RARE EARTHS

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In 2001, rare-earth production was primarily from the rare-earth mineral bastnäsite. Rare-earth ores were mainly supplied by China, with lesser amounts mined in Brazil, India, Russia, and the United States. Demand decreased for rare earths used in petroleum fluid cracking catalysts and in rare-earth phosphors for television, x-ray intensifying, and fluorescent and incandescent lighting. Consumption was estimated to have decreased as imports of rare-earth compounds, metals, and alloys declined. Production of bastnäsite continued in the United States and production of cerium concentrates was on a limited scale. U.S. imports of cerium compounds increased (table 1).

Yttrium demand increased by about 4% in 2001 compared with that of 2000. Yttrium was used primarily in lamp and cathode-ray tube phosphors, and lesser amounts were used in structural ceramics and oxygen sensors.

The domestic use of scandium decreased in 2001. Overall consumption of the commodity remained small. Commercial demand decreased as the domestic economy slowed. Demand was primarily for aluminum alloys used in baseball and softball bats. Most scandium metal, alloys, and compounds were used in analytical standards, metallurgical research, and sporting goods equipment. Minor amounts of high-purity scandium were used in semiconductors and specialty lighting.

The rare earths are a moderately abundant group of 17 elements composed of 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 at about 0.5 ppm. 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: lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu). Cerium, which is more abundant than copper (whose average concentration in the Earth's crust is 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, whose atomic number is 21, is the lightest rare-earth element. 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, whose atomic number is 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's average concentration in the Earth's crust is 33 ppm and 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 rare-earth ores are lateritic ion-adsorption clays and the minerals bastnäsite, loparite, and monazite (table 2).

The rare earths were discovered in 1787 by Swedish Army Lieutenant Karl Axel Arrhenius when he collected the black mineral ytterbite (later renamed gadolinite) from a feldspar and quartz mine near the village of Ytterby, Sweden (Weeks and Leicester, 1968, p. 667). Because they have similar chemical structures, the rare-earth elements proved difficult to separate. It was not until 1794 that the first element, an impure yttrium oxide, was isolated from the mineral ytterbite by Finnish chemist Johann Gadolin (Weeks and Leicester, 1968, p. 671).

Rare earths were first produced commercially in the 1880s in Sweden and Norway from the rare-earth mineral monazite. Production in Scandinavia was prompted by the invention in 1884 of the Welsbach incandescent lamp mantle, which initially required the oxides of lanthanum, yttrium, and zirconium, with later improvements requiring only the oxides of thorium and cerium. The mantles also used small amounts of neodymium and praseodymium as an indelible brand name label. The first rare-earth production in the United States was recorded in 1893 in North Carolina; however, a small tonnage of monazite was reportedly mined as early as 1887. South Carolina began production of monazite in 1903. Foreign production of monazite occurred in Brazil as early as 1887, and India began recovery of the ore in 1911.

Production

In 2001, one mining operation in California accounted for all domestic mine production of rare earths. Molycorp, Inc. (a wholly owned subsidiary of Unocal Corporation), mined bastnäsite, a rare-earth fluorocarbonate mineral, by open pit methods at Mountain Pass, CA. Mine production was estimated to be 5,000 metric tons (t) of rare-earth oxide (REO) in concentrates. Molycorp's parent company established $87 million for the environmental remediation of four sites, an oil field, an oil refinery, and the closed lanthanide processing sites at Washington, PA, and York, PA (Unocal Corporation, 2002). The minerals sector of Unocal reported sales revenue of $28 million (unaudited), a decrease of $1 million from the 2000 level. Unocal's minerals sector included minerals other than the lanthanides (i.e. carbon, molybdenum, and niobium) and is undifferentiated in its report.

Refined lanthanides were processed by two companies in 2001. Molycorp, which ceased production of refined compounds at its separation plant at Mountain Pass in 1998, continued to produce bastnäsite concentrate.

Santoku America, Inc. (a subsidiary of Santoku Corporation of Japan), produced rare-earth magnet and rechargeable battery alloys at its operations in Tolleson, AZ. Santoku America produced both types of high-strength permanent magnets, namely neodymium-iron-boron and samarium-cobalt. For the rechargeable battery industry, Santoku produced nickel-metal hydride alloys incorporating specialty rare-earth mischmetals. The plant also produced a full range of high-purity rare-earth metals in cast and distilled forms, foils, and sputtering targets, including scandium and yttrium. Santoku's affiliate Anan Kasei Ltd. in Japan continued its joint venture with Rhodia Electronics and Catalysis, Inc., in producing phosphors, polishing compounds, three way catalytic converter catalysts, fuel additive emission-reduction catalyst, and rare-earth-based nontoxic colorants and coatings for plastics.

Rhodia Rare Earths, Inc., changed its name effective January 1, 2001, to Rhodia Electronics and Catalysis, Inc. The new name reflects Rhodia's goal to be a development partner and supplier of rare earths and advanced materials for the electronics and catalysis markets worldwide (Rhodia Rare Earths, Inc., 2000§[1]).

Rhodia's operations produced finished rare-earth products from imported materials at its plant in Freeport, TX. Rhodia continued to operate its large-scale rare-earth separation plant in La Rochelle, France, and had additional capacity at its joint-venture Anan Kasei, Ltd. (Rhodia Rare Earths, 67%, and Santoku Corporation, 33%) in Kobe, Japan. These plants provide Rhodia's U.S. operations with most of their supply.

W.R. Grace & Co. (parent company of Grace Davison) voluntarily filed for Chapter 11 bankruptcy protection to avoid financial collapse from asbestos claims. The asbestos claims are related to asbestos purchased by the company and added to fire-proofing products prior to 1973. W.R. Grace ceased adding asbestos to the products in 1973. The company believed that a large increase in unmeritorius personal injury claims created an increased risk that W.G. Grace would not be able to fairly address all the valid and pending claims. Through 2001, approximately 325,000 personal injury claims had been filed. The Grace Davison division continued to refine rare earths from rare-earth chlorides and other rare-earth compounds for petroleum fluid cracking catalysts at Chattanooga, TN. Grace Davison also produced rare-earth compounds for chemical catalysis and polishing compounds (W.R. Grace & Company, 2001§).

Essentially all purified yttrium was derived from imported compounds. The minor amounts of yttrium contained in bastnäsite from Mountain Pass, CA, are not recovered as a separate product.

Three scandium processors operated in 2001. High-purity products were available in various grades, with scandium oxide produced at up to 99.999% purity. Sausville Chemical Co. refined scandium at its facilities in Knoxville, TN. The company expected to produce high-purity scandium compounds, including acetate, chloride, fluoride, nitrate, and oxide. Boulder Scientific Co. processed scandium at its Mead, CO, operations. It refined scandium primarily from imported oxides to produce high-purity scandium compounds, including carbide, chloride, diboride, fluoride, hydride, nitride, oxalate, and tungstate.

Scandium also 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.

Principal domestic producers of neodymium-iron-boron magnet alloys were Magnequench International, Inc. (MQ), Anderson, IN; and Santuko America, Inc., Tolleson (previously Phoenix), AZ. Leading U.S. producers of rare-earth magnets were Crumax Magnetics, Inc., Elizabethtown, KY; Electron Energy Corporation, Landisville, PA; Magnequench UG (previously Ugimag, Inc.), Valparaiso, IN; MQ, Anderson, IN; and Magnetic Materials Division of Hitachi Metal America, Ltd., Edmore, MI, and China Grove, NC.

In May 2001, Moltech Power Systems, a maker of nickel-metal hydride (Ni-MH) rechargeable batteries, declared bankruptcy and filed for Chapter 11 bankruptcy protection. In April 2002, the bankruptcy court approved the sale of Moltech's assets, which includes manufacturing equipment, inventory, intellectual property, and related business to the Chinese company Huayi Group. Huyai Group, headquartered in Shanghai, owns 218 manufacturing operations with assets of $5.7 billion (Moltech Corporation, 2002§).

MQ announced on May 8 that it had filed patent infringement suits against several major electronic and computer companies. The infringement involved the use of patented neodymium-iron-boron (NIB) magnets used in the drive motors of CD and DVD drives, hard disks, zoom lenses in camcorders, and other electronic applications (Magnequench International, Inc., 2001). The companies included in the suit are Acer Inc., Best Buy Co. Inc., Circuit City Stores, Inc., Compaq Computer Corp., Grupo Sanborns SA de CV, Hewlett-Packard Co., Philips Business Electronics North America Corp., Sony Computer Entertainment America Inc., and Toshiba Corp. MQ believes it has indisputable evidence against the companies involved and noted that it had previously sent warning letters. The MQ NIB patents had previously been validated by the U.S. International Trade Commission.

