RARE EARTHS

By James B. Hedrick

The rare earths are a relatively abundant group of elements that range in crustal abundance from cerium, the 25th most abundant element of the 78 common elements at 60 parts per million, to lutetium, the 61st most abundant element at 0.5 part per million. 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. With 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 ytterbite by Finnish chemist Johann Gadolin. The elemental forms of rare earths are iron gray to silvery lustrous metals; typically soft, malleable, and 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 rare earths' unique properties are used in a wide variety of applications.

Domestic mine production of rare earths decreased in 1996. The domestic economy continued to improve, and inflation, based on the Bureau of Labor Statistics consumer price index, increased at the low rate of 3%. Estimated domestic apparent consumption increased again in 1996 because demand was strong for rare-earth compounds used in automotive catalytic converters, permanent magnets, and rechargeable rare-earth-nickel hydride batteries. Earnings by the major domestic processor also reportedly increased amid gains in sales. *(See table 1.)* Demand also increased for rare earths used in petroleum fluid cracking catalysts, while rare-earth phosphors for television, x-ray intensifying, and fluorescent and incandescent lighting remained stable. Yttrium was used primarily in lamp and cathode-ray tube phosphors, structural ceramics, and oxygen sensors.

The domestic use of scandium increased in 1996, but overall consumption remained small. Commercial demand increased as new applications entered the market. Most metal and compounds were sold for metallurgical research and analytical standards. Minor amounts were used in specialty lighting and semiconductors.

Legislation and Government Programs

The calendar year 1996 included parts of the U.S. Government fiscal years for 1996 and 1997. Public Law 104-106, the National Defense Authorization Act for Fiscal Year 1996, was not enacted until February 10, 1996, because of significant delays in the Congressional budget process and a Presidential veto. The National Defense Authorization Act for Fiscal Year 1997, Public Law 104-201, was enacted on September 23, 1996. All stocks of rare earths in the National Defense Stockpile (NDS) were previously sold; however, at yearend 1996 the NDS contained 455 metric tons (501 short tons) of unshipped rare earths contained in sodium sulfate.

Production

Domestic mine production data for rare earths are developed by the U.S. Geological Survey (USGS) from a voluntary survey of U.S. operations entitled, "Rare Earths." The one mine to which a survey form was sent responded, representing 100% of domestic mine production. Mine production data from one source, which is typically withheld to avoid disclosing company proprietary data, was authorized for release by Molycorp, Inc. (bastnasite concentrate only).

The United States remained a major world producer of rare earths in 1996 with only one domestic mine in operation. Domestic production was entirely from Molycorp, a wholly owned subsidiary of Unocal Corp. Bastnasite, a rare-earth fluorocarbonate mineral, was mined by open pit methods at Mountain Pass, CA. Molycorp's mine was the leading producer of rare earths in the United States and second in the world. Mine production, as reported from company sources, decreased from the previous year's level of 22,200 tons of rare-earth oxide (REO) to 20,400 tons REO in 1996.

Refined lanthanides were produced by three companies in 1996. Molycorp produced refined compounds from bastnasite at its separation plant at Mountain Pass, CA.

Rhône-Poulenc Basic Chemicals Co. (RP) produced lanthanide compounds from rare-earth intermediate compounds at its facility at Freeport, TX. A new production unit was started at RP's Freeport site to produce rare-earth catalysts. The catalysts will be used in automobile emission-control catalytic converters. The catalyst is a mixture of cerium, praseodymium, lanthanum, yttrium, sodium, and zirconium (Industrial Minerals, 1996h). Grace Davison refined rare earths for petroleum fluid cracking catalysts from rare-earth chlorides and other rare-earth compounds at Chattanooga, TN.

Except for minor amounts of yttrium contained in domestically produced bastnasite concentrates, essentially all purified yttrium was derived from imported compounds.

Three scandium processors operated in 1996. High-purity products were available in various grades with scandium oxide produced up to 99.999% purity.

Sausville Chemical Co. refined scandium concentrates at its facilities in Garfield, NJ, to produce high-purity scandium oxide, fluoride, nitrate, chloride, and acetate. Joint-venture research partner Recovery Dynamics of Johnson City, TN, will locate its new refinery facility in Elizabethton, TN. The joint venture is expected to start scandium refining by yearend 1997 on a larger scale than previously available.

Boulder Scientific Co. processed scandium at its Mead, CO, operations. Boulder refined scandium primarily from imported oxides to produce high-purity scandium compounds, including diboride, carbide, chloride, fluoride, hydride, nitride, oxalate, and tungstate.

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

Principal domestic producers of neodymium-iron-boron magnet alloys were Magnequench International, Inc., Anderson, IN; Neomet Corp., West Pittsburg, PA; and Rhône-Poulenc Basic Chemicals Co., Phoenix, AZ. Leading U.S. producers of rare-earth magnets were Magnequench International, Anderson, IN; Hitachi Magnetics, Edmore, MI; Crucible Materials, Elizabethtown, KY; and Ugimag, Valparaiso, IN.

Consumption

Statistics on domestic rare-earth consumption are developed by surveying various processors and manufacturers, evaluating import-export data, and analyzing U.S. Government stockpile shipments. Domestic apparent consumption of rare earths increased in 1996 compared with that of 1995. Domestic production of mischmetal, rare-earth silicide, and other rare-earth alloys in 1996 was essentially the same as that in 1995, while consumption of the alloys increased. Shipments of mixed rare-earth alloys declined 13%. Consumption of mixed rare-earth compounds showed a gain as demand continued for mixed intermediates for petroleum fluid cracking catalysts and automotive catalytic converters. Domestic shipments of mixed compounds decreased 56% in 1996.

