RARE EARTHS

By Dudley J. Kingsnorth Industrial Minerals Company of Australia Pty Ltd
and Judith Chegwidden Roskill Information Services Ltd, UK

Rare earths are critical minor constituents of many advanced materials that are essential inputs to the manufacture of items such as mobile electronic equipment, televisions and automobiles, where they may be present as glass stabilisers, phosphors, in magnet alloys, catalysts or as ceramic capacitors. Although rare earths have a relatively high unit value, the impact of this cost has little, if any, impact on the selling price of the final item. In addition, as they are generally present in minute concentrations, they are not usually recycled.

China dominates the market and supplies over 85% of world demand. It has recently taken steps to increase prices through the restriction of exports and support for minimum prices by the major producers. Other sources of rare earth raw materials are Russia, India and the US.

The rare earth elements form a series of 17 chemically similar metals, the 15 lanthanides (generic symbol: Ln) plus yttrium and scandium. However, it is the unique magnetic and spectroscopic properties of rare earth oxides that are of particular interest to scientists and industrialists.

The rare earths are normally referred to in terms of rare earth oxides (REO) and classified into three groups: Light, Medium and Heavy as detailed in Table 1.

World Rare Earth Resources

Hard rock deposits of bastnaesite and placer deposits of monazite and xenotime contain most of the world's economic concentrations of rare earth elements, and traditionally, it has been these that have been exploited for rare earths. The light rare earths predominate in these minerals and account for the largest proportion of rare earth oxides produced.

World production of light rare earths comes mainly from bastnaesite deposits in Inner Mongolia, where they are a by-product of iron-ore mining. Monazite and xenotime are usually obtained as by-products of titanium minerals and tin production, often from placer deposits. The less abundant, but more valuable, yttrium and heavy rare earths, are mainly sourced from ionic absorption clays in southern China. Up until 1994 the mineral sand mines of Western Australia supplied 25% of world demand for rare earth ores through the export of by-product monazite.

Current world reserves of rare earths are estimated to be about 70-90 Mt REO contained, which, based on typical metallurgical recoveries, should be sufficient for the next 500 years. The largest proportion of these reserves lie in China (43 Mt) and are equivalent to around 50% of the world's proven reserves, while the US accounts for another 13.6 Mt, Australia 5.1 Mt and India 2.3 Mt.

Rare Earth Elements

Element	Type	Atomic No.	Symbol
Lanthanum		57	La
Cerium	Light	58	Ce
Praseodymium		59	Pr
Neodymium		60	Nd
Promethium*		61	Pm
Samarium	Medium	62	Sm
Europium		63	Eu
Gadolinium		64	Gd
Terbium		65	Tb
Dysprosium		66	Dy
Holmium		67	Ho
Erbium	Heavy	68	Er
Thulium		69	Tm
Ytterbium		70	Yb
Lutetium		71	Lu
Yttrium		39	Y
Scandium		21	Sc

* Does not occur naturally

The most common minerals that are processed to recover the rare earths are listed in Table 2.

Mine production of rare earths is dominated by China, the only other countries producing quantities of any significance are the US, Russia and India. The main producers of light rare earths from bastnaesite are Baotou Iron, Steel and Rare Earth Enterprises, Gansu Rare Earth Corp. and Baotou Hefa Rare Earth Development Group Co. Ltd. The mining of ionic clays in southern China is carried out by a large number of small companies. Total mine production capacity is thought to be around 85,000 t/y REO and production peaked at 80,500 t in 1999.

Loparite is mined in Russia, by Lovozerskaya Mining Co., in the Kola peninsula. This ore is concentrated and sold to the Solikamsk Magnesium Plant for further processing. Russian exports of rare earth oxides totalled 4,077 t in 1999 but dropped to 2,492 t in 2000. Practically all exports go to Estonia for further processing by Silmet.

Monazite is produced and processed by Indian Rare Earths from mineral sand deposits in Tamil Nadu, Kerala and Orissa. Production capacity is around 5,000 t/y but actual output has been curtailed following cyclone damage to the processing facilities in Orissa. Recovery in production in 2000 was marked by exports of 1,557 t of cerium compounds to France.

China leads the production of processed rare earths, while Rhodia Electronics and Catalysis (with operations in France, Japan, the US and two joint ventures in China) is the major supplier of ‘value-added’ products. The other main processors are Mitsui Mining & Smelting and Shin-Etsu of Japan, AMR Technologies of Canada (which manages/operates two joint ventures in China and a magnet alloy plant in Thailand), and Silmet of Estonia. The market is highly competitive as, until recently, supply has exceeded demand.