[1] References that include a section twist (§) are found in the Internet References Cited section.

MQ has nine production facilities worldwide, one each in China, Germany, Japan, Singapore, Switzerland, the United Kingdom, and three locations in the United States. The company produces NIB powders used in bonded magnets and permanent magnets. The highest magnetic strength commercial product available from MQ is rated at 42 megagauss oersteds (Magnequench International, Inc., 2001§).

Demand increased for rare earths used in NI-MH batteries. The rechargeable batteries are used in cellular phones, portable computers, personal data assistants (PDAs), camcorders, and other portable devices. Japan, the leading producer, shipped 654 million units in 2001, a 64% decrease compared with 2000 (Roskill's Letter from Japan, 2002a). Nickel-metal hydride batteries were the leading rechargeable battery product, followed by nickel-cadmium and lithium-ion types. Shipments of nickel-cadmium and lithium-ion batteries also decreased.

Etrema Products, Inc. (a wholly owned subsidiary of Edge Technologies, Inc., of Ames, IA), requested funding for an improved SONAR system from the U.S. Government. The funding is to develop, fabricate, install, and deploy an improved next generation broad-band SONAR based on the giant magnetostrictive alloy TERFENOL-D®. TERFENOL-D® is an alloy of iron and the rare-earth elements terbium and dysprosium that expands or contracts with the application or removal of an external magnetic field. It is also used in actuators, acoustic devices, ultrasonics, and other smart materials for the oil and gas industry (Etrema Products, Inc., 2001).

Consumption

Statistics on domestic rare-earth consumption were developed by surveying various processors and manufacturers, evaluating import-export data, and analyzing U.S. Government stockpile shipments. Domestic apparent consumption of rare earths decreased in 2001 compared with that of 2000. Domestic consumption of rare-earth metals and alloys also decreased in 2000, especially those used in permanent magnets and rechargeable batteries.

Based on information supplied to the U.S. Geological Survey (USGS) by U.S. rare-earth refiners and selected consumers and an analysis of import data, the approximate distribution of rare earths by use was as follows: automotive catalytic converters, 15%; glass polishing and ceramics, 34%; permanent magnets, 8%; petroleum refining catalysts, 16%; metallurgical additives and alloys, 14%; rare-earth phosphors for lighting, televisions, computer monitors, radar, and x-ray intensifying film, 9%; and miscellaneous, 4%.

In 2001, yttrium consumption was estimated to have increased to 473 t from 454 t in 2000. Yttrium information was based on data retrieved from the PIERS database, a product of The Commonwealth Business Media, Inc. Yttrium compounds and metal were imported from several sources in 2001. Yttrium was imported from China (79.3%); the United Kingdom (9.85%); Japan (5.87%); and Germany (4.99%). The estimated use of yttrium, based on imports, was primarily in lamp and cathode-ray tube phosphors (82.3%), lasers and electronics (12.7%), and structural ceramics and abrasives (5.0%).

Tariffs

In 2001, U.S. tariff rates specific to the rare earths, including scandium and yttrium, were unchanged from 2000 (U.S. International Trade Commission, 2001§). Selected rare-earth tariff rates for countries with normal-trade-relations and non-normal-trade-relations status, respectively, were as follows: Harmonized Tariff Schedule of the United States (HTS) 2805.30.0000, rare-earth metals, including scandium and yttrium, whether intermixed or interalloyed, 5.0% ad valorem and 31.3% ad valorem; HTS 2846.10.0000, cerium compounds, 5.5% ad valorem and 35% ad valorem; HTS 2846.90.2010, mixtures of REOs except cerium oxide, free and 25% ad valorem; HTS 2846.90.2050, mixtures of rare-earth chlorides, free and 25% ad valorem; HTS 2846.90.4000, yttrium-bearing materials and compounds containing by weight greater than 19% but less than 85% yttrium oxide equivalent, free and 25% ad valorem; HTS 2846.90.8000, individual rare-earth compounds, including oxides, nitrates, hydroxides, and chlorides (excludes cerium compounds, mixtures of REO, and mixtures of rare-earth chlorides), 3.7% ad valorem and 25% ad valorem; HTS 3606.90.3000, ferrocerium and other pyrophoric alloys, 5.9% ad valorem and 56.7% ad valorem; HTS 7202.99.5040, ferroalloys, other (including rare-earth silicide), 5.0% ad valorem and 25% ad valorem; and HTS 7601.20.9090, aluminum alloys, other (including scandium-aluminum alloys), free and 10.5% ad valorem.

Special rare-earth tariffs for Canada and Mexico were the result of Presidential Proclamation 6641, implementing the North American Free Trade Agreement, effective January 1, 1994. Under the agreement, tariff rates for most rare-earth products from Canada and Mexico were granted duty-free status, and those that were scheduled for staged reductions have achieved duty-free status. Tariff rates for most other foreign countries were negotiated under the Generalized Agreement on Tariffs and Trade Uruguay Round of Multilateral Trade Negotiations.

Stocks

All U.S. Government stocks of rare earths in the National Defense Stockpile (NDS) were shipped in 1998. Periodic assessments of the national defense material requirements may necessitate the inclusion of rare earths in the NDS at a future date.

Prices

Rare-earth prices either increased or were essentially unchanged in 2001 compared with 2000. The following estimates of prices were based on trade data from various sources or were quoted by rare-earth producers. 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 products to be quoted on a daily basis. The average price of imported rare-earth chloride was $1.61 per kilogram in 2001, an increase from $1.38 per kilogram in 2000. In 2001, imported rare-earth metal prices averaged $12.17 per kilogram, an increase from $11.52 per kilogram in 2000.

Mischmetal and specialty mischmetals composed most rare-earth metal imports. (Mischmetal is a natural mixture of rare-earth metals typically produced by metallothermic reduction of a mixed rare-earth chloride.) The price range of basic mischmetal was from $5.00 to $6.00 per kilogram (in metric ton quantities) at yearend 2001, a lower range than in 2000 (Elements, 2001§). The average price for imported cerium compounds, excluding cerium chloride, increased to $4.92 per kilogram in 2001 from $4.57 per kilogram in 2000. The primary cerium compound imported was cerium carbonate.

The estimated market price for bastnäsite concentrate was $5.51 per kilogram ($2.50 per pound). The price of monazite concentrate, typically sold with a minimum 55% REO, including thorium oxide content, free-on-board (f.o.b.) as quoted in U.S. dollars and based on the last U.S. import data, was unchanged at $400.00 per metric ton. In 2001, no monazite was imported into the United States. Prices for monazite remained depressed because the principal international rare-earth processors continued to process only thorium-free feed materials.

The nominal price for basic neodymium-iron-boron alloy, published at yearend by High Tech Materials for metric ton quantities, was $10 to $28 per kilogram ($4.54 to $12.70 per pound), f.o.b. shipping point. Most alloy was sold with additions of cobalt (typically 4% to 6%) or dysprosium (no more than 4%). The cost of the additions was based on pricing before shipping and alloying fees; with the average cobalt price decreasing to $23.26 per kilogram ($10.55 per pound) in 2001, the cost would be about $0.23 per kilogram ($0.11 per pound) for each percent addition.

Rhodia quoted rare-earth prices, per kilogram, net 30 days, f.o.b. New Brunswick, NJ, or duty paid at point of entry, in effect at yearend 2001, as listed in table 3. No published prices for scandium oxide in kilogram quantities were available. Yearend 2001 nominal prices for scandium oxide were compiled from information provided by several domestic suppliers and processors. Prices were mixed from those of the previous year for most grades and were listed as follows: 99% purity, $700 per kilogram; 99.9% purity, $2,300 per kilogram; 99.99% purity, $2,700 per kilogram; and 99.999% purity, $4,100 per kilogram.

Scandium metal prices for 2001 were unchanged from those of 2000 and were as follows: 99.9% REO purity, metal pieces, distilled dendritic, ampouled under argon, $279 per 2 grams; 99.9% REO purity, metal pieces, ampouled under argon, $198 per gram; 99.9% purity, metal ingot, ampouled under argon, $218 per gram; and 99.9% REO purity foil, 0.025-millimeter (mm) thick, ampouled under argon, 25 mm by 25 mm, $277 per item (Alfa Aesar, 2001, p. 1284) .