The approximate distribution of rare earths by use, based on information supplied by U.S. rare-earth refiners, selected consumers, and analysis of import data, was as follows: automotive catalytic converters, 46%; petroleum refining catalysts, 25%; permanent magnets, 12%; glass polishing and ceramics, 7%; metallurgical additives and alloys, 7%; rare-earth phosphors for lighting, televisions, computer monitors, radar, and x-ray intensifying film, 3%; and miscellaneous, less than 1%.

Yttrium consumption was estimated by the USGS commodity specialist at 207 tons for 1996, a decrease of 158 tons from that of 1995. The approximate distribution of yttrium by end use, based on analysis of import data, was as follows: lamp and cathode-ray tube (CRT) phosphors, 98%; and oxygen sensors and miscellaneous, 2%. Yttrium compounds were sourced from China, 80.8%, and Japan, 19.2%.

Tariffs

U.S. tariff rates, specific to the rare earths, including scandium and yttrium, were changed slightly in 1996. Revisions to the Harmonized Tariff duty for cerium compounds (2846.10.00) decreased for most-favored-nation status from 6.5% ad valorem to 6.2% ad valorem. A tariff of 3 cents per kilogram was added to “mineral substances, not elsewhere specified or included” (2530.90.0050), which includes rare-earth metal ores, excluding monazite. Special rare-earth tariffs for Canada and Mexico were the result of Presidential Proclamation 6641, implementing the North American Free Trade Agreement (NAFTA), effective January 1, 1994.

Under the agreement, Mexico’s tariff for “rare-earth metals, including yttrium and scandium, whether intermixed or interalloyed” (2805.30.00) decreased from 2% ad valorem to 1% ad valorem. Mexico’s tariff for “aluminum alloys, other” (7601.20.9090), which would include scandium-aluminum alloys, decreased from 1.6% ad valorem to 1.2% ad valorem. For all other rare-earth Harmonized Tariff Schedule classifications, Canada and Mexico were granted free status. Tariff rates for most other foreign countries were negotiated under the Generalized Agreement on Tariffs and Trade (GATT) Uruguay Round of Multilateral Trade Negotiation. New staged rate schedules taking effect January 1, 1996, were negotiated at the GATT Uruguay Round of negotiations in 1994. U.S. tariff rates for rare earths are listed in the Harmonized Tariff Schedule of the United States (1996), publication 2937, with supplement, and the Harmonized Tariff Schedule of the United States (1997), publication 3001, as compiled by the United States International Trade Commission. U.S. tariffs are available in Publication 3001 from the U.S. Government Printing Office under document serial number 949-013-00000-6 File Code 1A.

Stocks

U.S. Government stocks of rare earths in the National Defense Stockpile remained at 455 tons throughout 1996. Rare-earth stocks held in the stockpile were contained in sodium sulfate and were inventoried on a contained-REO basis. All NDS stocks of rare earths were previously sold and were being held for shipment.

Prices

Rare-earth prices were mixed in 1996. Domestic prices for cerium were unchanged while neodymium prices decreased slightly. Prices decreased slightly for dysprosium, erbium, gadolinium, holmium, and lutetium, while most other rare-earth oxide prices remained unchanged. The following prices were estimated by the USGS specialist based on domestic trade data from various sources. The price of rare-earth chloride in 1996 was $2.60 per kilogram, while cerium concentrate prices were $27.14 per kilogram. All rare-earth prices remained nominal and subject to change without notice. Competitive pricing policies remained in effect with prices for most rare-earth products quoted on a daily basis.

The estimated market price for bastnasite concentrate was $3.91 per kilogram. The price range of Australian monazite (minimum 55% rare-earth oxide including thoria, free-on-board/free into container depot), as quoted in Australian dollars (A$), remained unchanged at the previous years range of A$300 to A$350 per ton. Changes in the United States-Australia foreign exchange rate in 1996, resulting from a weaker U.S. dollar on world markets, caused the U.S. dollar exchange rate to be down $0.07 against the Australian dollar at yearend. The U.S. price range, converted from Australian dollars, increased slightly to US$244 to US$285 per ton at yearend 1996, compared with US$222 to US$259 per ton at yearend 1995 (Metal Bulletin, 1995, 1996). Prices for monazite remained depressed because several principal world rare-earth processors continued to process only thorium-free feed materials.

The nominal price for basic neodymium-iron-boron alloy, compiled by the author from several U.S. producers, was unchanged from 1995's price of $28.43 per kilogram ($12.90 per pound), free-on-board (f.o.b.) shipping point, 1,000-pound minimum. Most alloy was sold with additions of cobalt (up to 15%, typically 4% to 6%) or dysprosium (up to 3%). The cost of the additions was based on market pricing; with the average cobalt price decreasing in 1996 to $56.22 per kilogram (average $25.50 per pound), the cost would be about $0.56 for each percent addition per kilogram ($0.26 for each percent addition per pound).

Standard-grade domestic mischmetal was priced slightly lower than the previous year at $9.50 per kilogram.