There have been a number of moves to close down the smaller and less efficient plants in China but there are still very many companies in this sector. It has been estimated, however, that the eight largest companies account for over 70% of production of rare earth chemical concentrates and separated rare earths. An increasing proportion of Chinese exports is in the form of separated rare earth oxides, salts and metals.

Until its processing operations at Mountain Pass were suspended in March 1998 by the California EPA, Molycorp was the only major fully integrated rare earths producer in the Western world; mining, concentrating, refining and marketing rare earths from ore to finished product. Its present operations are confined to the production of an estimated 5,000 t/y REO in bastnaesite concentrates and the sale of rare earth compounds from stocks. The company has recently announced plans to build a new tailings dam that will enable it to return to full production of 20,000 t/y REO,

Composition of Rare Earth Minerals

Mineral	Formula	Major occurrences	REO max (%)
Bastnaesite	$LnFCO_3$	China, US	75
Monazite	$(Ln, Y)PO_4$	China, Australia, Brazil, India, Malaysia, Africa	65
Loparite	$(Na,Ca, Ln,Y)(Nb,Ta,Ti)_2O_6$	CIS	32
Xenotime	YPO_4	China, Australia, Malaysia, Africa	62
Ionic Clays	Weathered Xenotime and Apatite	China	N/A

including the resumption of production of separated rare earths. All plans to resume full production depend on obtaining environmental permits for these tailings ponds and the installation of new processing equipment.

Grace Davison produces separated rare earths from rare earth chlorides and other concentrates at its plant in Chattanooga. Much of the output is used within the W.R. Grace & Co. group for catalyst manufacture. There is limited processing capacity elsewhere in the US as companies producing products such as magnet alloys have found it difficult to compete with Chinese sources.

Rhodia Electronics and Catalysis, the major producer of 'value-added' rare earth products, operates the only substantial rare earth separation plant outside China, at La Rochelle in France. As this facility has no captive source of rare earth minerals, Rhodia imports the majority of the raw materials in the form of rare earth carbonates, chlorides and nitrates from China, with minor quantities from Estonia and India. In the future, Rhodia will concentrate on expanding processing capacity at its Chinese plants at Liyang and Baotou. The plant at La Rochelle will increasingly be dedicated to the production of specialty chemicals for the electronics industry, autocatalysts and Eolys, a diesel additive. The current capacity of the plant at La Rochelle varies between 10,000 t/y and 13,000 t/y depending on the product mix. Rhodia also makes co-precipitated oxides for phosphor manufacture and cerium-based polishing powders in France.

The AS Silmet Group in Estonia has been processing rare earths since 1969. Although the plant in Estonia was originally designed to process loparite ores from Russia it now uses rare earth chloride feedstock from Solikamsk Magnesium Plant. Estonia shipped more than 2,000 t of rare earths in 2000; some for further processing and some for direct sale to the end-user. The future viability of the Silmet plant may depend on the company obtaining EU or other funding to clear up the pollution caused during the years that Silmet processed uranium for the Soviet military industrial complex.

Other European processors of rare earths are focused on the production of cerium polishing powders, magnet alloys, and metal wires and powders.

There are several Japanese processors each with a particular market niche, based on their own high purity/high value products. These processors import raw materials from China, India and the US (to a lesser extent in the past few years, due to the partial closure of Molycorp). In the 1990s the Japanese rare earth companies struggled to make satisfactory returns on their investments due to the appreciation of the yen and the marketing strategy of the Chinese producers. As a result there were many plant closures in Japan during the past decade. In many cases the processing equipment has been re-located to China where it has become an integral part of new supply arrangements.

Through an aggressive pricing strategy, China made a concerted effort in the 1990s to become the dominant rare earths producer/supplier, and now supplies an estimated 85-90% of the world's rare earths as concentrates, intermediate products and rare earth chemicals.

This approach came at a price with many rare earth processing companies losing money in 1998/99 because of overproduction following the marked decline in Asian demand at that time. In order to redress the situation the following actions were taken by China in 2000:

- The major producers of light rare earths set a minimum price for a range of products.
- Subsidies/assistance to inefficient producers were curtailed.
- The Chinese Government limited the number of rare earths export licences.