Scandium compound prices as listed by Aldrich Chemical Co. (2000, p. 1476-1477) were as follows: scandium acetate hydrate 99.9% purity, $61.40 per gram; scandium chloride hydrate 99.99% purity, $53.80 per gram; scandium nitrate hydrate 99.9% purity, $63.30 per gram; and scandium sulfate pentahydrate 99.9% purity, $61.00 per gram. Prices for standard solutions for calibrating analytical equipment were $23.80 per 100 milliliters of scandium atomic absorption standard solution and $360.50 per 100 milliliters of scandium plasma standard solution.

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

Foreign Trade

U.S. imports and exports of rare earths declined slightly in 2001 compared with those of 2000. U.S. exports totaled 9,270,000 kilograms (kg) valued at $50.1 million, a 2.4% decrease in quantity and a 14.4% decrease in value compared with those of 2000 (table 4). Imports totaled 27,100,000 kg gross weight valued at $140 million, a 5.9% decrease in quantity and a 1.6% decrease in value compared with those of 2000 (table 5).

In 2001, U.S. exports of rare earths decreased in all trade categories except mixtures of rare-earth chlorides, which increased. Principal destinations in 2001, in descending order, were Japan, Canada, the Republic of Korea, and Germany. The United States exported 737,000 kg of rare-earth metals valued at $6.3 million, a 46% decrease in quantity compared with that of 2000. Principal destinations, in descending order of quantity, were Japan and Brazil, with much smaller amounts to Canada and Mexico. Exports of cerium compounds, primarily for glass polishing and automotive catalytic converters, increased 4.2% to 4,110,000 kg valued at $18.4 million. Major destinations, in descending order of quantity, were the Republic of Korea, Germany, Japan, and the United Kingdom.

Exports of inorganic and organic rare-earth compounds decreased to 1,600,000 kg in 2001 from 1,650,000 kg in 2000, and the value of the shipments decreased by 25% to $17.5 million. Shipments, in descending order of quantity, were to Algeria, Argentina, the Republic of Korea, and Taiwan.

U.S. exports of ferrocerium and other pyrophoric alloys increased to 2,820,000 kg valued at $7.93 million in 2001 from 2,530,000 kg valued at $7.39 million in 2000. Principal destinations, in descending order of quantity, were Canada, the United Arab Emirates, Germany, and Hong Kong.

In 2001, U.S. imports of compounds and alloys decreased for six out of seven categories, as listed in table 5. China and France dominated the import market, especially for mixed and individual rare-earth compounds, followed by Japan and India (fig. 1).

Imports of cerium compounds totaled 5,760,000 kg valued at $28.3 million. After an increase in imports in 2000, the quantity of cerium compounds imported decreased by 10.6%, the result of decreased demand for automotive exhaust catalysts. China was the major supplier for the seventh consecutive year, followed by France, Japan, and Austria.

Imports of yttrium compounds containing between 19 and 85 weight-percent oxide equivalent (yttrium concentrate) increased by 33.3% to 130,000 kg in 2001 and the value increased by 66.2% to $4.31 million. China was the leading supplier of yttrium compounds, followed by France and Japan.

Imports of individual rare-earth compounds, traditionally the major share of rare-earth imports, decreased by 18.5% compared with those of 2000. Rare-earth compound imports decreased to 12,200,000 kg valued at $73 million. The major sources of individual rare-earth compounds were China, France, Estonia, and Japan. Imports of mixtures of REOs, other than cerium oxide, decreased by 6.5% to 2,040,000 kg valued at $9.2 million. The principal source of the mixed REOs was China, with smaller quantities imported from Japan, Hong Kong, and Germany. Imports of rare-earth metals and alloys into the United States totaled 1,180,000 kg valued at $14.4 million in 2001, a 43% decrease in quantity compared with those of 2000. The principal rare-earth metal sources, in descending order of quantity, were China and Japan. Metal imports decreased as demand for mischmetal for steel additives and specialty mischmetals for rechargeable batteries decreased.

In 2001, imports of rare-earth chlorides increased by 94% to 5,620,000 kg valued at $9.06 million. Supplies of rare-earth chloride, in descending order of quantity, came from China, India, Russia, France, and the United Kingdom. In the United States, rare-earth chloride was used mainly as feed material for manufacturing fluid cracking catalysts. Imports of ferrocerium and pyrophoric alloys were essentially unchanged at 132,000 kg valued at $1.47 million. France was the principal supplier, with smaller amounts imported from Austria and Chile.

World Review

China, France, India, and Japan were major import sources of rare-earth chlorides, nitrates, and other concentrates and compounds (table 5). Thorium-free intermediate compounds as refinery feed were still in demand as industrial consumers expressed concerns with the potential liabilities of radioactive thorium, the costs of complying with environmental monitoring and regulations, and costs at approved waste disposal sites. In 2001, demand for rare earths decreased in the United States, and imports decreased by 5.9%.

In 2001, estimated world production of rare earths increased to 119,000 t of REOs (table 6). Production of monazite concentrate was estimated at 5,700 t (table 7).

World reserves of rare earths were estimated by the USGS to be 100 million metric tons (Mt) of contained REOs in 2001. China, with 43%, had the largest share of those world reserves. China's reserves are primarily contained in bastnäsite-bearing carbonatites. Australia's reserves include rare earths contained in monazite owing to its widespread availability as a very low-cost byproduct of heavy-mineral sands processing. Australia's other major reserve of rare earths is in the Mount Weld carbonatite.

Australia.—Australia remained one of the world's major potential sources of rare-earth elements from its heavy-mineral sands and rare-earth laterite deposits. Monazite is a constituent in essentially all of Australia's heavy-mineral sands deposits. It is normally recovered and separated during processing but in most cases is either returned to tailings because of a lack of demand or stored for future sale. In 2001, major producers of heavy-mineral sand concentrates in Australia, in order of potential production, were Iluka Resources, Ltd., Tiwest Joint Venture, Consolidated Rutile, Ltd. (CRL) (43% owned by Iluka Resources Ltd.), and RZM/Cable Sands, Ltd. (CSL).

Iluka operated eight mines in Australia and two in the United States in 2001 (Iluka Resources Ltd., 2002a, p. 1). Iluka's Australian subsidiary WA Titanium Minerals operated six mines in Western Australia, two of which opened in 2000. The company operated the Capel North West Mine near Capel, Western Australia. WA Titanium operated the North Mine and the Newman concentrator near Eneabba, Western Australia. Other mining operations were the South Mine near Eneabba and the Yoganup, the Yoganup Extended, and the Busselton Mines in the southwestern region. Iluka's two east coast mines, in which it has a 48.9% interest, were operated by CRL on North Stradbroke Island, Queensland.

Iluka upgraded the heavy-mineral sand resources by 28% at three of its Murray Basin tenements in northwestern Victoria. The deposits included the Boulka in Ouyen, the Snapper in Pooncarrie about 120 kilometers (km) north of Mildura, and the Dispersion, about 70 km east of Mildura. Iluka reported grades of greater than 22% heavy minerals with mineral zones containing up to 27% rutile and 15% zircon at Dispersion (Iluka Resources Ltd., 2002b).

BeMaX Resources NL and Probo Mining Pty. Ltd. announced they would begin development of their joint venture Ginkgo Mineral Sands project (Ginkgo) in the Murray Basin near Pooncarie, New South Wales. Reserves are 184 Mt of ore grading 3.2% heavy minerals. Production from the Ginkgo deposit was expected to commence in late 2003 with shipments commencing in early 2004 (BeMaX Resources NL, 2002; Mineral Sands Report, 2002a).

BeMaX reported inferred resources at its joint-venture Snapper deposit in the northern Murray Basin, New South Wales, at 104 Mt grading 4.8% heavy minerals. The BIP Joint Venture between BeMaX (75%) and Probo Mining (25%) controls the Snapper and the Ginkgo heavy-mineral deposits (Mineral Sands Report, 2001f). The Snapper deposit is located 10 km southwest of the Ginkgo deposit. The Ginkgo deposit has a resource of 252 Mt grading 2.8% heavy minerals (BeMaX Resources NL, 2001§).

Exploration company Metal Sands Pty. Ltd. released the results of its drilling in southwestern Western Australia. The resource had an estimated 3.37 Mt of ore grading 2.38% ilmenite, including 1.85 Mt grading 0.08% zircon (Metal Sands Pty. Ltd., 2002).