Rhône-Poulenc 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 1996, as shown in table 2. *(See table 2)*

No published prices for scandium oxide in kilogram quantities were available. Yearend 1996 nominal prices for scandium oxide per kilogram were compiled by the author from information from several domestic suppliers and processors. Prices decreased slightly from those of the previous year for most grades and were listed as follows: 99% purity, $1,400; 99.9% purity, $2,900; 99.99% purity, $4,400; and 99.999% purity, $6,750.

Scandium metal prices for 1996, as listed by the Johnson Matthey Alfa AESAR catalog, were unchanged from those in 1995 as follows: 99.99% REO purity, lump, sublimed dendritic, ampouled under argon, $169 per gram; 99.9% REO purity, <250-micron powder, ampouled under argon, $559 per 2 grams; and 99.9% purity, lump, sublimed dendritic lump, ampouled under argon, $442 per 2 grams; 99.9% REO purity, foil, 0.025 millimeter thick, ampouled under argon, 25 millimeters by 25 millimeters, $95 per item (Alfa AESAR, 1995).

Scandium compound prices for 1996, as listed by Aldrich Chemical Co., were as follows: scandium acetate hydrate 99.9% purity, $42.30 per gram; scandium chloride hydrate $99.99% purity, $56.90 per gram; scandium nitrate hydrate 99.9% purity, $54.80; and scandium sulfate pentahydrate 99.9% purity, $60.05 per gram. Prices for standard solutions for calibrating analytical equipment were $21.85 per 100 milliliters of scandium atomic absorption standard solution and $338.15 per 100 milliliters of scandium plasma standard solution (Aldrich, 1996).

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

Foreign Trade

Exports and imports of rare earths increased in 1996. U.S. exports totaled 13,500 kilograms valued at $79 million, a 23% increase in quantity and 18% increase in value. Imports totaled 23,800 kilograms gross weight valued at $139 million, a 40% increase in quantity and nearly 15% increase in value compared with that of 1995.

Exports of rare earths increased in three out of four trade categories in 1996. U.S. exports are shown in table 3. The United States exported 208,000 kilograms of rare-earth metals, a 44% decrease from that of 1995, valued at $4.5 million. Principal destinations in descending order were Japan, France, the United Kingdom, and the Republic of Korea. Exports of cerium compounds, primarily for glass polishing and automotive catalytic converters, increased 19% to 6,100,000 kilograms valued at $37.9 million. Major destinations were the Republic of Korea, Singapore, Germany, and Taiwan.

Exports of inorganic and organic rare-earth compounds increased from 1,550,000 kilograms in 1995 to 2,210,000 kilograms in 1996, while the value of the shipments increased 7% to $13.4 million. Shipments, in descending order of quantity, were to Brazil, Colombia, Canada, and Japan.

U.S. exports of ferrocerium and other pyrophoric alloys increased from 3,910,000 kilograms to 4,970,000 kilograms valued at $21.1 million. Principal destinations were Jordan, Canada, Germany, and Hong Kong.

The approximate distribution of imports based on analysis of Journal of Commerce data was as follows: automotive catalytic converters, 37%; petroleum refining catalysts, 16%; phosphors for lighting, televisions, computer monitors, radar, and x-ray intensifying film, 4%; metallurgical additives and alloys, 9%; permanent magnets, 15%; glass polishing and ceramics, 17%; ferrocerium and pyrophoric alloys, 2%; and miscellaneous, less than 1%.

Imports of compounds and alloys increased for five out of seven categories. U.S. imports are shown in table 4. China and France dominated the import market, especially for mixed and individual rare-earth compounds. *(See table 4)*

Cerium compounds accounted for 4,760,000 kilograms of imports valued at $30 million. The quantity of cerium compounds imported increased 16% due to continued demand for automotive exhaust catalysts. China was the major supplier for the second year in a row.

Imports of yttrium compounds containing between 19 weight-percent and 85 weight-percent oxide equivalent (yttrium concentrate) increased 37% in 1996. France was the leading supplier of yttrium compounds in this category.

Individual rare-earth compounds, excluding cerium compounds, accounted for the major share of rare-earth imports.

Imports increased 76% in 1996 to 15,300,000 kilograms valued at $67.6 million. The major sources of individual rare-earth compounds were China and France with the value of the imports increasing 19%.

Imports of mixtures of rare-earth oxides, other than cerium oxide, increased almost 30% to 879,000 kilograms valued at $21.9 million. Principal sources in descending order were China, Japan, and Austria. Imports of rare-earth metals and alloys into the United States totaled 357,000 kilograms in 1996, a 53% decrease from the 1995 level. Valued at $3.7 million, the principal rare-earth metal sources were China and the United Kingdom. Metal imports decreased as demand for permanent magnet alloys was met primarily from domestic supplies.

Imports of rare-earth chlorides fell 14.3% in 1996 to 2,330,000 kilograms valued at $12.4 million. Supplies of rare-earth chloride came primarily from India, China, and Japan. Rare-earth chloride was used mainly as feed material for manufacturing fluid cracking catalysts. Imports of ferrocerium and pyrophoric alloys increased 36% to 120,000 kilograms valued at $1.98 million. Principal suppliers in descending order were France, Austria, and Brazil.

World Review

China, India, and the United States were major sources of rare-earth chlorides, nitrates, and other concentrates and compounds. Thorium-free intermediate compounds were still in demand as refinery feed as industrial consumers expressed concerns with radioactive thorium's potential liabilities, the costs of complying with environmental monitoring and regulations, and escalating costs at approved waste disposal sites. Demand for rare earths increased in Asia, Europe, and the United States as most world economies continued to improve.

