., 2007b). Previous drilling by Hecla Mining Company intersected two zones of mineralized lithology with 12.3 m (40.3 feet) of oxidized carbonatite grading 9.56% REO and 14.0 m (45.9 feet) of nonoxidized carbonatite grading 5.65% REO (Rare Element Resources Ltd., 2007a).

Consumption

Data on domestic rare-earth consumption were developed by surveying various processors and manufacturers, evaluating import and export data, and analyzing U.S. Government stockpile shipments. Domestic apparent consumption of rare earths decreased in 2007 compared with that of 2006.

In 2007, yttrium consumption was estimated to have decreased to 676 t from 742 t in 2006**.** Yttrium information was based on data retrieved from the PIERS database. Yttrium compounds and metal were imported from several sources in 2007. Yttrium compounds and metal were imported from China (86%), Austria (8%), Japan (2%), Hong Kong (2%), and other (2%). The estimated use of yttrium, based on imports, was primarily in fluorescent lamp and CRT phosphors (89%), ceramics (10%), and specialty alloys (1%), with a minor amount for metal casting (Commonwealth Business Media, Inc., undated).

Stocks

The last of the U.S. Government stocks of rare earths in the National Defense Stockpile (NDS) was shipped in 1998. Periodic assessments of the national defense material requirements may necessitate the inclusion of rare earths, including scandium and yttrium, in the NDS at a future date.

Prices

The prices of most rare-earth materials increased in 2007 compared with those of 2006. The following estimates of prices were based on trade data from various sources or were quoted by rare-earth producers. Rhodia Group of France quoted REO prices, net 30 days, f.o.b. New Brunswick, NJ, or duty paid at point of entry, in effect at yearend 2007 are listed in table 3. All rare-earth prices remained nominal and subject to change without notice. The competitive pricing policies in effect in the industry caused most rare-earth product prices to be quoted on a daily basis from the producers and processors. The average price of imported rare-earth chloride was $3.33 per kilogram in 2007, a 160% increase from $1.28 per kilogram in 2006. Imported rare-earth metal prices averaged $9.90 per kilogram, an increase from the revised $8.28 per kilogram in 2006. Mischmetal and specialty mischmetals comprised most of the rare-earth metal imports. (Mischmetal is a natural mixture of rare-earth metals typically produced by metallothermic reduction of a mixed rare-earth chloride). When purchased in metric ton quantities, the price of praseodymium-neodymium (didymium) mischmetal at yearend 2007 decreased to ¥200 ($27.36) per kilogram from ¥220 ($28.12) per kilogram in 2006. The price of basic mischmetal increased to $7 to $8 per kilogram (metric ton quantities) in 2007 from $5 to $6 per kilogram in 2006, free-on-board (f.o.b.) China. Domestic prices were higher than Chinese prices because of shipping costs related to its classification as a pyrophoric hazardous material. The average price for imported cerium compounds, excluding cerium chloride, increased to $3.03 per kilogram in 2007 from $2.80 per kilogram in 2006. The primary cerium compound imported was cerium carbonate. Prices on world markets for mixed rare-earth carbonate and didymium oxide declined at yearend (China Rare Earth Information, 2007a).

The 2007 nominal price for bastnäsite concentrate was $6.61 per kilogram ($3.00 per pound) of contained lanthanide oxide, an increase from the $6.06 per kilogram ($2.75 per pound) of contained lanthanide oxide in 2006. The price of monazite concentrate, typically sold with a minimum 55% REO content, including contained thorium oxide, f.o.b., quoted in U.S. dollars and based on U.S. import data was unchanged at $480.00 per metric ton ($0.87 per kilogram of contained REO) in 2007. Prices for monazite remained depressed from their historical levels because the principal international rare-earth processors continued to process only thorium-free feed materials.

The nominal price range for neodymium metal for metric ton quantities, f.o.b. shipping point, increased to ¥245 ($33.52) per kilogram in December 2007 from ¥220 to ¥225 ($28.12 to $28.76) per kilogram in December 2006 (China Rare Earth Information, 2007c). Most NIB alloy was sold with additions of cobalt (typically 4% to 6%) or dysprosium (no more than 4%). The cost of the addition was based on pricing before shipping and alloying fees, with the average cobalt price increasing to $67.35 per kilogram in 2007. The cost would be about $0.67 per kilogram for each percentage point addition. The domestic price of dysprosium metal, adjusted for the foreign exchange rate, f.o.b. China, increased to ¥840 ($114.91) per kilogram at yearend 2007, from ¥870 to ¥890 ($111.22 to $113.78) per kilogram at yearend 2006. A cost of about $1.15 per kilogram for each percentage point would be incurred for the addition (China Rare Earth Information, 2007c).

No published prices were available for scandium. Yearend 2007 nominal prices for scandium oxide were compiled from information provided by several domestic suppliers and processors. Prices in 2007 were unchanged for the high-purity oxides but higher for the mid- to ultrahigh-purity oxides than those of 2006. The 2007 scandium oxide prices were as follows: 99% purity, $700 per kilogram; 99.9% purity, $1,400 per kilogram; 99.99% purity, $1,620 per kilogram; 99.999% purity, $2,540 per kilogram; and 99.9995% purity, $3,260 per kilogram.

Scandium metal prices for 2007 were unchanged from those of 2006 and were as follows: 99.9% purity, metal pieces, distilled dendritic, ampouled under argon, $325 per 2 grams; 99.9% purity, metal ingot, $131 per gram; scandium rod, 12.7-millimeter (mm) diameter, 99.9% (metals basis excluding tantalum), $497 per 10 mm; and 99.9% REO purity foil, 0.025-mm thick, ampouled under argon, 25 mm by 25 mm, $149 per sheet (Alfa Aesar, 2005, p. 2073).

Scandium compound prices in 2007 increased from those of 2006 and were as follows: scandium acetate, 99.9% purity, $73.10 per gram; scandium chloride hydrate, 99.9% purity, $74.70 per gram; scandium fluoride anhydrous powder, 99.99% purity, $108.00 per gram; scandium iodide anhydrous powder, 99.999% purity, $142.00 per gram; scandium nitrate hydrate, 99.9% purity, $77.80 per gram; and scandium sulfate pentahydrate, 99.9% purity, $76.00 per gram. Prices for standard solutions for calibrating analytical equipment were $35.40 per 100 milliliters of scandium atomic absorption standard solution (Aldrich Chemical Co., 2006, p. 2171–2172).

Prices for kilogram quantities of scandium metal in ingot form have historically averaged about twice the cost of scandium oxide, and higher purity distilled scandium metal prices have averaged about five times that price.