In April, Iluka announced that it had discovered additional heavy-mineral sands resources in Western Australia. Measured, indicated, and inferred resources were increased to 88 Mt of heavy minerals. This resource is split between Western Australia's southwest region, which includes Capel at 48 Mt, and the midwest region, which includes Eneabba at 40 Mt. Iluka's heavy-mineral sand resources in its rest-of-world category, including other parts of Australia, in decreasing order, were Sri Lanka, 119 Mt; the United States, 25 Mt; North Stradbroke Island, Queensland, Australia, 15 Mt; and Murray Basin, Victoria, Australia, 9 Mt (Mineral Sands Report, 2001c).

Australian Zirconia Ltd. (a wholly owned subsidiary of Alkane Exploration Ltd.) announced that it is making minor adjustments to its pilot plant to produce a marketable zirconium oxide and hafnium oxide product from its Dubbo hard-rock rare earth-yttrium-zirconium-hafnium-niobium-tantalum bearing deposit in New South Wales. Another production run of the plant was planned for December to produce a first run niobium-tantalum product (Alkane Exploration Ltd., 2001). The multimineral deposit is located on the Toongi alkaline intrusive that contains hafnium, lanthanides, niobium, tantalum, yttrium, and zirconium in the igneous rock trachyte. Measured resources at the Dubbo deposit are 42 Mt grading 1.91% zirconium oxide, 0.04% hafnium oxide, 0.449% niobium oxide, 0.027% tantalum oxide, 0.138% yttrium oxide, and 0.713% REO (Australian Zirconia Ltd., 2000).

Basin Minerals Ltd. announced it had acquired a loan to proceed with a final feasibility study of the Douglas heavy-mineral sands deposit in the Murray Basin in western Victoria. Basin Minerals' Douglas deposit covers an area of 5,860 square kilometers and has a resource of 22.4 Mt of heavy minerals. The area contains the Acapulco, Bondi, Bondi East, and Echo strandline deposits containing 11.3 Mt of ilmenite (including leucoxene), 1.26 Mt of rutile, and 1.62 Mt of zircon. Basin Minerals reported it had filed an environmental effects statement with the Victoria government (Mineral Sands Report, 2002b).

Basin Minerals has estimated an inferred resource for the Culgoa deposit in the Murray Basin to be 11.8 Mt at 16.8% heavy minerals with a cutoff grade of 3% heavy minerals. Culgoa has 1.985 Mt of heavy-mineral concentrate with a waste-to-ore ratio of 2:1. The high-grade mineralization is between 60 and 140 meters (m) wide and averages 4 m in thickness over a strike of 17.6 km. Culgoa's heavy-mineral content averages 79% valuable heavy minerals and 21% gangue (TZ Minerals International, [undated]§).

Mineral Deposits Limited (MDL) announced it had received approval to proceed with an extension of its dredging at Fullerton, New South Wales. The 14-km extension should extend the mine life by about 10 years at present mining rates. Part of the extension extends onto aboriginal lands, for which MDL has obtained leases from the Worimi Land Council (Mineral Sands Report, 2001d).

Iluka purchased a 4.8% share of Basin Minerals, which has several heavy mineral sands holdings in the Murray Basin. Basin Minerals properties included the Douglas project with reserves of 35.9 Mt of ore grading 10.3% heavy minerals (Mineral Sands Report, 2001b).

Iluka announced a takeover bid for its 43%-owned subsidiary CRL. Through its subsidiary Iluka Corp. Ltd., Iluka Resources offered $A1.00 per share for all the outstanding stock, a 21% premium to the stock price at the time of offer (Mineral Sands Report, 2001a).

Sons of Gwalia (SOG) increased its share of BeMaX to 19.9%. SOG held a 16.82% equity in BeMaX prior to the sale of 5.1 million shares. Imperial One Ltd. (IOL), the largest shareholder, increased its share of BeMaX to 24.36%. IOL was BeMaX's original joint-venture partner when the exploration company started (Mineral Sands Report, 2001e).

***Brazil.*—**Reserves of monazite contained in marine alluvial deposits were 42,000 t, and in stream placers, 40,000 t in 2000, the latest available data. The reserves of marine origin were distributed in deposits primarily in the States of Rio de Janeiro (26,730 t), Espírito Santo (4,136 t), and Bahia (10,186 t). The main placer reserves were in the States of Minas Gerais (24,396 t), Espírito Santo (11,372 t), and Bahia (3,481 t) (Fabricio da Silva, 2001, p. 93-94).

***Canada.*—**Tiomin Resources Inc.'s Natashquan heavy-mineral sand deposit is on a care-and-maintenance basis while the company focuses on development of the Kwale deposit in Kenya. The Natashquan deposit, on the north shore of the St. Lawrence River in Quebec, contains ilmenite, magnetite, and zircon. Only a small portion of the deposit has been drilled and resources are estimated to be 2.1 billion metric tons (Gt) of ore grading 5.9% heavy minerals. The dredgeable resource at Natashquan has been calculated using geologic modeling to be about 770 Mt grading 9.0% heavy minerals for the north zone and 890 Mt grading 7.19% heavy minerals for the south zone. A 116-hole drilling program confirmed the modeling resource estimate (Tiomin Resources Inc., [undated]a§).

***China.*—**Production of rare-earth concentrates in China was 73,000 t REOs in 2000, the latest available data. Refined and processed products reached 65,000 t REOs. Production of individual high-purity rare-earth compounds and metals was 25,000 t REOs, an increase of 66% from those of 1998. Consumption within China increased by 20% in 2000 to about 19,200 t REOs. Metallurgical applications, the major domestic use, consumed 5,200 t of equivalent REOs (China Rare Earth Information, 2002a).

Santoku Corporation entered into a joint-venture agreement with Baotou Rare Earth High and New Technology Industry Development Zone, Rhodia, and Westlake to form the rechargeable battery materials company Baotou Santoku Battery Materials Co. Ltd. (BSBM). Santoku will reportedly invest 70% of the capital for the Baotou venture. Initially, BSBM plans to manufacture mischmetal and nickel-hydride alloys for use in rechargeable batteries for consumption in China. Future production will be slated for export throughout Asia (Rare-earth Information Center Insight, 2001a).

Baotou Iron and Steel Group Inc. (Baogang) produced 7,900 t of rare-earth products in 2001. The production represents an increase of 14% compared with 2000. Baogang reported a profit of Y64.72 million (China Rare Earth Information, 2002b).

***Estonia.*—**AS Silmet (a subsidiary of Silmet Group) separated rare earths at its plant in Sillamäe. Located on the northeastern coast of Estonia on the Gulf of Finland, the plant has capacity of 3,000 metric tons per year (t/yr) of rare earth products. Rare-earth material for the Sillamäe plant originates as loparite concentrate from Russia. Preliminary processing of the loparite ore is done in Solikamsk, Russia, to produce intermediate rare-earth concentrates. These concentrates are shipped for use as feed material for the Sillamäe rare-earth separation plant. The majority of production is exported to Japan; however, exports to the United States have been increasing (Baltic Review, [undated]§).

The Sillamäe radioactive tailings pond, an environmental problem from the Soviet era (before 1991), has been undergoing remediation since 1999. Under direction of the private-public environmental company Ökosil, created by a cooperative venture between the Government of Estonia and Silmet Group, the cleanup of the tailings pond is planned for completion in 2006.

***France.*—**Rhodia is to refocus its direction to become a development partner and supplier of advanced materials, especially to the electronics and catalyst markets. Three new business units in Rhodia were structured to embrace the company's market focus—new markets, electronics, and catalysis. The growth in added value products will be an extension of its core business in rare-earth technologies (Rhodia

Europe, 2001).

India.—In December, V.V. Minerals (VVM) announced that it had discovered mineral sands resources of 23.9 Mt of ore containing 9.45 Mt of heavy minerals, including monazite. VVM has been a producer of garnet with byproduct production of ilmenite. With its drilling program in Tamil Nadu, VVM is expecting to produce greater quantities of ilmenite and byproduct rutile and zircon. Additional drilling in 2002 at closer intervals is expected to further delineate its heavy-mineral deposit (Mineral Sands Report, 2002c).

Indian Rare Earth Ltd. (IRE) operates three heavy-mineral sand mines at Chavara in Kerala State, Manavalakurichi in Tamil Nadu State, and the Orissa Sands Complex in Orissa State. In 2001, IRE recovered and processed monazite to produce thorium-free rare-earth chloride and byproduct thorium hydroxide.