World reserves of rare earths were estimated by the USGS at 100 million tons of contained REO. China has the largest share of world reserves with 43%.

Australia.—BHP Titanium Minerals Pty. Ltd. neared completion of its Beenup heavy-mineral sands mine. The $200 million project, announced in December 1994, was expected to begin production in early 1997. The mining and ilmenite smelting project was expected to employ 120 people (Department of Resource Development, 1996).

Consolidated Rutile Ltd. (CRL) relocated its dredge and floating wet concentrator from its depleted Bayside location to its Ibis-Alpha deposit on North Stradbroke Island, Queensland. During the relocation CRL, invested A$21 million to upgrade the concentrator to process 3,000 tons of mineral sands per hour, including all relocation and construction costs. Mine life of the Ibis-Alpha deposit is expected to be 9 years (Industrial Minerals, 1996g).

Brazil.—Decommissioning of the São Paulo rare-earth separation plant, which began in 1992, continued as Indústrias Nucleares do Brazil SA (INB) cleaned up natural radioactivity associated with thorium byproduct and waste. A new pilot separation plant at Buena, Rio de Janeiro, produced oxides of cerium, lanthanum, praseodymium, neodymium, samarium, and a europium-gadolinium concentrate from rare-earth chloride. A full-scale plant at Buena is scheduled for completion by yearend 1997 at a cost of $7 million. Feed for the new rare-earth plant, which is slated to produce 1,560 tons of rare-earth chloride per year, is from INB's monazite-bearing mine at Buena Norte, Rio de Janeiro (Industrial Minerals, 1996a).

Canada.—Ming Financial Corp. (Vancouver) and Iron Ore Co. of Canada (Montreal) signed an agreement to develop the Strange Lake rare-earth deposit on the border of Quebec and Labrador. Ming Financial will reportedly earn an interest in the deposit and ownership rights based on funding feasibility and development of the site (Victoria Times-Colonist, 1996). The deposit is unique in its mineralogy. The Strange Lake deposit contains 55 million tons of ore grading 3% zirconium oxide, 0.38% yttrium oxide, 0.29% niobium oxide, 0.076% beryllium oxide, and additional rare-earth oxides. The ore at Strange Lake is contained in an alkalic granitic complex of Precambrian age. The principal ore minerals are pyrochlore, gittinsite, and gadolinite (Bish Chanda, Iron Ore Company of Canada, written commun., 1983).

China.—A new rare-earth refining plant started production in July in Chenyang, Liaoning Province. Operated by Xingguang North Rare Earths Materials Co. Ltd., the plant had a capacity of 2,000 tons per year cerium oxide and cerium chloride.

Panxi Rare Earth Co. Ltd. of Xichang City, Sichuan Province, began processing bastnasite at its new plant to process 2,000 tons per year of bastnasite into lanthanum-lanthanide chloride, cerium carbonate, and cerium chloride (Industrial Minerals, 1996e).

Advanced Materials Resources Ltd. (AMR) of Toronto, Canada, announced plans to increase cerium carbonate production at its Zibo refinery in Shandong Province, China. The expansion of 960 tons per year will be added to existing capacity at Zibo of 750 tons per year. AMR continued to seek Chinese Government approval to install a refining plant at the Mianning rare-earth carbonatite, presently mined by the Mianning County Mining Co., Sichuan Province (Industrial Minerals, 1996b).

France.—Rhône-Poulenc SA (France) and Navistar International Corp. (U.S.) announced a joint venture to develop technology to reduce diesel emissions using cerium. The companies reported reduced emissions using a Navistar diesel engine and Rhône-Poulenc's cerium additive that exceeds the U.S. Government's emission standard for the year 2004. The additive was used in standard-grade diesel fuel to reduce both particulate and nitrogen oxide emissions (Chemical Market Reporter, 1997).

Mozambique.—BHP Minerals Ltd. (Australia) and Kenmare Resources PLC (Ireland) formed a joint venture to explore and possibly develop the Congolone coastal mineral sands deposit northeast of Angoche (Industrial Minerals, 1996d). According to Kenmare, the heavy-mineral sands deposit contains 6.5% ilmenite, 0.2% rutile, 0.4% zircon, 0.1% monazite, and 0.6% magnetite (Kenmare Resources PLC, 1988). Reserves at

Congolone were stated at 166.8 million tons of ore with an average grade of 3.25% heavy minerals (Mining Journal, 1989).

Gencor Ltd. and Edlow Resources, joint venture, TiGen, completed its prefeasibility study of heavy-mineral sands deposit near Moebase in northern Mozambique (Gencor Ltd., 1996). A drilling program of 30,000 meters delineated a resource of 1.3 billion tons of ore containing 3.8% heavy minerals, including monazite (U.S. State Department, 1997).

At Quelemane, also in northern Mozambique, a heavy-mineral sands deposit containing resources of 520 million tons of ore grading 4.5% heavy minerals was discovered. Genbique, a wholly owned exploration license holding company of Gencor Ltd., holds the exploration licenses at both the Moebase and Quelemane deposits (U.S. State Department, 1997).

South Africa.—Rare Earth Extraction Co. (Rareco) received approval to begin mining monazite at the Steentampskraal deposit north of Vanrhynsdorp, Cape Province. The Steentampskraal deposit was previously mined for its monazite. Production was expected to begin in 1998 at a rate of 24,000 tons per year. Mine life of the deposit is estimated to be 10 years at the planned rate. A rare-earth processing plant to be constructed at the site to produce 6,000 tons per year rare-earth chloride was expected to cost R$15 million. In a second phase of construction, Rareco expected to build a cerium refining plant to produce cerium carbonate for the automotive catalytic converter market (Industrial Minerals, 1996c).