Foreign Trade

U.S. exports and imports of rare earths decreased in quantity in 2007 compared with those of 2006. Data in this section are based on gross weight, while data in the tables may be converted to equivalent REO content, as specified. U.S. exports totaled 7,610 t valued at $61.3 million, an almost 20% decrease in quantity and an 11% decrease in value compared with those of 2006 (table 4). Imports totaled 24,100 t gross weight valued at $128 million, an almost 10% decrease in quantity and a 23% increase in value compared with those of 2006 (table 5).

In 2007, U.S. exports of rare earths decreased in quantity in three out of four trade categories. Principal destinations in 2007, in descending order of quantity, were Japan, Canada, China, Germany, the United Kingdom, Mexico, Egypt, the Republic of Korea, the United Arab Emirates, Hong Kong, Estonia, and the Netherlands. The United States exported 1,230 t of rare-earth metals valued at $20.2 million, a 101% increase in quantity and a 190% increase in value compared with that of 2006. Principal destinations of the rare-earth metals, in descending order by quantity, were Japan, China, Hong Kong, Taiwan, the United Kingdom, and the Republic of Korea. Exports of cerium compounds, primarily for glass polishing and automotive catalytic converters, decreased in quantity by 27% to 1,470 t and decreased in value by 44% to $11.1 million. Major destinations, in descending order of quantity, were Egypt, Japan, Mexico, Austria, the United Kingdom, China, the Netherlands, and India.

Exports of inorganic and organic rare-earth compounds decreased by 52% to 1,300 t in 2007 from 2,700 t in 2006, and the value of the shipments decreased 20% to $13.8 million from $17.3 million. Most of the shipments, in descending order of quantity, were to Mexico, Estonia, Japan, the United Kingdom, the Republic of Korea, and Canada.

U.S. exports of ferrocerium and other pyrophoric alloys decreased 13% to 3,620 t valued at $16.2 million in 2007 from 4,180 t valued at $11.0 million in 2006. Principal destinations, in descending order of quantity, were Canada, Germany, China, United Arab Emirates, the United Kingdom, Saudi Arabia, Hong Kong, and Egypt.

In 2007, U.S. imports of compounds and alloys decreased in quantity for five out of the seven categories listed in table 5. China dominated the import market, especially for mixed and individual rare-earth compounds, followed by France, Japan, Russia, and Austria (figure 1). These five countries accounted for almost 98% of the domestic imports.

Imports of cerium compounds totaled 4,010 t valued at $12.1 million. The quantity of cerium compounds imported increased by 4% as a result of a slight increase in demand for automotive exhaust catalysts, and the value increased by 12%. China was the major supplier for the 12th consecutive year, followed by France, Japan, Austria, and the United Kingdom.

Imports of yttrium compounds that contained between 19 and 85 weight-percent yttrium (yttrium concentrate) decreased by 87% to 35.7 t in 2007, and the value decreased by 20% to $1.86 million. China was the leading supplier of yttrium compounds, followed by Japan and France.

Imports of individual rare-earth compounds, traditionally the major share of rare-earth imports, decreased by 7% compared with those of 2006. Rare-earth compound imports decreased to 13,200 t valued at $78.1 million. The major sources of individual rare-earth compounds, in decreasing order by quantity, were China, France, Japan, Russia, Austria, and the United Kingdom.

Imports of mixtures of REOs, other than cerium oxide, increased in quantity by 63% to 2,570 t from 1,570 t in 2006 and increased in value 71% to $14.9 million. The principal source of the mixed REOs was China, with much smaller quantities, in decreasing order of tonnage, imported from Italy, Japan, Estonia, and Germany.

Imports of rare-earth metals and alloys into the United States totaled 653 t valued at about $6.5 million in 2007, a 10% decrease in quantity compared with that of 2006. The value, however, increased 8% from that of the previous year. The principal rare-earth metal source was China, with much smaller amounts, in decreasing order of tonnage, from Japan, the United Kingdom, Russia, and Austria.

In 2007, imports of rare-earth chlorides decreased by 41% to 3,510 t, but the value increased 52% to $11.7 million. Supplies of rare-earth chloride, in descending order by quantity, came from China, with minor amounts from Hong Kong, the Republic of Korea, Taiwan, the United Kingdom, and Japan. In the United States, rare-earth chloride was used mainly as feed material for manufacturing fluid cracking catalysts.

Imports of ferrocerium and pyrophoric alloys decreased by 3% in quantity to 139 t valued at $2.3 million from 143 t valued at $2.1 million in 2006. Principal sources of these alloys, in descending order by quantity, were France, Austria, and China.

World Review

Australia.—Lynas Corporation Ltd. (Sydney, Australia) announced that it had commenced mining in July at its Mount Weld rare-earth deposit in Western Australia (Lynas Corporation Ltd., 2008, p. 10). The company planned to construct rare-earth plants in Australia to produce rare-earth concentrate and a plant in Malaysia to produce separated rare-earth products. Completion of the Malaysia plant was scheduled for the end of 2008 (Industrial Minerals, 2007).

Lynas planned to supply Rhodia Electronics and Catalysis with up to 10,500 metric tons per year (t/yr) of rare-earth concentrate or intermediate material for Rhodia's rare-earth solvent extraction plants in La Rochelle, France, and Liyang, Jiangsu Province, China.

Lynas also has ownership of the Crown Polymetallic project in Western Australia. The deposit is in the northern and northeastern regions of the Mount Weld carbonatite and contains additional mineral resources, including rare earths. The Crown Polymetallic deposit contains resources of 37.7 Mt of ore grading 0.024% tantalum oxide, 1.07% niobium oxide, 1.16% lanthanide oxides, 0.30% zirconium oxide, 42.8% iron oxide, 8.0% phosphate, 0.09% yttrium oxide, 11.3% aluminum oxide, and 4.0% titanium oxide (Lynas Corporation Ltd., 2008, p. 19).

Alkane Resources Ltd. announced total resources of 73.2 Mt at its Dubbo zirconia project (DZP) in New South Wales. The mineralized section of the DZP deposit is in the Toongi body, a remnant trachyte tuff that was emplaced in the early Jurassic Period, dating from 184 million years ago. The Toongi body is located within a vertical alkaline igneous intrusive with surface dimensions of 900 by 550 m. The resource at the DZP was 73.2 Mt and was split between the measured resource of 35.7 Mt, which extends from the surface to 55 m of depth and the inferred resource of 37.5 Mt, which extends from 55 to 100 m of depth. The measured and inferred grades in the trachyte were similar and contained 1.96% zirconium oxide, 0.04% hafnium oxide, 0.14% yttrium oxide, 0.46% niobium oxide, 0.03% tantalum oxide, 0.014% uranium oxide, and 0.75% REO (Alkane Resources Ltd., 2007). The Toongi Body comprises a very-fine grained mineral assemblage that contains eudialyte, armstrongite, natroniobite, bastnäsite and parasite, and very small amounts of ancylite-(Ce).