Kerala Minerals and Metals Ltd. (KMML) mined and processed heavy-mineral sands from beach sands along the Chavara coast in Kerala State. KMML announced it was building a new mineral separation plant to increase capacity to about 3 million metric tons per year (Mt/yr) of ilmenite, with concomitant increases in the other heavy minerals. Monazite from the KMML deposits on the Chavara coast had an average composition of 57.5% REOs with 7.96% thorium oxide and 28.2% phosphate, with a specific gravity of 5.14. The heavy-mineral composition of the coast and adjoining seabeds contained 240 Mt ilmenite, 20 Mt rutile, 50 Mt zircon, 60 Mt sillimanite, and 4 Mt of monazite (Kerala Minerals and Metals Ltd., 2001§).

Japan.—Japan refined 5,104 t of rare earths in 2001, a decrease from the 5,625 t produced in 2000. The rare earths were produced from imported ores and intermediate raw materials (Roskill's Letter from Japan, 2002b). Inventories of rare earths increased to 701 t, up from the previous year's level of 567 t. Imports of rare earths during the year were 19,736 t, a decrease from the 26,928 t imported in 2000. The value of imports decreased to ¥18,600 million in 2001 from ¥23,843 million in 2000 (Roskill's Letter from Japan, 2002d). Japanese rare-earth imports declined in all product categories. Imports from the United States, however, were 664 t, an increase from the 530 t imported in 2000.

Estimated production of Japanese bonded neodymium-iron-boron magnets in 2001 was 591 t, a decrease from the 700 t produced in 2000 (Roskill's Letter from Japan, 2002c). After a decade of double-digit growth, the decrease in neodymium-iron-boron magnet production is the second decline in 2 years.

Japanese shipments of rare-earth-containing Ni-MH rechargeable batteries decreased by 36% in 2001 to 650 million units (Roskill's Letter from Japan, 2002a). Ni-MH shipments were 653.8 million units in 2001, a decrease from the 1,015.3 million units shipped in 2000. The lower shipments were the result of decreased demand for consumer products that use Ni-MH batteries, including cellular phones, laptop computers, PDA's, and portable tools.

Japanese imports of rare earths from China were as follows: cerium compounds, 3,474 t; rare-earth compounds, 3,380 t; rare-earth metals, 3,213 t; cerium oxide, 3,212 t; lanthanum oxide, 1,283 t; yttrium oxide, 854 t; and ferrocerium, 45 t (Roskill's Letter from Japan, 2002d).

Total imports in 2001 were as follows: rare-earth compounds, 5,361 t; other cerium compounds, 4,434 t; cerium oxide, 3,832 t; rare-earth metals, 3,346 t; lanthanum oxide, 1,498 t; yttrium oxide, 881 t; and ferrocerium, 384 t (Roskill's Letter from Japan, 2002d). No rare-earth chlorides were imported in 2001 (Roskill's Letter from Japan, 2002e). China continued as the leading source of rare-earth imports for Japan with 12,909 t in 2001, a substantial decrease from the 22,431 t, imported in 2000.

Kenya.—Tiomin Resources Inc. explored four heavy-mineral sands deposits in the coastal region between Mambrui and Shimoni. The deposits from north to south are the Mambrui, Kilifi, Vipingo, and Kwale. Located 6 to 12 km inland from the coast, the deposits are in the Magarini Formation of Pliocene age. The Mambrui has a resource of 700 Mt grading 3.7% heavy minerals. The Kilifi dunal system is believed to be aeolian in origin. The Kwale deposit is the most advanced of Tiomin's properties, although it is the smallest of the group. The deposit consists of two large dunes located 10 km from the coast and only 65 km from the city of Mombasa. Kwale's resources are 200 Mt of heavy-mineral sands containing 3.8 Mt of ilmenite, 1.1 Mt of rutile, 0.6 Mt of zircon, and lesser amounts of monazite (Tiomin Resources Inc., [undated]b§).

Madagascar.—Rio Tinto Iron and Titanium Inc. (RIT) announced that its three deposits near Fort Dauphin graded 4.5% to 5.5% heavy minerals. The heavy-mineral suite reportedly is ilmenite-rich with a 75% to 80% content but with a correspondingly small zircon and rutile content (Mineral Sands Report, 2001h). A feasibility study on mining heavy-mineral sands near Tolagnaro (Fort Dauphin) in southeastern Madagascar was started by QIT Madagascar Minerals S.A. (QMM), a Malagasy company owned 80% by RIT and 20% by the Malagasy Government.

Mozambique.—RIT announced the discovery of heavy-mineral sands deposits in the Provinces of Gaza and Inhambane. The placer deposits are in a coastal dunal system representing a fossil shoreline. Initial drilling indicated an inferred resource of 70 Mt of ilmenite and other heavy minerals, including zircon. Additional drilling on the deposit is planned (Mineral Sands Report, 2002e).

Kenmare Resources plc of Dublin, Ireland, completed its feasibility study of the Moma titanium minerals project, which indicated the project was viable. Exploratory drilling proved the deposit is capable of supporting a 625,000-t/yr heavy-mineral sands operation for 20 years (Kenmare Resources plc, 2001).

Russia.—Solikamsk Magnesium Works (SMZ) reported it had processed 9,521 t of loparite ore in 2000, up by 15.4% from that of 1999. Output was up by 48.2% in 2000 to 1,104 t of intermediate rare-earth compounds, feed material destined for the rare-earth separation plant in Sillamäe, Estonia. SMZ reported value had increased by 21.3% to Rub94.215 million. Rare-earth materials accounted for 34% of SMZ's output, the remainder being magnesium and its alloys (MetalMerge, 2001§).

The Lovozero deposit in the Murmansk region is the principal source of light-group rare earths (LREE) in Russia. The deposit was operated by AO Sevredmet's Lovozero Mining Combine until March 2000. Sevredmet went into receivership March 15, 2000, and the mining company restructured under OAO Sevredmet. The new public company Lovozero Mining Company (LMC) was formed at the Umbrozero mining facility to operate the loparite concentrator facility. LMC has projected output from the concentrator to be 5,150 t/yr of rare-earth carbonates (96% of Russian demand). LMC ships loparite concentrate for further processing to Solikamsk and then on for further refining and separation to Estonia, Kazakhstan, and Kyrgyzstan (Russian Ministry of Economic Development and Trade, State Investment Agency, [undated]§).

South Africa.—Rare Earth Extraction Co. Ltd. (RARECO) decided to postpone development of its deposit at Steenkampskrall because of international economic conditions. RARECO quoted the financial crisis in Asia and Russia and decreased commodity prices, including rare earths, as the principal causes for the postponement (Rare Earth Extraction Co. Ltd., 2001§).

Ticor Ltd. of Australia announced it would acquire 40% of the shares in Iscor's IHM Hillendale project in KwaZulu Natal Province. The remaining 60% is owned by Kumba Resources Ltd. (a subsidiary of Iscor Ltd.). The IHM project, which was renamed Ticor South Africa in August, consists of three deposits—the Hillendale and the Fairbreeze in KwaZulu Province and the Gravelotte in Northern Province—which total 16 Mt of heavy minerals. Mining using water jets was used for the project because traditional dredging was determined to be inadequate (Ticor Ltd., 2000§). The Ticor South Africa mine and concentrator were commissioned in June 2000 with production from the deposit beginning in April 2001. The mine initially produced 196,000 t of ore with the concentrator producing 8,500 t of heavy-mineral concentrate. A heavy-mineral dry separation plant at Empangeni also commenced production. The Ticor South Africa mining operation officially opened in September (Australian Mining, 2002§).

Namakwa Sands (a wholly owned subsidiary of Anglo American plc) continued to increase producion of heavy-mineral sands as a result of an expansion (phase two) at its mine at Brand-se-Baai. The phase two expansion increased ore capacity to 12 Mt/yr from 4 Mt/yr (Mineral Sands Report, 2001g).

Current Research and Technology

Traditionally, infrared (IR) detectors have depended on photon detectors where an incoming photon excites an electron across a band gap. Unfortunately, a phonon may do the same type of excitation at room temperature, so that IR detectors must be cooled with cryocoolers. A new type of rare-earth-containing IR detector uses lead-scandium-tantalum trioxide, $PbSc_{0.5}Ta_{0.5}O_3$ (PST), to thermally detect IR by measuring the heat produced in the detector. The temperature rise, however, is not only determined by the IR energy coming in, but from the thermal mass of the detector. A manufacturing method is being researched to produce a thin-film (low-mass) detector that is a single-phase ceramic material that is not supported by a substrate (Rare-earth Information Center Insight, 2001b).

