

# Rare earth elements: Global market overview



J.S. Dickson<sup>1, a</sup>

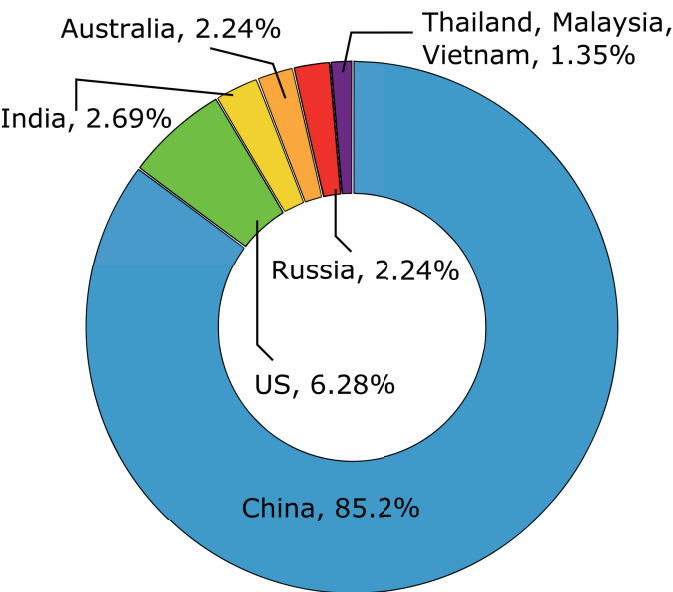
<sup>1</sup> Industrial Minerals, 8 Bouverie Street, London, UK, EC4Y 8AX

<sup>a</sup> corresponding author: james.dickson@indmin.com

Recommended citation: Dickson, J.S., 2015. Rare earth elements: Global market overview. In: Simandl, G.J. and Neetz, M., (Eds.), Symposium on Strategic and Critical Materials Proceedings, November 13-14, 2015, Victoria, British Columbia. British Columbia Ministry of Energy and Mines, British Columbia Geological Survey Paper 2015-3, pp. 5-11.

## 1. Introduction

Rare earth elements (REE), as defined by the International Union of Pure and Applied Chemistry (IUPAC), include yttrium (Y), scandium (Sc), and the lanthanides, comprising 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). In the scientific community, subdivisions into light (LREE) and heavy (HREE) categories are based on electron configuration. In this context, LREE include La, Ce, Pr, Nd, Pm, Sm, Eu, and Gd and HREE include Y, Tb, Dy, Ho, Er, Tm, Yb, and Lu (Connelly et al., 2005). Industry commonly refers to LREE as lanthanides from La to Sm, and HREE as lanthanides from Eu to Lu, plus Y (Simandl, 2014). World mine production of rare earth oxides (REO) for 2014 is estimated at approximately 117,000 tonnes, including  $Y_2O_3$ , which accounts for 7000 tonnes of the total (Gambogi, 2015a, b). In 2014, the main producing countries for REE less Y were China, with 86% of worldwide production (Gambogi, 2015a), the United States, India, Australia, Russia, and Thailand (Fig. 1).



**Fig. 1.** Proportion of REE, less Y, contributed by producing countries in 2015 (Gambogi, 2015a).

The United States historically dominated production. However, its position declined throughout the late 1990s and 2000s (Xie, 2014; Simandl, 2014). China reached the peak of its dominance in 2007, when it produced just under 97% of the world's REE less Y output (Hedrick, 2008).

## 2. Many metals, many uses, many deposit types

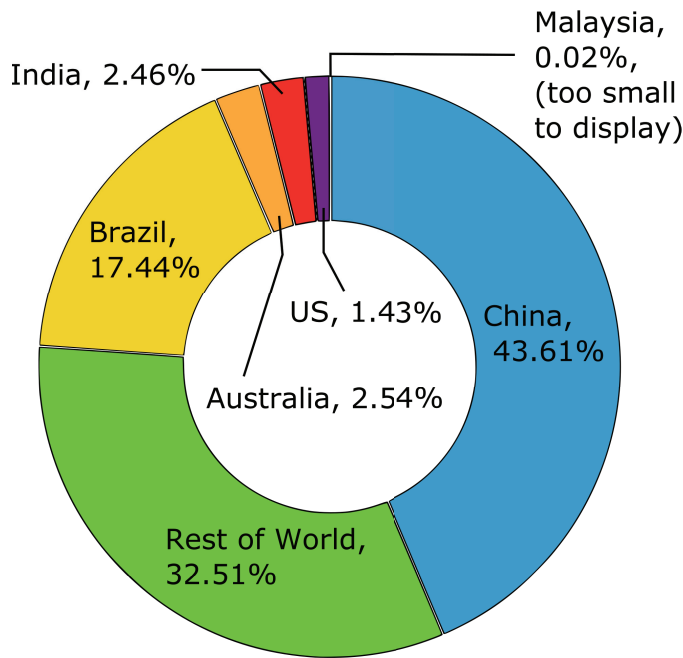
REE are used in permanent magnets, catalytic converters, polishing powders, fluorescent and arc lighting, lighter flints, lantern mantles, and data storage devices (Royal Society of Chemistry, 2015; Humphries, 2012; Haque et al., 2014) and are well known for their importance in the high-technology industries (Xie et al., 2014). REE have distinct uses and are not easily substituted. The most common REE in the Earth's crust, cerium, is roughly as abundant as copper, at 0.006% by composition, while the equilibrium mass of the least common REE, natural Pm in the Earth crust is equal to 560 g (Belli et al., 2007).