Alkane Resources planned to mine three principal products—a range of zirconium products, a niobium-tantalum concentrate, and an yttrium-rare earth concentrate. Alkane expected about 50% of the DZP's revenue to come from the range of zirconium products, 40% to 45% from the niobium-tantalum concentrate, and 5% to 10% from the yttrium-rare earth concentrate. Construction of a pilot plant to produce the three concentrates commenced in late 2007 at Lucas Heights, New South Wales, with completion expected in 2008 (Alkane Resources Ltd., 2008).

Arafura Resources continued to develop its Nolans rare earth-phosphate deposit in the Northern Territory. The Nolans deposit is located 135 km north-northwest of Alice Springs, which has the infrastructure to support a mining operation with a gas pipeline, rail access, roads, and provisions. Measured resources of the project are 5.1 Mt grading 3.2% REO, 13.5% phosphate, and 0.57% uranium oxide. Indicated resources at Nolans are 12.3 Mt grading 2.8% REO, 13.4% phosphate, and 0.43% uranium oxide (Arafura Resources Ltd., 2008). A prefeasibility study was published in November, showing a net present value estimate of $A1.8 billion after tax. A pilot plant was scheduled to be built between February and July 2008. Based on a prefeasibility study, annual production would generate four products during a 20 year mine life—20,000 t of REO; 150,000 t of phosphoric acid; 400,000 t of calcium chloride; and 150 t of uranium oxide. Production at the Nolans project was scheduled to be operating at 50% of capacity by 2011, scaling up to 100% of capacity by 2013 (Arafura Resources Ltd., 2007).

Brazil.—Reserves of rare earths were 48,000 t contained in various types of deposits, including alkaline intrusives, carbonatites, fluvial or stream placers, lateritic ores, and marine placers. The reserves, comprising measured and indicated quantities of contained rare-earth in monazite, were distributed in deposits primarily in the States of Minas Gerais (11,730 t), Bahia (4,333 t), and Rio de Janeiro (1,874 t) (Departmento Nacional de Produção Mineral, 2007, p. 48, 145, 224). Brazil produced 1173 t of monazite in 2007, an increase from 958 t in 2006 (Fabricio da Silva, 2008).

Canada.—Rare-earth exploration and drilling was ongoing at several deposits in the Northwest Territories and Saskatchewan.

The Thor Lake project is a multielement mineral deposit located northeast of Yellowknife in the Northwest Territories. Avalon Ventures Ltd. continued to explore the rare-metal peralkaline igneous intrusion. Six zones of mineralization in the ring complex host beryllium, niobium, REE (including yttrium), tantalum, and zirconium. In 2007, a drilling program confirmed the presence of two mineralized alteration zones that vary in thickness from 10 to 35 m and have been traced laterally 1,100 m, with potential for additional expansion (Avalon Ventures Ltd., 2007c). Two of the six known mineralized zones were studied, the North T Zone and the Lake Zone deposits. Indicated mineral resources of the North T Zone were 1.1 Mt with 0.71% REO, 0.48% beryllium oxide, and 0.53% niobium oxide. Inferred resources in the Lake Zone of the Thor Lake deposit were 375 Mt grading 0.41% REO, 0.014% tantalum oxide, 0.22% niobium oxide, and 1.19% zirconium oxide (Avalon Ventures Ltd., 2007b).

Rare-earth minerals at Thor Lake include allanite, bastnäsite, fergusonite, xenotime, and lesser amounts of monazite, parasite, and synchysite. As of January, inferred mineral resources at Thor Lake, based on a cutoff grade of 0.05% yttrium oxide, were 83.224 Mt of ore grading 0.99% REO, 0.025% tantalum oxide, 0.31% niobium oxide, and 1.96% zirconium oxide. Avalon noted that large parts of the deposit remain untested and planned additional drilling and testing to delineate the ore body. Fergusonite, a rare-earth-iron-tantalum-niobium-titanate mineral, was analyzed for its REO content and was found to contain, 29.05% yttrium, 0.30% lanthanum, 4.40% cerium, 1.70% praseodymium,15.6% neodymium, 10.4% samarium, 1.60% europium, 14.3% gadolinium, 1.80% terbium, 9.80% dysprosium, 1.20% holmium, 4.10% erbium, 0.70% thulium, 4.40% ytterbium, and 0.7% lutetium (Avalon Ventures Ltd., 2007c).

Avalon announced the closing of a private placement for 7,610,000 units and 2,750,000 flow-through common shares generating Can$16.9 million in gross proceeds. Proceeds were planned for continued exploration and development projects, with priority for the Thor Lake rare-metals project. Funding of up to Can$5 million was allocated for additional drilling and metallurgical studies at the Thor Lake deposit (Avalon Ventures Ltd., 2007a).

Avalon received land use permits to proceed with drilling in July. A total of 3,000 m of drilling was planned in 20 drill holes to delineate high-grade rare-earth mineralized sections in the southern part of the Lake Zone. Prior drilling in the area intersected a 5-m interval grading 4.11% lanthanide oxide and 0.70% yttrium oxide (Avalon Ventures Ltd., 2007d).

Great Western Minerals' preliminary assessment on the recovery of the mineralized material at Hoidas Lake was completed by Melis Engineering Ltd. in cooperation with SGS Lakefield Research of Canada. Initial studies proposed a whole-rock hydrochloric acid leach to produce a rare-earth chloride feed for separation. The leach achieved an average 82% REE recovery from a combined apatite and allanite concentrate. Previous metallurgical tests had recovered up to 96% REE from an allanite-enriched concentrate. The process was designed for a zero discharge of water to the environment. A 13.8 t bulk sample of REE mineralized material was produced for testing in a pilot plant planned at the deposit site (Great Western Minerals Group Ltd., 2007e).

Great Western Minerals announced it had offered for sale a nonbrokered financial instrument of 7.5 million common flow-through shares. The funds generated by the sale of the shares will be used to fund a drilling program at the Hoidas Lake rare earth element project in northern Saskatchewan and initiate construction of a pilot plant in 2008 (Great Western Minerals Group Ltd., 2007c).

Resource estimates for Hoidas Lake increased as of January 31 according to Great Western Minerals (2007f). Measured and indicated resources increased by 108% to 1.15 Mt from 553,000 t in 2006. The resource grade also increased to 2.36% total REE in 2007 from 2.43% total REE. The Hoidas Lake resource model was based on 84 drill holes in a pattern extending over 700 m. Core drilling totaling 7,761 m provided 2,628 samples that were assayed. The drilling program determined REE mineralization was open along strike and at depth. An expansion of the drilling program was expected to commence in 2008 and include 6,000 to 8,000 m of core drilling. The drilling was planned to target areas identified by geophysics, including VLF-EM and magnetic surveys, as potential ore-bearing strata (Great Western Minerals Group Ltd., 2007a).