Vietnam.—Westralian Sands Ltd. (WSL) (Australia) announced that it was withdrawing from its joint-venture heavy-mineral sands project, Austinh Ltd. The joint venture between WSL (60%), Meteco-Ha Tinh Mining Company (Vietnam) (30%), and Mideco—part of the Ministry of Industry (Vietnam) (10%) was involved in disputes throughout 1995 over Austinh's alleged violation of WSL's exclusive export rights. Two of the joint-venture partners, Meteco-Ha Tinh and Mideco then reportedly charged WSL for apparent misappropriation of funds and illegal imports of a processing plant and equipment, with the subsequent impounding of 41 containers of heavy minerals at Haiphong Port. WSL relinquished its marketing rights at the beginning of 1996 and by May had its foreign joint venture license revoked (Industrial Minerals, 1996f).

Three bastnasite-bearing deposits are reportedly located in the Phong Tho district of Lai Chau Province. Located near north Nam Xe, south Nam Xe, and Dong Pao, proven and probable reserves total 9.38 million tons of REO at an unspecified grade. The Vietnamese Government announced it had signed an agreement with LG Metal Group (Republic of Korea) to explore and develop the Dong Pao rare-earth deposit (Industrial Minerals, 1996f).

Outlook

Rare-earth usage in the United States and the rest of the world continues to grow in volume and diversity. The U.S. economy continued to improve in 1996 with inflation staying at a low rate. Consumption of rare earths increased substantially in most applications. Rare-earth markets are expected to continue to use greater amounts of higher purity mixed and separated products. Strong demand is expected to continue for rare earths used in automotive catalytic converters and permanent magnets, a trend that is expected to continue into the next decade. Future growth is forecast for rare earths in magnetic refrigeration, rechargeable nickel hydride batteries, fiber optics, and medical applications, including magnetic resonance imaging (MRI) contrast agents and dental and surgical lasers.

World reserves are sufficient to meet forecast world demand well into the 21st century. Several world-class rare-earth deposits in Australia and China have yet to be developed because world demand is currently being satisfied by existing production. Coupled with the likelihood that new deposits will continue to be located, world resources should be adequate to fulfill demand for the foreseeable future.

Domestic companies have shifted away from radioactive-bearing rare-earth ores. This trend has had a negative impact on monazite-producing mineral sands operations worldwide. Future long-term demand for monazite, however, is expected to increase due to its abundant supply and 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.

Domestic demand in 1997 is expected to exhibit moderation after the strong growth seen in 1995 and 1996. World markets are expected to continue to be very competitive based on lower wages and fewer environmental and permitting requirements. China and the United States are expected to remain significant rare-earth suppliers, while the future economic restructuring of Eastern Europe and Asia has a large potential for both new sources and new consumers.

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 continues to grow. It is likely that new applications will continue to be discovered and developed.

References Cited

Aldrich Chemical Co., Aldrich catalog handbook of fine chemicals 1996-1997: St. Louis, MO, 1996, p. 1309-1310.

Chemical Market Reporter, 1997, Rhône-Poulenc links with engine maker for cerium additive: Chemical Market Reporter, January 13, v. 2, no. 251, p. 3.

Department of Resource Development [Australia], 1996, Department of Resource Development, Western Australian Government, project listings: commissioned projects (Accessed July 15, 1997, on the World Wide Web at URL http://www.drd.wa.gov.au/pcommiss.htm).

Gencor Ltd., 1996, Gencor Ltd. annual report 1996: Johannesburg, South Africa, 108 p.

———(London), 1996a, Brazil—Dancing to a new tune: Industrial Minerals, November, no. 350, p. 21-51.

———1996b, China—AMR ups cerium output: Industrial Minerals, February, no. 341, p. 10.

———1996c, Green light for Cape rare earth mine: Industrial Minerals, December, no. 351, p. 18-20.

Industrial Minerals (London), 1996d, Kenmare & BHP sign Congolone jv: Industrial Minerals, August, no. 347, p. 74.

———1996e, Mineral notes—Chinese rare earths expanding: Industrial Minerals, November, no. 350, p. 99.
———1996f, Minerals of Vietnam: Industrial Minerals, November, no. 350, p. 75.
———1996g, New heavy mineral deposit for CRL: Industrial Minerals, December, no. 351, p. 67.
———1996h, New RE catalyst unit for Rhône-Poulenc: Industrial Minerals, August, no. 347, p. 23.
Johnson Matthey, 1995, Alfa AESAR 1995-96 catalog: 1995, Ward Hill, MA, p. 724.
Kenmare Resources PLC, 1988, Kenmare resources PLC annual report 1988: Dublin, Ireland, p. 14.
Metal Bulletin (London), 1995, Non-ferrous ores: Metal Bulletin, no. 8041, December 29, p. 21.
———1996, Non-ferrous ores: Metal Bulletin, no. 8141, December 31, p. 25.
Mining Journal (London), 1989, Congolone gets the go-ahead: Mining Journal, November 3, v. 313, no. 8044, p. 357-359.
U.S. Embassy, Pretoria, South Africa, January 1997, Mineral highlights: U.S. State Department Telegram 001178, (February 1997), p. 9-10.
Victoria Times-Colonist [Canada], 1996, Ming and IOC sign pact: July 18, 1996.