Researchers have succeeded in developing a rare-earth laser crystal that emits a continuous three-color beam (red, green, and blue). Using neodymium (Nd^{3+})-doped lithium niobate ($LiNbO_3$), the crystal is aperiodically poled and exhibits highly nonlinear polarization versus voltage coefficients. As a result, the laser crystal has simultaneous phase matching of the differing nonlinear processes. The red and green emissions are obtained by frequency doubling, and the blue emission is created by self-sum frequency doubling (Rare-earth Information Center Insight, 2001c).

A group of researchers at the University of Oxford, United Kingdom, produced an organolanthanide phosphor (OLP) for potential commercial use in flat panel displays. The polymer material is an organoterbium emitter. Color and efficiency of the emission are a function of the lanthanide. The team fabricated a high-efficiency organic electroluminescent device that produced green light with peak luminescence of 2000 candelas per square meter (Capecchi and others, 2000).

Improved creep-resistant alloys have been developed using rare earths to function effectively at higher temperatures. Commercially available magnesium-yttrium-neodymium-zirconium alloy is rated for sustained operating temperatures of 250º C. To extend this range and still keep the weight low, researchers at Technische Universität Clausthal, Germany, have developed a quaternary alloy of magnesium, gadolinium, scandium, and manganese. The additions of scandium and manganese reduce the solubility of gadolinium in the magnesium, allowing a reduced amount of high-weight gadolinium to be used. To achieve the high-creep resistance, the alloy is annealed at a high temperature to achieve a uniform melting, followed by a low temperature anneal to allow the scandium-manganese alloy to precipitate out in a fine-grained uniform dispersion. The precipitate pins the magnesium in the alloy's crystal lattice so that it is unable to be dislocated, or creep. Although three phases were introduced in the alloys phase diagram (a precipitation hardening phase and two others), the creep rate was reduced by one order of magnitude (Stulíková and others, 2001).

Researchers have used cerium and titanium dioxide to make an improved electrorheological (ER) fluid. Using an electric field, ER fluids have variable viscosity, stiffness, and heat transference. Under an electric field, the particles in the ER fluid are polarized and organize into chain structures, thus increasing the viscosity. Cerium-doped titanium dioxide in dimethylsilicone oil had a sheer stress five to six times higher than pure titanium dioxide. The rare-earth material has potential applications in viscous clutches, variable-cushion shock absorbers, and other variable coupling devices (Yin and Zhao, 2001).

The General Electric Company's GE Lighting division announced the introduction of a neodymium-doped glass light bulb for use in typical incandescent applications around the home. The powder-blue colored bulb uses neodymium to absorb the yellow spectrum, which is more prevalent in the emission from a tungsten filament than from natural sunlight. By absorbing the yellow spectrum the neodymium light bulb provides a more sunlight-like light, providing richer colors and improved surface definition of the home environment (GE Lighting, 2001).

PPG Industries has developed a water-based yttrium coating to provide corrosion resistance and a lead-free surface primer for paints. Automobile paints have traditionally required a primer layer of metal ions between the base-metal surface and the polymeric binder of the paint coating to prevent corrosion and improve adherence. Although lead has been banned in paints since January 1971, an exemption exists for soluble lead pigments up to 1,000 ppm used in electrodeposition coatings. Since there had been no suitable substitute, PPG developed the yttrium product to provide an environmentally sound alternative. In the process, an yttrium hydroxide coating is applied by electrodeposition from an yttrium salt and converted to yttrium oxide during heat curing (Rare-earth Information Center Insight, 2001d).

A europium complex was used to study triboluminescence, light emitted when a material is subjected to mechanical pressure. Piezoelectricity's noncentrosymmetric structure was believed to be a necessary condition for triboluminescence to occur; however, recent observations contradict this assumption. Four organic europium complexes based on the europium 2-thenoyltrifluoroacetone:1,2 dimethylpyridinium system were studied in detail to determine crystal structure and triboluminescence. It was discovered that centrosymmetric space groups in the thienyl rings and carbon trifluoride groups were the source of the triboluminescence (Rare-earth Information Center Insight, 2001e).

Researchers in China reviewed the use of rare earths in cemented carbides. When rare earths are incorporated in a cemented carbide, a 50% to 100% improvement in the carbide tool life was noted. Various rare-earth additions have been tried using various compounds and manufacturing processes. The improvements in the properties of the carbides are dependent on both the rare earth used and how it is incorporated in the mixture (Xu, Ai, and Huang, 2001).

Outlook

The use of rare earths, especially in automotive pollution catalysts, permanent magnets, and rechargeable batteries, is expected to continue to increase as future demand for automobiles, electronics, computers, and portable equipment grows. Rare-earth markets are expected to require greater amounts of higher purity mixed and separated products to meet the demand. Strong demand for cerium and neodymium for use in automotive catalytic converters and permanent magnets is expected to continue throughout the decade. Future growth is forecast for rare earths in rechargeable Ni-MH batteries, fiber optics, and medical applications, including magnetic resonance imaging (MRI) contrast agents, positron emission tomography (PET) scintillation detectors, medical isotopes, and dental and surgical lasers. Long-term future growth is expected for rare earths in magnetic refrigeration alloys.

World reserves are sufficient to meet forecast world demand well into the 21st century. Several very large rare-earth deposits in Australia and China (e.g., Mianning, China, and Mount Weld, Australia) have yet to be fully developed because world demand is currently (2001) being satisfied by existing production. World resources should be adequate to satisfy demand for the foreseeable future.

Domestic companies have shifted away from using naturally occurring radioactive rare-earth ores. This trend has had a negative impact on monazite-containing mineral sands operations worldwide. Future long-term demand for monazite, however, is expected to increase because of its abundant supply and its recovery as a low-cost byproduct. The cost and space to dispose of radioactive waste products in the United States are expected to continue to increase, severely limiting domestic use of low-cost monazite and other thorium-bearing rare-earth ores.

World markets are expected to continue to be very competitive based on lower wages and fewer environmental and permitting requirements. China is expected to remain the world's principal rare-earth supplier. Economic growth in several developing countries will provide new and potentially large markets in Southeast Asia and Eastern Europe.

The long-term outlook is 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.

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TABLE 1
SALIENT U.S. RARE EARTH STATISTICS 1/

(Metric tons of rare-earth oxides unless otherwise specified)

	1997	1998	1999	2000	2001
Production of rare-earth concentrates 2/	10,000 e/	5,000 e/	5,000 e/	5,000 e/	5,000 e/
Exports:					
Cerium compounds	5,890	4,640	3,960	4,050	4,120
Rare-earth metals, scandium, yttrium	991	724	1,600	1,650	884
Ores and concentrates	--	--	--	--	--
Rare-earth compounds, organic or inorganic	1,660	1,630	1,690	1,760	1,600
Ferrocerium and pyrophoric alloys	3,830	2,460	2,360	2,300	2,500
Imports for consumption: e/					
Monazite	11	--	--	--	--
Cerium compounds	1,820	4,940	5,970	6,450	3,850
Ferrocerium and pyrophoric alloys	121	117	120	118	118
Metals, alloys, oxides, other compounds	10,000	8,950	17,200	17,300	15,200
Stocks, producers and processors, yearend	NA	NA	NA	NA	NA
Consumption, apparent	NA	NA	NA	NA	NA
Prices, yearend, per kilogram:					
Bastnasite concentrate, rare-earth oxide (REO) basis	$3.53 e/ r/	$4.19 e/	$4.85 e/	$5.51 e/	$5.51 e/
Monazite concentrate, REO basis	$0.73	$0.73	$0.73 e/	$0.73 e/	$0.73 e/
Mischmetal, metal basis	$8.45 3/	$16.00 3/	$16.00 3/	$16.00 3/	$16.00 3/
Employment, mine and mill	NA	NA	NA	NA	NA
Net import reliance as a percentage of apparent consumption 4/	(5/)	(5/)	(5/)	(5/)	(5/)

e/ Estimated. r/ Revised. NA Not available. -- Zero.
1/ Data are rounded to no more than three significant digits, except prices.
2/ Comprises only the rare earths derived from bastnasite as obtained from Molycorp, Inc.
3/ Source: Elements, TradeTech, Denver, CO.
4/ Imports minus exports plus adjustments for Government and industry stock changes.
5/ Net importer.