An alternative process for producing a concentrate that would reduce chemical use was developed by SGS Lakefield for the Hoidas Lake mineralized material. Using an optical sorting technique, the ore is separated into two or more streams based on mineral characteristics. Once crushed to an optimum size, the ore is spread out on a conveyor belt then free falls through an optical scanner that scans each particle and stores information regarding the characteristics of each particle as it moves through the sorter. A microprocessor determines which process stream each particle will take or whether it will be rejected as gangue. The sorter, reportedly, was able to discern ore particles sufficiently to direct 92% of the REE minerals to 60% of the retained material. The optical sorting would significantly reduce the costs of energy, equipment, reagents, and transportation (Great Western Minerals Group Ltd., 2007d).

Rare Earth Metals Corp. (North Vancouver, British Columbia) announced the results of its initial drilling program at its rare-earth property at Eden Lake, Manitoba. The program drilled six holes totaling 765 m of which four intersected carbonatite veins and lenses with rare-earth bearing mineralization. One drill core encountered apatite-bearing carbonatite in a 50 m section of altered rock. Further drilling was needed to delineate the extent of the carbonatite intrusion (Rare Earth Metals Corp., 2006).

China.—Production of rare-earth concentrates in China was estimated to be 120,800 t of REOs in 2007, a decrease from the 133,000 t reported in 2006 (Metal-Pages Ltd., 2008). China consumed 72,550 t of equivalent REO in a variety of applications in 2007, an increase from the 62,800 t consumed in 2006. The distribution of rare-earth consumption in China was as follows: permanent magnets, 30.7%; metallurgical applications, 15.2%; petrochemical catalysts, 10.4%; polishing powders, 10.2%; hydrogen storage alloys for batteries, 8.5%; phosphors for fluorescent lighting, flat panels, color televisions, 6.2%; glass and ceramic additives, 4.5%; automotive catalysts, 3.7%; and miscellaneous applications, 10.6% (China Rare Earth Information, 2008).

Production of separated and smelted rare-earth products was 126,000 t in 2007, a decrease from the 157,000 t produced in 2006 (Metal-Pages Ltd., 2008). Mine production was primarily from bastnäsite and other rare-earth minerals mined in Inner Mongolia and bastnäsite from Sichuan Province, while ion adsorption ore was produced primarily in the southeastern Provinces of Jiangxi, Guangdong, and Fujian (Grauch and Mariano, 2008).

China exported 54,393 t of rare-earth compounds and metals in 2007, a slight increase from the 52,230 t exported in 2006. The total value of exports in 2007 was $764 million. China exported 41,893 t of rare-earth compounds valued at $457 million in 2007. Exports of rare-earth compounds were as follows: cerium oxide, 2,898 t; cerium hydroxide, 1,062 t; cerium carbonate, 10,885 t; other cerium compounds, 1,892 t; yttrium oxide, 2,658 t; lanthanum oxide, 7,893 t; neodymium oxide, 1,082 t; europium oxide, 47 t; dysprosium oxide, 178 t; and terbium oxide, 292 t (Roskill's Letter from Japan, 2008g).

In 2007, China exported 12,500 t of rare-earth metals valued at $307 million. Exports of rare-earth metals, primarily used in NIB magnets and fluorescent phosphors, were 3,300 t of neodymium metal; 55.9 t of dysprosium metal; and 14.3 t of terbium metals. Exports of battery-grade mischmetal were 748 t in 2007, a decrease from 1,015 t in 2006.

China produced 50,800 t of permanent magnets in 2007, an increase from 41,350 t produced in 2006. The average growth rate of permanent magnets between 2005 and 2007 was 20.1% (China Rare Earth Information, 2008). Production of NIB permanent magnets in China, based on finished products, was estimated to be 70,000 t in 2007, a substantial increase from 40,900 t in 2006. Total REO equivalent consumed in the production of the NIB magnets was 22,300 t (China Rare Earth Information, 2009a).

China produced 18,600 t of hydrogen storage materials in 2007, an increase from 15,000 t produced in 2006. Of the 18,600 t produced, China exported 748 t of mischmetal for NiMH rechargeable batteries, with most of that quantity (720 t) shipped to Japan (Roskill's Letter from Japan, 2008g). Exports of mischmetal were lower in 2007 compared with the 1,015 t exported in 2006.

About one-third of all rare earths produced in China are consumed by the iron and steel industries. Principal products were rare earth-ferrosilicon (rare-earth silicide) and rare earth-magnesium-ferrosilicon, which consumed 25,000 t of equivalent REO. Production in 2006, the latest available data, was 180,000 t of rare-earth magnesium silicon alloy and 50,000 t of rare-earth silicide (gross weight). Rare-earth silicide production was located in various areas of China including Inner Mongolia Autonomous Region, 22,000 t; Sichuan Province, 14,000 t; Shanxi Province, 5,000 t; Henan Province, 4,000 t; and other provinces, 5,000 t (China Rare Earth Information, 2009b).

In 2007, China produced 4,490 t of REO in phosphors for application in electroluminescent phosphors, flat panel displays, fluorescent lighting, long-afterglow phosphors, and various other uses. In 2007, rare-earth phosphors represented 6.2% of total rare-earth consumption (China Rare Earth Information, 2009a). Total rare-earth phosphor production, which includes other elements in the phosphor material, was 8,481 t. Phosphors were produced for trichromatic lamps, 6,400 t; CRT color televisions, 1,000 t; long afterglow phosphors, 900 t; and other phosphors, 181 t. The use of phosphors for trichromatic lamps doubled from the 2006 level (China Rare Earth Information, 2008).

China enacted export tariffs on various rare-earth products in 2007 to increase prices and discourage exports. Rare-earth export tariffs for 2007 were 10%. Tariffs were specific to essentially all export products and included, by increasing Chinese tariff number, rare-earth metallic minerals (uncalcined iron minerals with particle size less than 0.8 mm), cerium oxide, cerium hydroxide, cerium carbonate, other cerium compounds, yttrium oxide, lanthanum oxide, neodymium oxide, europium oxide, other REOs, mixed rare-earth chlorides, nonmixed rare-earth chlorides, rare-earth fluorides, mixed rare-earth carbonates, nonmixed rare-earth carbonates, other compounds of rare-earth metals, yttrium, and scandium (China Rare Earth Information, 2007b).