SOURCES OF INFORMATION

U.S. Geological Survey Publications

Rare-earth elements. Ch. in United States Mineral Resources, U.S. Geological Survey Professional Paper 820, 1973.

Rare Earths. Ch. in Mineral Commodity Summaries.[1]

Scandium. Ch. in Mineral Commodity Summaries.[1]

Thorium. Ch. in Mineral Commodity Summaries.[1]

Yttrium. Ch. in Mineral Commodity Summaries.[1]

Other

American Metal Market, daily.

China Rare Earth Information Newsletter (China).

Elements: Rare Earths, Specialty Metals, and Applied Technology.

European Rare-Earth and Actinide Society (ERES) Newsletter (Switzerland).

Industrial Minerals (London), monthly.

Metal Bulletin (London), semiweekly.

Rare Earth. Ch. in Mineral Facts and Problems, U.S. Bureau of Mines Bulletin 675, 1985.

Rare-earth Information Center INSIGHT.

Rare-earth Information Center News.

Roskill Information Service Ltd. (London). The Economics of Rare Earths, 9th edition, 1994.

Unocal Corp. annual report.

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[1]Prior to January 1996, published by the U.S. Bureau of Mines.

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

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

	1992	1993	1994	1995	1996
Production of rare-earth concentrates 2/	20,700	17,800	20,700	22,200	20,400
Exports:					
Cerium compounds	1,940	1,620	4,460	5,120	6,100
Rare-earth metals, scandium, and yttrium	44	194	329	444	250
Ores and concentrates	--	--	--	--	2
Rare-earth compounds, organic or inorganic	1,310	1,090	2,420	1,550	2,210
Ferrocerium and pyrophoric alloys	2,430	4,270	3,020	3,470	4,420
Imports for consumption: e/					
Monazite	--	--	--	40 r/	101
Metals, alloys, oxides, compounds	5,330	6,670	7,840	14,100	18,700
Stocks, producers and processors, yearend	W	W	W	W	W
Consumption, apparent e/	21,400	17,000	17,800	W	W
Prices, yearend, dollars per kilogram:					
Bastnasite concentrate, REO basis	$2.87	$2.87	$2.87	$2.87	$2.87
Monazite concentrate, REO basis	$0.41	$0.40	$0.46	$0.44	$0.48
Mischmetal, metal basis 3/	$12.68	$12.68	$12.68	$9.50	$8.75
Employment, mine and mill 4/	372	352	NA	NA	NA
Net import reliance 5/ as a percent of apparent consumption	33	(6/)	(6/)	(7/)	(7/)

e/ Estimated. r/ Revised. NA Not available. W Withheld to avoid disclosing company proprietary data.

1/ Data are rounded to three significant digits, except prices.

2/ Comprises only the rare earths derived from bastnasite as obtained from Molycorp, Inc., company representative.

3/ Source: Elements--Rare Earths, Specialty Metals and Applied Technology.

4/ Employment at a rare-earth mine in California and at a mineral sands operation in Florida. The latter mine produced monazite as a byproduct and employees were not assigned to specific commodities. The mineral sands operation in Florida ceased recovery of monazite at the end of 1994.

5/ Imports minus exports plus adjustments for Government and industry stock changes.

6/ Net exporter.

7/ Net importer.

TABLE 2
RHÔNE-POULENC RARE-EARTH OXIDE PRICES IN 1996

Product (oxide)	Percent purity	Standard package quantity (kilograms)	Price per kilogram
Cerium	95.00	25	$19.00
Cerium	99.50	25	23.00
Dysprosium	95.00	20	65.00
Erbium	96.00	20	150.00
Europium	99.99	10	700.00
Gadolinium	99.99	50	115.00
Holmium	99.90	10	485.00
Lanthanum	99.99	25	23.00
Lutetium	99.99	2	4,500.00
Neodymium	95.00	20	22.00
Praseodymium	96.00	20	32.00
Samarium	96.00	25	75.00
Terbium	99.90	5	685.00
Thulium	99.90	5	3,600.00
Ytterbium	99.00	10	230.00
Yttrium	99.99	50	85.00