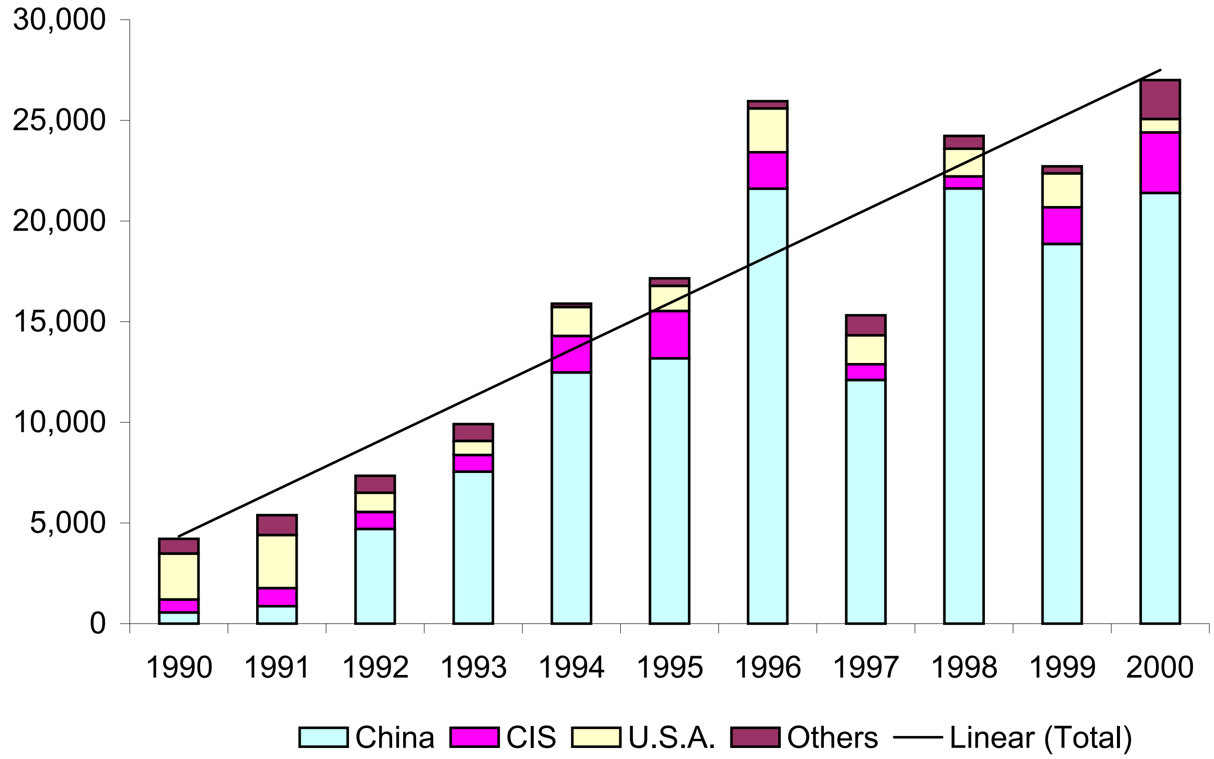
While the above events were unfolding, on the commercial/marketing front there were a number of constraints building up in the supply of rare earth mineral concentrates. As the bastnaesite/monazite produced in Baotou is a by-product of an iron ore mining operation, when iron ore production recently declined due to substitution by imported high-grade iron ore from Australia, the availability of rare earth concentrates was also curtailed. At the same time the local and national governments imposed strict environmental controls on the mining and processing of the ionic clays in southern China in order to arrest the growing dissent of the local population. The net result was a reduction of output in 2000 to 75,500 t.

The extent to which developed countries now depend on China as a source of rare earths is illustrated by Figure 2 which shows clearly that there has been a rapid growth in European imports of most grades of rare earth compounds since 1990 and that China has consolidated its position as the leading supplier.

Current Market Demand

A breakdown of the demand for rare earths (1999) in terms of application and

EU and EFTA: Imports of rare earth compounds (t)



geographical location is given in Table 3. This table has an estimated accuracy of ± 15% due to the lack of published data.

Future Trends

Worldwide there is adequate operating rare earths processing capacity to meet forecast demand until 2004, although there could be restraints on the supply of raw materials. Over the next few years, the trend in demand will be towards continuing growth in the use of individual compounds, metals and special mixtures for use in magnets, glass additives, catalysts, batteries and specialty alloys.

Current demand for light rare earths for the production of fluid cracking catalysts appears to have levelled off. Meanwhile, as environmental awareness increases, the demand for cerium for autocatalysts - to reduce exhaust emissions - is expected to grow at rates considerably in excess of the growth in Gross World Product (GWP).

A range of cerium chemicals is used in autocatalyst manufacture and the trend is to use blended oxides (usually cerium and zirconium) such as Rhodia's Actalys™ range. Rhodia is also developing Eolys™, a cerium-based diesel additive which aids the reduction of particulate emissions.