France.—Rhodia organized its corporation into seven enterprises with the rare-earth unit, Rhodia Electronics and Catalysis, and the performance silica unit, Rhodia Silica Systems, under Rhodia Silcea. In 2007, Rhodia Silcea had sales of €463 million (Rhodia Group, 2007b, p. 40).

Rhodia also produced rare-earth-containing catalysts for automotive emission applications, fluid cracking catalysts for oil refining, desulfurization catalysts, styrene monomer catalysts, chemical catalysts for oxidation, dehydrogenation, and hydrogenation, and polymerization catalysts to promote the drying of paints and produce environmentally friendly tires. Rhodia's other operations produced finished rare-earth products from imported materials at its plant in Freeport, TX, and produced high-purity rare earths at its separation plant in La Rochelle. Additional rare-earth capacity was operated through Anan Kasei in Kobe, Japan.

Rhodia Silcea announced the acquisition of an alumina washcoat business from W.R. Grace. The acquisition will complement Rhodia's existing rare-earth catalysts used in automotive emission controls and catalytic converters (Rhodia Group, 2007a).

Japan.—Japan imported 39,700 t of refined rare earths in 2007, a decrease from the revised 41,400 t imported in 2006. China continued to be the leading source of rare-earth imports for Japan with 35,800 t of refined and mixed concentrates in 2007, a decrease from 45,000 t in 2006. Production of sintered NIB permanent magnets increased to the range of 10,500 to 12,000 t in 2007, based on the production of 17,500 to 20,000 t of magnetic alloys. Magnet production consumed an estimated 4,700 to 5,400 t of neodymium metal and 700 to 800 t of dysprosium metal. There are three Japanese NIB alloy producers, one of which uses neodymium exclusively, and the other two use didymium, a mixture of mostly neodymium and praseodymium.

Japan produced rare earths from imported ores and intermediate raw materials. Imports of refined rare-earth products were 40,564 t, a 3% decrease from the revised 41,955 t imported in 2006. Japanese imports of refined rare-earth products decreased for cerium compounds, cerium oxide, rare-earth compounds, and rare-earth metals, and increased for ferrocerium, lanthanum oxide, and yttrium oxide (Roskill's Letter from Japan, 2008h).

Japanese imports of rare earths in 2007 were as follows: rare-earth metals, 9,320 t; cerium oxide, 11,012 t; cerium compounds other than cerium oxide, 8,015 t; rare-earth compounds, 6,261 t; lanthanum oxide, 3,310 t; and yttrium oxide, 1,805 t. China continued to be the leading source of rare-earth imports for Japan. Japanese imports of rare earths from China were as follows: rare-earth metals, 9,296 t; cerium oxide, 9,580 t; cerium compounds other than cerium oxide, 6,373 t; rare-earth compounds, 5,703 t; lanthanum oxide, 3,110 t; and yttrium oxide, 1,720 t (Roskill's Letter from Japan, 2008f).

Japan produced 8,575 t of various rare-earth metals in 2007, a 4% increase from the 8,227 t produced in 2006 (Roskill's Letter from Japan, 2008e).

Being the leading producer of rechargeable batteries in the world, Japan produced 305.4 million units of rare-earth-containing NiMH batteries in 2007, a 7% decrease from the revised 327.3 million units produced in 2006 (Roskill's Letter from Japan, 2008b). The value of NiMH batteries in 2007, however, increased by 35% from that of the previous year. The increase in price was the result of increased cost for the rare earths, especially mischmetal, and the increased cost for nickel. The primary use of NiMH batteries in Japan was in portable rechargeable electric tools. NiMH battery shipments in 2007 were 352 million units, an increase from 331 million units shipped in 2006 (Roskill's Letter from Japan, 2008a).

In 2007, shipments of consumer electronics containing rare-earths were estimated to be 625,000 color televisions; 966,000 plasma display panel televisions; 7.4 million LCD televisions; and 5.5 million DVD players and recorders (Roskill's Letter from Japan, 2008c).

Japanese production of sintered NIB magnets in 2007 was estimated to be 10,500 to 12,000 t, an increase from the revised 10,000 t produced in 2006. Magnet production consumed an estimated 3,000 t of neodymium metal and 360 t of dysprosium metal (Roskill's Letter from Japan, 2008h). Japanese production of rare-earth bonded magnets was estimated to be 600 t in 2007, an increase from the 450 t produced in 2006 (Roskill's Letter from Japan, 2008d).

Malawi.—Lynas announced it would commence development of the Kangankunde Hill rare-earth deposit. The deposit has an inferred resource of 107,000 t grading 4.24% REO with a very low thorium content. A pilot plant was completed to produce a gravity concentrate (Lynas Corporation Ltd., 2007). The Kangankunde Hill deposit has monazite in carbonatite dikes and veins and has an average thoria content of 0.08%.

Malaysia.—Lynas announced that the estimated cost to build a rare-earth separation plant in Malaysia would be $220 million, an increase of $166.5 million from the estimated cost to build the plant in China in 2006. The proposed site for the plant is on the east coast of Malaysia near Kuantan in the State of Pahang (Lynas Corporation Ltd., 2007). The separation plant would process rare-earth concentrate produced from Lynas' rare-earth deposit at Mount Weld. The advantages of the new location were a potential 10-year tax free period (in process), an infrastructure with deep-water port facilities and existing utilities, a skilled labor force fluent in English and Mandarin, and the availability of chemical reagent manufacturers adjacent to the site.

Zambia.—The Nkombwa Hill carbonatite in the Isoka District of northeastern Zambia has an average apatite grade of 15 weight percent. The primary rare-earth minerals at Nkombwa Hill are bastnäsite and monazite with lesser amount of daqingshanite-(Ce) and rare-earth bearing isokite (Witika, 2006).

Outlook

Rare-earth use in automotive pollution control catalysts, permanent magnets, and rechargeable batteries are expected to continue to increase as future demand for conventional and hybrid automobiles, computers, electronics, and portable equipment grows. Rare-earth markets are expected to require greater amounts of higher purity mixed and separated products to meet the demand. Demand for cerium and neodymium for use in automotive catalytic converters and catalysts for petroleum refining is expected to expand by 6% to 8% per year for the next 5 years if the world economy remains strong. Rare-earth magnet demand is expected to grow by 10% to 16% per year through 2012, increasing to 45,000 to 50,000 t by 2012 (Kingsnorth, 2008). Future growth is expected for rare earths in rechargeable NiMH batteries, especially those used in hybrid vehicles, increasing to 10,000 to 20,000 t of REO by 2012. NiMH demand is also expected to grow (moderated by demand for lithium-ion batteries) with increased use in portable equipment, such as cellular telephones, laptop computers, portable DVD, CD, and MP3 players, and digital cameras and camcorders. Increased rare-earth use is 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. Future growth potential is projected for rare-earth alloys employed in magnetic refrigeration (Gschneidner and Pecharsky, 2008).