TABLE 3
U.S. EXPORTS OF RARE-EARTHS, BY COUNTRY 1/

Country	1995 Quantity (kilograms)	1995 Value	1996 Quantity (kilograms)	1996 Value
Cerium compounds: (2846.10.0000)				
Brazil	25,200	$207,000	36,200	$515,000
Canada	499,000	5,950,000	447,000	4,740,000
Egypt	36,000	221,000	72,000	249,000
France	9,730	55,200	84,200	269,000
Germany	78,200	573,000	570,000	3,810,000
Hong Kong	51,600	394,000	20,700	173,000
India	17,500	96,100	140,000	521,000
Japan	492,000	6,630,000	441,000	4,950,000
Korea, Republic of	1,660,000	8,600,000	2,210,000	11,800,000
Malaysia	218,000	4,610,000	494,000	3,960,000
Mexico	33,900	267,000	54,400	450,000
Singapore	1,490,000	5,380,000	830,000	2,630,000
Taiwan	373,000	1,500,000	551,000	2,250,000
United Kingdom	10,500	278,000	25,900	475,000
Other	118,000 r/	743,000 r/	120,000	1,140,000
Total	5,120,000	35,500,000	6,100,000	37,900,000
Rare-earth compounds: (2846.90.0000)				
Austria	6,510	147,000	4,370	103,000
Brazil	561,000	1,370,000	724,000	1,750,000
Canada	230,000	814,000	378,000	1,320,000
Chile	1,810	382,000	--	--
China	332,000	676,000	577	21,800
Colombia	--	--	397,000	422,000
France	32,400	345,000	209,000	840,000
Germany	52,200	1,960,000	62,000	2,090,000
Hong Kong	2,160	415,000	1,130	61,300
Japan	151,000	2,600,000	226,000	4,220,000
Korea, Republic of	18,500	1,110,000	17,000	1,080,000
Mexico	4,390	23,900	22,100	153,000
Taiwan	104,000	1,640,000	47,400	1,470,000
United Kingdom	15,400	638,000	60,000	747,000
Other	35,000 r/	1,280,000 r/	57,600	1,190,000
Total	1,550,000	13,400,000	2,210,000	15,500,000
Rare-earth metals, including scandium and yttrium: (2805.30.0000)				
Bahamas, The	18,300	26,600	--	--
Canada	60,500	386,000	9,510	61,300
China	37,200	20,000	2,350	6,130
France	40,700	83,200	39,400	118,000
Germany	2,360	106,000	1,460	50,800
Hungary	895	43,600	1,950	58,300
Indonesia	17,600	62,500	150	9,980
Japan	72,400	1,320,000	60,300	1,740,000
Korea, Republic of	1,920	145,000	15,000	320,000
Netherlands	5,490	171,000	--	--
Taiwan	79,800	123,000	292	46,900
United Kingdom	28,300	1,060,000	27,800	950,000
Other	4,110 r/	140,000 r/	46,400	917,000
Total	370,000	3,690,000	208,000	4,540,000

See footnotes at end of table.

TABLE 3--Continued

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

Country	1995 Quantity (kilograms)	1995 Value	1996 Quantity (kilograms)	1996 Value
Ferrocerium and other pyrophoric alloys: (3606.90.0000)				
Australia	119,000	$264,000	57,500	$232,000
Barbados	40,700	46,900	15,400	18,200
Canada	1,040,000	2,110,000	1,190,000	1,910,000
France	83,300	500,000	87,700	467,000
Germany	452,000	2,090,000	624,000	1,900,000
Greece	91,500	102,000	24,200	106,000
Hong Kong	194,000	789,000	210,000	753,000
India	24,700	207,000	363	7,810
Italy	5,230	291,000	14,300	215,000
Japan	62,900	1,550,000	112,000	2,100,000
Jordan	--	--	1,240,000	4,170,000
Korea, Republic of	13,900	148,000	110,000	475,000
Kuwait	63,100	103,000	170,000	89,700
Mexico	137,000	504,000	140,000	1,610,000
Netherlands	22,100	326,000	12,600	243,000
New Zealand	55,100	98,200	53,700	95,600
Peru	495,000	378,000	20,000	117,000
Philippines	23,000	28,600	76,900	498,000
Saudi Arabia	101,000	396,000	29,200	666,000
Singapore	83,800	270,000	156,000	505,000
Sweden	1,580	457,000	2,500	85,400
Taiwan	105,000	197,000	36,700	105,000
Thailand	29,600	381,000	14,700	45,500
United Arab Emirates	208,000	335,000	140,000	257,000
United Kingdom	101,000	417,000	76,900	1,820,000
Other	352,000	2,220,000 r/	366,000	2,580,000
Total	3,910,000	14,200,000	4,970,000	21,100,000

r/ Revised.

1/ Data are rounded to three significant digits; may not add to totals shown.

Source: Bureau of the Census.

TABLE 4

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

Country	1995 Quantity (kilograms)	1995 Value	1996 Quantity (kilograms)	1996 Value
Cerium compounds, including oxides, hydroxides, nitrates, sulfate chlorides, and oxalates: (2846.10.0000)				
Austria	33,200	$406,000	28,300	$353,000
China	2,480,000	13,300,000	4,040,000	21,300,000
France	1,440,000	8,810,000	553,000	6,150,000
Germany	21,000	362,000	837	46,400
Japan	99,100	2,280,000	79,200	1,720,000
Russia	22,100	158,000	9,080	74,400
United Kingdom	302	6,590	42,200	393,000
Other	478	14,300	--	--
Total	4,090,000	25,400,000	4,760,000	30,000,000
Yttrium compounds content by weight greater than 19% but less than 85% oxide equivalent: (2846.90.4000)				
Austria	1,200	43,400	--	--
China	9,810	315,000	9,060	313,000
France	3,100	162,000	22,300	426,000
Germany	658	82,100	230	33,600
Japan	120	7,930	410	31,500
Russia	105	1,850	5,630	110,000
Switzerland	2,000	78,900	--	--
Taiwan	400	11,500	2,300	37,900
United Kingdom	13,400	285,000	2,250	72,900
Other	--	--	16	3,960
Total	30,800	988,000	42,200	1,030,000

See footnotes at end of table.