TABLE 2
RARE EARTH CONTENTS OF MAJOR AND POTENTIAL SOURCE MINERALS 1/

(Percentage of total rare-earth oxide)

Rare earth	Bastnasite, Mountain Pass, CA, USA 2/	Bastnasite, Bayan Obo, Inner Mongolia, China 3/	Monazite, North Capel, Western Australia 4/	Monazite, North Stradbroke Island, Queensland, Australia 5/	Monazite, Green Cove Springs, FL, USA 6/	Monazite, Nangang, Guangdong, China 7/
Cerium	49.10	50.00	46.00	45.80	43.70	42.70
Dysprosium	trace	.1000	.7000	0.6000	.9000	.8000
Erbium	trace	trace	.2000	.2000	trace	.3000
Europium	.1000	.2000	.0530	.8000	.1600	.1000
Gadolinium	.2000	.7000	1.49	1.80	6.60	2.00
Holmium	trace	trace	.0530	.1000	.1100	.1200
Lanthanum	33.20	23.00	23.90	21.50	17.50	23.00
Lutetium	trace	trace	trace	.0100	trace	.1400
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	.8000	.8000	2.53	3.10	4.90	3.00
Terbium	trace	.1000	.0350	.3000	.2600	.7000
Thulium	trace	trace	trace	trace	trace	trace
Ytterbium	trace	trace	.1000	.1000	.2100	2.40
Yttrium	0.10	trace	2.40	2.50	3.20	2.40
Total	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000

See footnotes at end of table.

TABLE 2--Continued
RARE EARTH CONTENTS OF MAJOR AND POTENTIAL SOURCE MINERALS 1/

(Percentage of total rare-earth oxide)

	Monazite, East coast, Brazil 8/	Monazite, Mount Weld, Australia 9/	Xenotime, Lahat, Perak, Malaysia 2/	Xenotime, southeast, Guangdong, China 10/	Rare earth laterite Xunwu, Jiangxi Province, China 11/	Rare earth laterite Longnan, Jiangxi Province, China 11/
Cerium	47.00	51.00	3.13	3.00	2.40	.4000
Dysprosium	.4000	.2000	8.30	9.10	trace	6.70
Erbium	.1000	.2000	6.40	5.60	trace	4.90
Europium	.1000	.4000	trace	.2000	.5000	0.10
Gadolinium	1.00	1.00	3.50	5.00	3.00	6.90
Holmium	trace	.1000	2.00	2.60	trace	1.60
Lanthanum	24.00	26.00	1.24	1.20	43.40	1.82
Lutetium	not determined	trace	1.00	1.80	.1000	.4000
Neodymium	18.50	15.00	1.60	3.50	31.70	3.00
Praseodymium	4.50	4.00	.5000	.6000	9.00	.7000
Samarium	3.00	1.80	1.10	2.20	3.90	2.80
Terbium	.1000	.1000	.9000	1.20	trace	1.30
Thulium	trace	trace	1.10	1.30	trace	.7000
Ytterbium	.0200	.1000	6.80	6.00	.3000	2.50
Yttrium	1.40	trace	61.00	59.30	8.00	65.00
Total	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000

1/ Data are rounded to no more than three significant digits; may not add to totals shown.
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4/ Westralian Sands Ltd., 1979, Product specifications, effective January 1980: Capel, Australia, Westralian Sands Ltd. brochure, 8 p.
5/ Analysis from Consolidated Rutile Ltd.
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8/ Krumholz, Pavel, Brazilian practice for monazite treatment—Proceedings of the Symposium on Rare Metals, p. 78-82. (preprint).
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, Proceedings: Sydney, Australia, Lynas Gold NL, 8 p.
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TABLE 3
RHODIA RARE EARTH OXIDE PRICES IN 2001

Product (oxide)	Purity percentage	Standard package quantity (kilograms)	Price (dollars per kilogram)
Cerium	96.00	25	$19.20
Do.	99.50	900	31.50
Dysprosium	99.00	3	120.00
Erbium	96.00	2	155.00
Europium	99.99	1	990.00 1/
Gadolinium	99.99	3	130.00
Holmium	99.90	10	440.00 2/
Lanthanum	99.99	25	23.00
Lutetium	99.99	2	3,500.00
Neodymium	95.00	20	28.50
Praseodymium	96.00	20	36.80
Samarium	99.90	25	360.00
Do.	99.99	25	435.00
Scandium	99.99	1	6,000.00
Terbium	99.99	5	535.00
Thulium	99.90	5	2,300.00
Ytterbium	99.00	10	340.00
Yttrium	99.99	50	88.00

1/ Price for quantity greater than 40 kilograms is $900.00 per kilogram.
2/ Price for quantity less than 10 kilograms is $485.00 per kilogram.

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

	2000		2001	
Category and country 2/	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Cerium compounds: (2846.10.0000)				
Australia	5,630	$39,000	2,740	$15,400
Belgium	86,000	1,580,000	104,000	211,000
Brazil	205,000	337,000	241,000	486,000
Canada	201,000	1,520,000	300,000	2,640,000
France	124,000	515,000	121,000	401,000
Germany	832,000	2,460,000	518,000	1,900,000
Hong Kong	60,100	359,000	35,700	357,000
India	4,070	37,800	89,400	557,000
Japan	213,000	1,550,000	462,000	2,580,000
Korea, Republic of	1,150,000	4,950,000	1,080,000	4,900,000
Malaysia	178,000	889,000	122,000	594,000
Mexico	216,000	1,490,000	232,000	1,640,000
Netherlands	206,000	697,000	11,100	96,200
Singapore	15,100	83,100	13,600	69,900
South Africa	6,000	108,000	988	10,400
Taiwan	237,000	976,000	286,000	1,260,000
United Kingdom	133,000	400,000	386,000	703,000
Other	172,000	997,000	477,000	1,700,000
Total	4,050,000	19,000,000	4,490,000	20,100,000
Total estimated equivalent rare-earth oxide (REO) content	4,050,000	19,000,000	4,490,000	20,100,000
Rare-earth compounds: (2846.90.0000)				
Austria	80,000	2,230,000	30,000	885,000
Brazil	10,000	45,400	114	46,600
Canada	208,000	2,850,000	148,000	1,640,000
China	197,000	369,000	69,300	244,000
Colombia	13,100	3,100	--	--
Finland	82,000	2,720,000	17,200	578,000
France	60,900	936,000	77,700	403,000
Germany	48,600	1,010,000	43,300	1,810,000
India	76,800	231,000	91,200	519,000
Japan	39,100	1,410,000	35,100	1,800,000
Korea, Republic of	204,000	1,550,000	161,000	1,020,000
Mexico	8,080	114,000	50,100	422,000
Taiwan	284,000	7,980,000	119,000	3,510,000
United Kingdom	47,900	656,000	28,900	1,420,000
Other	401,000	2,590,000	812,000	4,020,000
Total	1,760,000	24,700,000	1,680,000	18,300,000
Total estimated equivalent REO content	1,760,000	24,700,000	1,680,000	18,300,000
Rare-earth metals, including scandium and yttrium: (2805.30.0000)				
China	299	74,000	12	37,200
France	125	4,510	1,110	34,600
Germany	2,270	155,000	4,780	244,000
Japan	1,180,000	3,110,000	438,000	1,520,000
Korea, Republic of	19,700	192,000	817	92,900
Taiwan	996	18,600	1	4,800
United Kingdom	15,000	250,000	1,940	281,000
Other	149,000	6,030,000	295,000	4,310,000
Total	1,370,000	9,830,000	742,000	6,520,000
Total estimated equivalent REO content	1,650,000	9,830,000	891,000	6,520,000
Ferrocerium and other pyrophoric alloys: (3606.90.0000)				
Argentina	26,600	61,500	25,800	161,000
Australia	3,600	107,000	1,830	58,300
Brazil	436	11,000	7,740	26,100
Canada	1,020,000	2,100,000	915,000	1,790,000
Chile	25,100	31,300	29,700	35,500
Colombia	1,000	3,510	17,300	23,200
Costa Rica	831	3,000	99	6,500
France	3,580	153,000	3,540	111,000
Germany	55,100	155,000	289,000	433,000
Greece	30,700	73,600	33,700	74,500

See footnotes at end of table.