World reserves are sufficient to meet forecast world consumption well into the 21st century. Several very large rare-earth deposits in Australia and China (for example, Mianning in China and Mount Weld in Australia) have yet to be fully developed. Existing production is currently not sufficient to meet world demand, and shortages exist for neodymium and dysprosium for magnet alloys and europium and terbium for phosphors. Although the Mountain Pass deposit in the United States contains sufficient resources to meet domestic demand for light-group REEs, the deposit does not contain sufficient heavy-group REEs to meet demand for those elements.

All domestic and most foreign companies have shifted away from using naturally occurring radioactive rare-earth ores. This trend has a negative impact on monazite-containing mineral sands operations worldwide, causing mine closures and reduced revenues. Long-term demand for monazite, however, is expected to increase because of the minerals abundant supply and low-cost byproduct recovery. Thorium's use as a nonproliferative nuclear fuel is considered a likely substitute for uranium in the future, especially in a world concerned with the threat of nuclear terrorism. If consumption of thorium increases, monazite could resume its role as a major source of rare earths. Storage requirements and permitting to dispose of radioactive waste products in the United States are expensive, severely limiting domestic use of low-cost monazite and other thorium-bearing rare-earth ores.

Rare-earth producers outside of China, generating less than 5% of the world's supply, were expected to continue to struggle in competition with China's lower wages, inexpensive utilities, and less restrictive environmental and permitting requirements. China was expected to remain a major world rare-earth supplier. Increasing prices, export limits, rising demand within China, and a ban on new mining permits were expected to make rare-earth deposits outside of China more economic. Economic growth in several developing countries could provide new and potentially large markets in Eastern Europe, India, and Southeast Asia.

The long-term outlook appears to be for an increasingly competitive and diverse group of rare-earth suppliers. As research and technology continue to advance the knowledge of rare earths and their interactions with other elements, the economic base of the rare-earth industry is expected to continue to grow. New applications are expected to continue to be discovered and developed, especially in areas that are considered essential, such as energy and defense.

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TABLE 1

SALIENT U.S. RARE EARTH STATISTICS[1]

		2003	2004	2005	2006	2007
Production of rare-earth concentrates, rare-earth oxide (REO) basis[e, 2]	metric tons	--	--	--	--	--
Exports, REO basis:						
Cerium compounds	do.	1,910	2,280	2,220	2,010	1,470
Rare-earth metals, scandium, yttrium	do.	730	1,010	636	611	1,230
Rare-earth compounds, organic or inorganic	do.	1,790	4,800	2,070	2,700	1,300
Ferrocerium and pyrophoric alloys	do.	2,880	3,720	4,320	3,710	3,210
Imports for consumption, REO basis:[e]						
Cerium compounds	do.	2,430	1,880	2,170	2,590	2,680
Ferrocerium and pyrophoric alloys	do.	102	105	130	127	123
Metals, alloys, oxides, other compounds	do.	14,100	15,300	13,000	16,000	14,900
Prices, yearend:						
Bastnäsite concentrate, REO basis[e]	dollars per kilogram	$5.51	$5.51	$5.51	$6.06 [r]	$6.61
Monazite concentrate, REO basis[e]	do.	$0.73	$0.73	$0.73	$0.73	$0.73
Mischmetal, metal basis[3]	do.	$10.00	$10.00	$10.00	$10.00	$10.00

do Ditto. [r]Revised. [e]Estimated. -- Zero.

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

[2] Includes only the rare earths derived from bastnäsite as obtained from Molycorp, Inc.

[3] Source: Hefa Rare Earths Canada Co. Ltd., Vancouver, British Columbia, Canada.

TABLE 2

RARE EARTH CONTENTS OF MAJOR AND POTENTIAL SOURCE MINERALS[1]

(Percentage of total rare-earth oxide)

	Bastnäsite		Monazite			
Rare earth	Mountain Pass, CA, United States[2]	Bayan Obo, Inner Mongolia, China[3]	North Capel, Western Australia[4]	North Stradbroke Island, Queensland, Australia[5]	Green Cove Springs, FL, United States[6]	Nangang, Guangdong, China[7]
Cerium	49.10	50.00	46.00	45.80	43.70	42.70
Dysprosium	trace	0.1	0.7	0.60	0.9	0.8
Erbium	trace	trace	0.2	0.2	trace	0.3
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
Holmium	trace	trace	0.053	0.1	0.11	0.12
Lanthanum	33.20	23.00	23.90	21.50	17.50	23.00
Lutetium	trace	trace	trace	0.01	trace	0.14
Neodymium	12.00	18.50	17.40	18.60	17.50	17.00
Praseodymium	4.34	6.20	5.00	5.30	5.00	4.10
Samarium	0.8	0.8	2.53	3.10	4.90	3.00
Terbium	trace	0.1	0.035	0.3	0.26	0.7
Thulium	trace	trace	trace	trace	trace	trace
Ytterbium	trace	trace	0.1	0.1	0.21	2.40
Yttrium	0.10	trace	2.40	2.50	3.20	2.40
Total	100	100	100	100	100	100

	Monazite—Continued		Xenotime		Rare earth laterite	
	Eastern coast, Brazil[8]	Mount Weld, Australia[9]	Lahat, Perak, Malaysia[2]	Southeast Guangdong, China[10]	Xunwu, Jiangxi Province, China[11]	Longnan, Jiangxi Province, China[11]
Cerium	47.00	51.00	3.13	3.00	2.40	0.4
Dysprosium	0.4	0.2	8.30	9.10	trace	6.70
Erbium	0.1	0.2	6.40	5.60	trace	4.90
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
Holmium	trace	0.1	2.00	2.60	trace	1.60
Lanthanum	24.00	26.00	1.24	1.20	43.4	1.82
Lutetium	not determined	trace	1.00	1.80	0.1	0.4
Neodymium	18.50	15.00	1.60	3.50	31.70	3.00
Praseodymium	4.50	4.00	0.5	0.6	9.00	0.7
Samarium	3.00	1.80	1.10	2.20	3.90	2.80
Terbium	0.1	0.1	0.9	1.20	trace	1.30
Thulium	trace	trace	1.10	1.30	trace	0.7
Ytterbium	0.02	0.1	6.80	6.00	0.3	2.50
Yttrium	1.40	trace	61.00	59.30	8.00	65.00
Total	100	100	100	100	100	100

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

[2] 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.

[3] 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.

[4] Westralian Sands Ltd., 1979, Product specifications, effective January 1980: Capel, Australia, Westralian Sands Ltd. brochure, 8 p.

[5] Analysis from Consolidated Rutile Ltd.

[6] Analysis from RGC Minerals (USA), Green Cove Springs, FL.