TABLE 4 --Continued

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

Country	1995 Quantity (kilograms)	1995 Value	1996 Quantity (kilograms)	1996 Value
Rare-earth compounds, including oxides, hydroxides, nitrates, and other compounds except chlorides: (2846.90.5000)				
China	5,380,000	14,100,000	11,200,000	19,900,000
France	2,930,000	23,600,000	3,490,000	27,000,000
Germany	14,100	971,000	732	162,000
Japan	222,000	9,630,000	334,000	12,100,000
Norway	5,210	2,990,000	534	97,500
Russia	19,900	381,000	15,700	566,000
United Kingdom	72,500	4,680,000	225,000	7,230,000
Other	19,300 r/	580,000 r/	35,900	480,000
Total	8,670,000	56,900,000	15,300,000	67,600,000
Mixtures of rare-earth oxide except cerium oxide: (2846.90.2010)				
Austria	21,800	812,000	15,700	979,000
China	524,000	8,850,000	810,000	14,500,000
France	70,900	4,120,000	15,400	973,000
Germany	--	--	4,630	306,000
Hong Kong	1,100	258,000	350	137,000
Japan	11,500	1,940,000	28,100	4,770,000
United Kingdom	40,600	574,000	2,940	115,000
Other	7,550 r/	122,000 r/	1,260	92,000
Total	678,000	16,700,000	879,000	21,900,000
Rare-earth metals, whether intermixed or alloyed: (2805.30.0000)				
Austria	17,600	$156,000	--	--
Belgium	33,400	288,000	2,780	84,200
China	593,000	4,380,000	342,000	2,690,000
Kazakstan	14,000	70,500	--	--
Russia	5,540	267,000	5,370	335,000
United Kingdom	84,400	2,360,000	6,250	507,000
Other	6,050 r/	148,000 r/	590	84,800
Total	754,000	7,670,000	357,000	3,710,000
Mixtures of rare-earth chlorides, except cerium chloride: (2846.90.2050)				
Belgium	19,700	232,000	2,920	42,500
China	325,000	4,330,000	329,000	4,950,000
Estonia	67,600	664,000	20,000	328,000
France	4,910	366,000	48	34,700
Germany	50	35,700	22,500	633,000
India	2,160,000	2,250,000	1,780,000	2,490,000
Japan	56,000	3,320,000	80,100	3,200,000
Russia	18,100	353,000	50,300	317,000
United Kingdom	64,600	756,000	44,100	335,000
Other	1,520 r/	72,500 r/	743	31,600
Total	2,720,000	12,400,000	2,330,000	12,400,000
Ferrocerium and other pyrophoric alloys: (3606.90.3000)				
Austria	6,740	180,000	6,320	157,000
Belgium	2,670	51,300	--	--
Brazil	4,500	77,900	6,000	121,000
France	72,800	1,090,000	105,000	1,650,000
Netherlands	1,080	23,000	1,620	34,600
Other	454	18,100	1,740	22,500
Total	88,300	1,440,000	120,000	1,980,000

r/ Revised.

1/ Data are rounded to three significant digits; may not add to totals shown.

Source: Bureau of the Census.

TABLE 5
RARE EARTHS: WORLD MINE PRODUCTION, BY COUNTRY 1/ 2/

(Metric tons of rare-earth oxide equivalent)

Country 3/	1992	1993	1994	1995	1996 e/
Australia e/	3,300	1,650	--	110 r/	--
Brazil	396	270 r/	256 r/	103 r/	200
China e/	21,300	22,100	30,700 r/	48,000 r/	55,000
India e/	2,200	2,500	2,500	2,700	2,700
Malaysia	427	224	234	448	340 4/
South Africa e/	240	240	72 4/	-- 4/	--
Sri Lanka e/	110	110	120	120	120
Thailand	89	220	57	--	--
U.S.S.R. e/ 5/	8,000	7,000	6,000	6,000	6,000
United States 6/	20,700	17,800	20,700	22,200	20,400 4/
Zaire e/	28	11	11	5 r/	5
Total	56,800	52,100 r/	60,600 r/	79,700 r/	84,800

e/ Estimated. r/ Revised.

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 July 3, 1997.

3/ In addition to the countries listed, rare-earth minerals are believed to be produced in Indonesia, Mozambique, North Korea, and Vietnam, but information is inadequate to formulate reliable estimates.

4/ Reported figure.

5/ Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

6/ Comprises only the rare earths derived from bastnasite as reported from company sources.

TABLE 6
MONAZITE CONCENTRATE: WORLD PRODUCTION, BY COUNTRY 1/ 2/

(Metric tons, gross weight)

Country 3/	1992	1993	1994	1995	1996 e/
Australia e/	6,000	3,000	--	--	--
Brazil e/	1,400 4/	1,400	1,400	1,400	1,400
China e/	1,800	1,800	1,800	1,800	1,800
India e/	4,000	4,600	4,600	5,000	5,000
Malaysia	777	407	425	814	450
South Africa e/ 5/	430	430	131	--	--
Sri Lanka e/	200	200	200	200	200
Thailand	89	220	57	60	--
United States	W	W	W	--	--
Zaire e/	50	20	20	20 r/	10
Total	14,700	12,100	8,630	9,230 r/	8,860

e/ Estimated. r/ Revised. W Withheld to avoid disclosing company proprietary data; excluded from "Total."

1/ Table includes data available through May 28, 1997.

2/ World totals and estimated data are rounded to three significant digits; may not add to totals shown.

3/ In addition to the countries listed, Indonesia, North Korea, the Republic of Korea, Nigeria, and the former U.S.S.R. may produce monazite, but output, if any, is not reported quantitatively, and available general information is inadequate for formulation of reliable estimates of output levels.

4/ Reported figure.

5/ Monazite occurs in association with titanium sands mining but is not necessarily recovered.