Cerium concentrates are used in the production of polishing powders for cathode ray tubes (CRTs), lenses and mirrors, and as additives for cathode ray tube faceplates, to reduce browning effects. Demand for these applications is forecast to grow faster than GWP due to the demand for larger TV screens in developed countries and the growth of consumerism in developing countries.

Recently the polishing powder producers have adapted their technology to meet the needs of the computer industry, where powders are used in mechano-chemical polishing of computer chips. This new sector of the industry is currently experiencing annual growth rates in excess of 50%.

In the past, bastnaesite was the main raw material for polishing powder production but most producers now use cerium concentrates from China.

Demand in the metal alloys sector is growing steadily as lanthanum-nickel-hydride batteries are acknowledged worldwide as an environmentally acceptable alternative to nickel-cadmium batteries. Currently these are the preferred battery for the new hybrid gasoline-electric vehicles, so if their use is increased through legislation then demand for lanthanum could increase significantly, shifting the demand/supply balance for the rare earths.

In the medium to long term, demand for lanthanum-rich mischmetal as an additive to magnesium alloys, to improve creep resistance in automotive applications, could be the key demand driver in this sector.

World Rare Earths Markets 1999 (t REO)						
Application	**N America**	**Europe**	**Asia**	**China**	**Others**	**Total**
Catalysts	12,500	5,000	3,000	3,000	500	**24,000**
Glass	4,000	3,500	9,500	2,500	500	**20,000**
Metallurgical	1,500	200	3,300	5,200	300	**10,500**
Magnets	1,500	1300	4,000	3,000	200	**10,000**
Ceramics	600	300	800	300	-	**2,000**
Phosphors	500	500	2,400	1,000	100	**4,500**
Other	500	200	700	1,500	100	**3,000**
Totals	**21,100**	**11,000**	**23,700**	**16,500**	**1,700**	**74,000**

Currently, the use of rare earths in the steel and casting industries is relatively static on a world scale. Chinese rare earth producers continue to invest considerable technical resources to develop new applications in these industries. Some reports suggest that they are now starting to enjoy some success in marketing their uses to North American foundries. Accordingly, this could be a growth area in the future.

The average growth in demand for rare earth bonded and sintered magnets was 15-20% throughout the 1990s. This rate of growth is expected to temper in the coming years due to supply constraints. Now that Magnaquench International, the major producer of sintered magnets, is owned by a Chinese company, coupled with the fact that China is the major source of raw materials, it is anticipated that the centre of magnet manufacture will move from Japan to China.

Production of NdFeB and SmCo metal alloys is largely concentrated in China, and to a lesser extent, Japan. Magnet alloys are also produced in the US, Germany and the UK but the number of plants operating has fallen over the past decade in the face of severe price competition from manufacturers in China.

Engineering, electrical and electronic ceramics are an important growth area in industrialised countries and specialty rare earth applications in this industry are expected to exhibit steady growth. Rare earth compounds are usually supplied in blends of ceramic raw materials.

Rare earths are a key constituent of many of the solid oxide fuel cells under development, and this has the potential along with those identified above to change the relative mix of rare earths demand.

Ongoing steady growth in demand for phosphors for use in cathode ray tubes and energy-efficient trichromatic lamps is forecast. Rhodia maintains a leading position in the manufacture of co-precipitated oxides for phosphor manufacture. However, China is now the largest centre for the production of phosphors, through the transfer of technology from Japanese companies wishing to move production off-shore to reduce costs.

Demand Forecast to 2004

Taking into account the varied rates of growth in demand for the different sectors total world demand is forecast to rise to approximately 100,000 t by the year 2004 (Table 4) with a total value of US$1,000 - US$1,200 million. Even though there is a trend towards higher value separated rare earths, it is expected that there could be only a limited increase in average value per kg due to the competitive nature of the rare earths industry, unless the supply constraints identified above continue to influence the market.

It is apparent from the above discussion that the demand for rare earths will continue to grow as new applications are identified through the industry's commitment to research and development. It is worthy of note that with the exception of metallurgical applications, there are few economic alternatives to the above uses unless rare earth prices were to rise significantly.

Forecast Growth of World Rare Earths Markets

Application	Rare Earths Demand (REO)		Annual Rate of Growth (%)
	1999 (t)	2004 (t)	
Catalysts[1]	24,000	28,500	3-5
Glass[2]	20,000	24,000	3-5
Metallurgical	10,500	16,000	8-10
Magnets	10,000	18,000	12-15
Ceramics	2,000	3,500	12-15
Phosphors	4,500	6,500	7-8
Other	3,000	3,500	2-4
Total	**74,000**	**100,000**	**4-10**

[1] Includes petroleum cracking catalysts and autocatalysts.
[2] Glass applications includes polishing powders for the electronics industry.