[7] 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.

[8] Krumholz, Pavel, 1991, Brazilian practice for monazite treatment: Symposium on Rare Metals, Sendai, Japan, December 12–13, 1991, Proceedings, p. 78–82.

[9] 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.

[10] Nakamura, Shigeo, 1988, China and rare metals—Rare earth: Industrial Rare Metals, no. 94, May, p. 23–28.

[11] Introduction to Jiangxi rare-earths and applied products, 1985, Jiangxi Province brochure, 42 p.

TABLE 3
RARE-EARTH OXIDE PRICES IN 2007

Product (oxide)	Purity (percentage)	Standard package quantity (kilograms)	Price (dollars per kilogram)
Cerium	96.00	20	50.00
Do.	99.50	20	65.00
Dysprosium	99.00	20	160.00
Erbium	96.00	20	165.00
Europium	99.99	20	1,200.00
Gadolinium	99.99	20	150.00
Holmium	99.90	10	750.00
Lanthanum	99.99	20	40.00
Lutetium	99.99	1 or 10	3,500.00
Neodymium	95.00	20	60.00
Praseodymium	96.00	20	75.00
Samarium	99.90	20	200.00
Do.	99.99	20	350.00
Scandium	99.99	NA	NA
Terbium	99.99	20	850.00
Thulium	99.90	5	2,500.00
Ytterbium	99.00	10	450.00
Yttrium	99.99	20	50.00

Do Ditto. NA Not available.

Source: Rhodia Electronics & Catalysis, Inc.

TABLE 4

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

	2006		2007	
Category[2] and country	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Cerium compounds (2846.10.0000):				
Australia	20	$7,040	137	$12,000
Austria	139,000	739,000	104,000	687,000
Belgium	2,400	25,200	1,970	31,100
Brazil	78,700	419,000	60,900	266,000
Canada	8,790	105,000	10,400	152,000
China	26,900	365,000	95,500	918,000
Egypt	270,000	1,220,000	252,000	882,000
France	35,100	274,000	30,800	271,000
Germany	56,200	289,000	34,900	294,000
Hong Kong	58,300	657,000	52,300	521,000
India	580,000	3,050,000	82,600	490,000
Japan	144,000	1,060,000	220,000	1,920,000
Korea, Republic of	19,100	76,700	3,520	45,500
Mexico	178,000	739,000	152,000	749,000
Netherlands	92,100	398,000	94,900	579,000
Singapore	13,700	99,000	4,440	31,100
Taiwan	19,100	156,000	24,600	195,000
United Kingdom	14,700	200,000	103,000	888,000
Other	269,000	9,960,000	139,000	2,200,000
Total	2,010,000	19,800,000	1,470,000	11,100,000
Total estimated equivalent rare-earth oxide (REO) content	2,010,000	19,800,000	1,470,000	11,100,000
Rare-earth compounds[3] (2846.90.0000):				
Argentina	15,400	344,000	82	4,140
Austria	4,640	78,000	--	--
Brazil	100,000	1,080,000	40,500	308,000
Canada	428,000	1,080,000	114,000	689,000
China	125,000	1,350,000	82,000	880,000
Colombia	--	--	16,000	47,300
Estonia	1,310,000	577,000	179,000	154,000
France	43,500	732,000	28,000	670,000
Germany	5,320	152,000	8,280	446,000
Guatemala	600	24,000	160	5,270
Hong Kong	5,490	66,800	19	37,400
India	6,910	45,900	334	14,600
Italy	38,600	140,000	7,490	34,000
Japan	59,900	7,580,000	163,000	6,590,000
Korea, Republic of	117,000	1,690,000	119,000	731,000
Mexico	108,000	869,000	269,000	1,510,000
Netherlands	20,700	218,000	1,620	31,400
Poland	2,500	34,000	--	--
Singapore	12,000	114,000	2,990	68,900
Taiwan	14,300	345,000	15,700	461,000
United Kingdom	126,000	385,000	130,000	612,000
Other	161,000	742,000	119,000	521,000
Total	2,700,000	17,300,000	1,300,000	13,800,000
Total estimated equivalent REO content	2,700,000	17,300,000	1,300,000	13,800,000

See footnotes at end of table.

TABLE 4—Continued

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

	2006		2007	
Category[2] and country	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Rare-earth metals, including scandium and yttrium (2805.30.0000):				
Belgium	2,010	$99,800	6,350	$253,000
Brazil	--	--	100	15,500
China	19,100	123,000	127,000	2,100,000
Germany	6,990	544,000	21,000	432,000
Hong Kong	--	--	104,000	250,000
India	4,450	204,000	7,460	315,000
Indonesia	--	--	--	--
Japan	569,000	5,380,000	665,000	10,200,000
Mexico	875	51,900	1,510	75,200
Switzerland	17	14,000	25	17,000
Taiwan	--	--	98,500	2,610,000
Other	8,590	536,000	194,000	3,900,000
Total	611,000	6,960,000	1,230,000	20,200,000
Total estimated equivalent REO content	733,000	6,960,000	1,470,000	20,200,000
Ferrocerium and other pyrophoric alloys (3606.90.0000):				
Argentina	43,600	65,800	60,000	216,000
Australia	12,600	997,000	562	26,300
Bahrain	23,900	26,100	25,100	26,800
Canada	827,000	2,010,000	689,000	2,220,000
China	3,200	9,860	462,000	4,490,000
Cyprus	17,200	26,600	--	--
Egypt	140,000	154,000	126,000	126,000
France	78,100	201,000	78,100	189,000
Germany	1,430,000	2,020,000	649,000	950,000
Greece	57,500	99,300	44,200	73,400
Hong Kong	142,000	483,000	127,000	257,000
Israel	98,800	112,000	75,900	559,000
Japan	24,900	571,000	30,500	1,670,000
Jordan	18,100	18,500	--	--
Korea, Republic of	91,400	1,190,000	115,000	1,580,000
Kuwait	--	--	49,600	55,000
Mexico	34,600	146,000	76,000	351,000
Morocco	39,400	40,500	63,000	66,300
Netherlands	303,000	1,080,000	74,200	217,000
New Zealand	--	--	13,400	20,300
Portugal	--	--	7,530	16,600
Russia	81,800	119,000	59,600	87,300
Saudi Arabia	45,000	70,600	131,000	200,000
Singapore	2,470	80,200	1,680	45,200
Taiwan	308	88,700	--	--
United Arab Emirates	218,000	283,000	274,000	298,000
United Kingdom	310,000	620,000	263,000	2,130,000
Other	140,000	514,000	124,000	323,000
Total	4,180,000	11,000,000	3,620,000	16,200,000
Total estimated equivalent REO content	3,710,000	11,000,000	3,210,000	16,200,000

[r] Revised. -- Zero.