TABLE 4--Continued
U.S. EXPORTS OF RARE EARTHS, BY COUNTRY 1/

Category and country 2/	2000 Gross weight (kilograms)	2000 Value	2001 Gross weight (kilograms)	2001 Value
Ferrocerium and other pyrophoric alloys--Continued: (3606.90.0000)				
Hong Kong	240,000	$547,000	238,000	$627,000
Ireland	227	3,900	--	--
Italy	3,340	82,300	818	9,930
Japan	213,000	1,230,000	126,000	1,440,000
Korea, Republic of	1,890	41,700	3,250	85,200
Kuwait	38,200	74,900	16,500	22,000
Mexico	85,500	699,000	49,000	1,140,000
Netherlands	83,100	270,000	70,400	220,000
New Zealand	12,900	36,900	35,700	65,300
Saudi Arabia	225	5,890	--	--
Singapore	37,100	112,000	37,500	131,000
South Africa	1,550	137,000	42,800	103,000
Spain	12	8,320	--	--
Taiwan	40,300	77,000	55,600	74,100
United Arab Emirates	262,000	316,000	314,000	308,000
United Kingdom	39,400	177,000	165,000	426,000
Other	365,000	1,090,000	381,000	666,000
Total	2,590,000	7,620,000	2,860,000	8,030,000
Total estimated equivalent REO content	2,300,000	7,620,000	2,540,000	8,030,000

-- 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 5
U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY 1/

Category and country 2/	2000 Gross weight (kilograms)	2000 Value	2001 Gross weight (kilograms)	2001 Value
Cerium compounds, including oxides, hydroxides, nitrates, sulfate chlorides, oxalates: (2846.10.0000)				
Austria	49,600	$468,000	59,000	$439,000
China	3,470,000	13,500,000	4,060,000	14,000,000
France	2,390,000	7,130,000	1,240,000	6,650,000
Japan	410,000	7,820,000	288,000	6,500,000
Other	134,000	561,000	115,000	737,000
Total	6,450,000	29,400,000	5,760,000	28,300,000
Total estimated equivalent rare-earth oxide (REO) content	4,310,000	29,400,000	3,870,000	28,300,000
Yttrium compounds content by weight greater than 19% but less than 85% oxide equivalent: (2846.90.4000)				
China	47,600	847,000	107,000	1,560,000
France	16,000	260,000	14,300	305,000
Germany	8,000	250,000	--	--
Japan	18,600	1,080,000	8,190	2,420,000
United Kingdom	623	8,410	262	9,340
Other	6,640	144,000	30	15,600
Total	97,400	2,590,000	130,000	4,310,000
Total estimated equivalent REO content	58,400	2,590,000	77,900	4,310,000
Rare-earth compounds, including oxides, hydroxides, nitrates, other compounds except chlorides: (2846.90.8000)				
Austria	23,600	732,000	38,900	1,300,000
China	7,840,000	21,400,000	8,850,000	31,000,000
Estonia	560,000	335,000	900,000	769,000
France	6,090,000	16,400,000	1,820,000	11,400,000
Germany	9,700	855,000	42,000	1,280,000

See foonotes at end of table.

TABLE 5 --Continued

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

	2000		2001	
	Gross weight		Gross weight	
Category and country 2/	(kilograms)	Value	(kilograms)	Value
Rare-earth compounds, including oxides, hydroxides, nitrates, other compounds except chlorides--Continued: (2846.90.8000)				
Hong Kong	524	$34,200	--	--
Japan	327,000	10,700,000	302,000	$7,550,000
Norway	22,000	12,800,000	34,500	14,800,000
Russia	2,430	42,200	124,000	196,000
Taiwan	--	--	18,000	48,900
United Kingdom	84,300	7,820,000	41,900	4,600,000
Other	3,810	205,000	26,000	195,000
Total	15,000,000	71,300,000	12,200,000	73,000,000
Total estimated equivalent REO content	11,200,000	71,300,000	9,150,000	73,000,000
Mixtures of REOs except cerium oxide: (2846.90.2010)				
Austria	6,950	348,000	--	--
China	2,120,000	5,070,000	2,030,000	8,160,000
France	445	14,500	3	2,050
Germany	7,570	191,000	1,740	93,300
Japan	24,300	3,450,000	7,160	655,000
Russia	75	33,700	301	141,000
United Kingdom	25,100	376,000	386	14,300
Other	6,210	54,500	5,770	89,600
Total	2,190,000	9,530,000	2,040,000	9,160,000
Total estimated equivalent REO content	2,190,000	9,530,000	2,040,000	9,160,000
Rare-earth metals, whether intermixed or alloyed: (2805.30.0000)				
China	1,420,000	13,600,000	613,000	7,660,000
Hong Kong	33,600	526,000	566	2,520
Japan	555,000	8,480,000	546,000	6,350,000
Russia	10	7,000	--	--
United Kingdom	42,100	982,000	16,700	278,000
Other	3,240	139,000	6,810	115,000
Total	2,060,000	23,700,000	1,180,000	14,400,000
Total estimated equivalent REO content	2,470,000	23,700,000	1,420,000	14,400,000
Mixtures of rare-earth chlorides, except cerium chloride: (2846.90.2050)				
China	1,800,000	1,820,000	4,020,000	6,180,000
France	17,200	332,000	26,600	549,000
India	913,000	756,000	1,490,000	1,720,000
Japan	21,800	660,000	1,510	110,000
United Kingdom	56,100	221,000	20,400	101,000
Other	83,600	192,000	65,100	403,000
Total	2,900,000	3,980,000	5,620,000	9,060,000
Total estimated equivalent REO content	1,330,000	3,980,000	2,590,000	9,060,000
Ferrocerium and other pyrophoric alloys: (3606.90.3000)				
Austria	15,300	262,000	16,300	267,000
Brazil	3,000	56,500	--	--
France	107,000	1,130,000	113,000	1,170,000
Other	7,630	112,000	3,310	33,200
Total	133,000	1,560,000	132,000	1,470,000
Total estimated equivalent REO content	118,000	1,560,000	118,000	1,470,000

-- 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 number.

Source: U.S. Census Bureau.

TABLE 6
RARE EARTHS: WORLD MINE PRODUCTION, BY COUNTRY 1/ 2/

(Metric tons of rare earth oxide equivalent)

Country 3/	1997	1998	1999	2000	2001 e/
China e/	53,000	60,000	70,000	73,000	80,600
India e/	2,700	2,700	2,700	2,700	27,000
Kyrgyzstan:					
Compounds	NA	691	956	NA	NA
Metals	NA	6,355	5,159	7,736	3,800
Malaysia	418	282 r/	625	446 r/	280
Soviet Union, former e/ 4/	2,000	2,000	2,000	2,000	2,000
Sri Lanka e/	120	120	120	-- r/	--
Thailand	12	-- e/	--	-- e/	--
United States e/ 5/	10,000	5,000	5,000	5,000	5,000
Total	68,300	77,100 r/	86,600 r/	90,900 r/	119,000

e/ Estimated. r/ Revised. NA Not available. -- Zero.
1/ World totals, U.S. data, and estimated data have been rounded to three significant digits; may not add to totals shown.
2/ Table includes data available through June 13, 2002.
3/ In addition to the countries listed, rare-earth minerals are believed to be produced in Indonesia, Mozambique, Nigeria, North Korea, and Vietnam, but information is inadequate for formulation of reliable estimates of output levels.
4/ The Soviet Union dissolved in December 1991; however, information is inadequate to formulate reliable estimates for individual producing countries, including Kazakhstan, Russia, and Ukraine.
5/ Comprises only the rare earths derived from bastnasite.

TABLE 7
MONAZITE CONCENTRATE: WORLD PRODUCTION, BY COUNTRY 1/ 2/

(Metric tons, gross weight)

Country 3/	1997	1998	1999	2000 e/	2001 e/
Brazil e/	200 r/ 4/	200 r/	200 r/	200 r/	200
India e/	5,000	5,000	5,000	5,000	5,000
Madagascar	100 e/ 5/	-- 5/	-- 5/	--	--
Malaysia	767	517	1,147	818 r/ 4/	510
Sri Lanka e/	200	200	200	-- r/	--
Thailand	12	--	--	--	--
Total	6,280 r/	5,920 r/	6,550 r/	6,020 r/	5,710

e/ Estimated. 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, 2002.
3/ In addition to the countries listed, China, Indonesia, Nigeria, North Korea, the Republic of Korea, and successor countries of the former Soviet Union may produce monazite; available general information is inadequate for formulation of reliable estimates of output levels.
4/ Reported figure.
5/ Source: World Mineral Statistics, British Geological Survey, 1995-1999.

FIGURE 1
PRINCIPAL SOURCES OF U.S. IMPORTS OF RARE EARTHS IN 2001, BY WEIGHT