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

[2] Harmonized Tariff Schedule of the United States category numbers.

[3] Inorganic and organic.

Source: U.S. Census Bureau.

TABLE 5

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

	2006		2007	
Category[2] and country	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Cerium compounds, including oxides, hydroxides, nitrates, sulfate chlorides, oxalates (2846.10.0000):				
Austria	36,400	$235,000	60,600	$356,000
China	3,540,000	6,350,000	3,630,000	7,770,000
France	73,600	884,000	121,000	1,080,000
Hong Kong	64,000	127,000	16,500	20,600
Japan	135,000	3,090,000	88,700	2,350,000
Korea, Republic of	2,760	26,700	2,520	24,700
United Kingdom	159	20,700	48,000	149,000
Other	10,700	86,800	45,000	399,000
Total	3,870,000	10,800,000	4,010,000	12,100,000
Total estimated equivalent rare-earth oxide (REO) content	2,590,000	10,800,000	2,680,000	12,100,000
Yttrium compounds content by weight greater than 19% but less than 85% oxide equivalent (2846.90.4000):				
China	273,000	1,090,000	29,800	310,000
France	420	26,000	815	40,100
Japan	5,850	1,180,000	5,070	1,510,000
Other	34	30,000	--	--
Total	279,000	2,320,000	35,700	1,860,000
Total estimated equivalent REO content	168,000	2,320,000	21,400	1,860,000
Rare-earth compounds, including oxides, hydroxides, nitrates, other compounds except chlorides (2846.90.8000):				
Austria	85,200	3,510,000	109,000	4,210,000
Canada	76	36,800	3,030	105,000
China	12,500,000	37,100,000	11,700,000	44,800,000
France	618,000	11,700,000	519,000	15,000,000
Germany	551	145,000	1,550	359,000
Hong Kong	37,000	257,000	220	5,040
Japan	685,000	11,800,000	421,000	10,900,000
Russia	145,000	721,000	346,000	547,000
South Africa	--	--	12,700	120,000
United Kingdom	5,780	749,000	68,300	112,000
Other	600	213,000	40,400	1,970,000
Total	14,100,000	66,300,000	13,200,000	78,100,000
Total estimated equivalent REO content	10,600,000	66,300,000	9,900,000	78,100,000
Mixtures of REOs except cerium oxide (2846.90.2010):				
Austria	9,320	154,000	--	--
China	1,520,000	4,340,000	2,510,000	9,090,000
Germany	407	14,900	822	43,200
Ireland	--	--	--	--
Italy	30,800	4,110,000	44,700	5,420,000
Japan	6,480	60,700	7,790	310,000
Russia	46	17,000	11	14,300
United Kingdom	10,300	47,400	67	30,400
Other	--	--	4,000	23,000
Total	1,570,000	8,740,000	2,570,000	14,900,000
Total estimated equivalent REO content	1,570,000	8,740,000	2,570,000	14,900,000

See footnotes at end of table.

TABLE 5—Continued

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

Category[2] and country	2006 Gross weight (kilograms)	2006 Value	2007 Gross weight (kilograms)	2007 Value
Rare-earth metals, whether intermixed or alloyed (2805.30.0000):				
Austria	159	$29,800	616	$138,000
China	672,000	4,700,000	636,000	5,710,000
Germany	3	6,610	2	2,250
Japan	30,900	701,000	8,470	168,000
Russia	402	56,900	619	112,000
United Kingdom	19,100	434,000	8,100	333,000
Other	221	51,700	--	--
Total	723,000	5,980,000	653,000	6,470,000
Total estimated equivalent REO content	867,000	5,980,000	784,000	6,470,000
Mixtures of rare-earth chlorides, except cerium chloride (2846.90.2050):				
Belgium	10,000	26,200	--	--
China	5,950,000	7,030,000	3,250,000	10,000,000
Germany	425	157,000	589	202,000
Hong Kong	10,000	134,000	147,000	743,000
Japan	3,410	132,000	6,400	102,000
Korea, Republic of	--	--	54,700	73,800
Mexico	--	2,640	--	--
Russia	87	122,000	101	241,000
Taiwan	--	--	40,600	160,000
United Kingdom	6,840	61,200	7,420	98,900
Other	10,100	28,800	43	37,400
Total	5,980,000	7,670,000	3,510,000	11,700,000
Total estimated equivalent REO content	2,750,000	7,670,000	1,610,000	11,700,000
Ferrocerium and other pyrophoric alloys (3606.90.3000):				
Austria	16,100	405,000	16,200	550,000
China	3,350	37,900	4,370	42,200
France	120,000	1,650,000	116,000	1,680,000
Other	3,210	21,900	2,300	47,800
Total	143,000	2,110,000	139,000	2,320,000
Total estimated equivalent REO content	127,000	2,110,000	123,000	2,320,000

-- Zero.

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

[2] Harmonized Tariff Schedule of the United States category numbers.

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]	2003	2004	2005	2006	2007
Brazil	--	402 [r, 4]	527 [r, 4]	527 [r, 4]	645 [p]
China	92,000	98,000	119,000	133,000 [r]	120,000
India	2,700	2,700	2,700	2,700	2,700
Kyrgyzstan:					
Compounds	NA	NA	NA	NA	NA
Metals	NA	NA	NA	NA	NA
Other	2,000	NA	NA	NA	NA
Malaysia	360	800	150	430 [r]	380
Total	97,100	102,000	122,000 [r]	137,000 [r]	124,000

[p] Preliminary. [r] Revised. NA Not available. -- Zero.

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

[2] Table includes data available through June 8, 2008.

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

[4] Reported figure.

TABLE 7
MONAZITE CONCENTRATE: ESTIMATED WORLD PRODUCTION, BY COUNTRY[1, 2]

(Metric tons, gross weight)

Country[3]	2003	2004	2005	2006	2007
Brazil	--	731 [4]	958 [r, 4]	958 [r]	1,173 [p]
India	5,000	5,000	5,000	5,000	5,000
Malaysia	795 [4]	1,683 [4]	320 [4]	894 [r, 4]	800
Total	5,800	7,410	6,280 [r]	6,850 [r]	6,970

[p] Preliminary. [r] Revised. -- Zero.

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

[2] Table includes data available through April 18, 2008.

[3] In addition to the countries listed, China, Indonesia, Nigeria, North Korea, the Republic of Korea, and countries of the Commonwealth of Independent States may produce monazite; available general information is inadequate for formulation of reliable estimates of output levels.

[4] Reported figure.

FIGURE 1
PRINCIPAL SOURCES BY WEIGHT OF U.S. IMPORTS OF RARE EARTHS IN 2007