Exploration companies are examining carbonatites, peralkaline igneous rocks, pegmatites, monazite  $\pm$  apatite veins, ion adsorption clays, placers, and some deep-ocean sediments as potential sources of REE (Kanawaza and Kamitani, 2006; Koschinsky et al., 2010). Currently, most LREE are extracted from carbonatite-related deposits and most HREE are derived from REE-bearing ion adsorption clays (Wall, 2014; Simandl, 2014).

Assuming favourable market conditions in the future, REE could be derived as a by-product of phosphate fertilizer production (Dickson, 2015c), uranium ore (Barkley et al., 1986) and alumina red mud processing (Ochsenkuhn-Petropulu et al., 1996), and exploitation of Olympic Dam subtype iron-oxide copper gold (IOCG) deposits (Simandl, 2014). Recycling is a potential future source of REE (Haque et al., 2014; Torrisi, 2014a).

Ion adsorption clays rich in REE are found in southern China (Kanawaza and Kamitani, 2006; Papangelakis and Moldoveanu, 2014), and in Madagascar (Desharnais et al., 2014). Small quantities of REE are also derived from placer deposits and the Lovozero peralkaline intrusion-related deposit (Simandl, 2014; Wall, 2014).

China accounts for 44% of the world's REE resources (Fig. 2; Gambogi, 2015a). China's dominance of the REE industry



**Fig. 2.** Global distribution of REE resources in 2014, excluding Y (Gambogi, 2015a).

was initiated by the country's low production and labour costs and lax environmental regulations (Broad, 2010; Folger, 2011).

### 3. Boom and bust

In 2010, a territorial dispute regarding the Japan-administered, China-claimed Senkaku Islands boiled over after a Chinese trawler collided with a Japanese Coast Guard vessel in Senkaku Island waters. This resulted in China temporarily banning REE exports to Japan (Agence France-Presse, 2010). Between 2006 and 2012, the Chinese government also emplaced stricter export quotas on REE (Morrison and Tang, 2012). These actions precipitated a spike in REE prices, and the shares of associated companies (Dickson and Syrett, 2015). The average price of  $\text{Ce}_2\text{O}_3$  increased by 2400% (from US\$6/kg to US\$149.5/kg) from June 2010 to August 2011. The price of  $\text{Nd}_2\text{O}_3$  increased by 991% (from US\$33/kg to US\$360/kg) and the price of  $\text{Dy}_2\text{O}_3$  increased by 700% (from US\$300/kg to US\$2400/kg) during the same period (Torrissi, 2014a).

High prices led to mine openings in the US and Australia by Molycorp Inc. and Lynas Corp.

During this period of high prices, REE users switched to less expensive, more reliably sourced substitutes, and the search for alternative materials accelerated (Elmqvist, 2011; Loh et al., 2015; Reddall and Gordon, 2012; Miller and Zheng, 2015). Cerium, in particular, was replaced by other polishing powder materials, or was recycled (Elmqvist, 2011; Loh et al., 2015) and REE oversupply ensued. In 2014, the World Trade Organization passed a ruling requiring China to suspend REE quotas, removing another barrier to oversupply (Associated Press, 2015; Haque et al., 2014), contributed to further by illegal mining in the country.

The pricing corrections that followed the spike, as oversupply took hold and demand dissipated, were as severe as the steep increases leading to 2011. In some cases, prices fell back by 98% (Industrial Minerals, 2015). While intermittent rallies have occurred since 2011, the downward trend in pricing has continued into 2015 (Industrial Minerals, 2015). Recent REE oxide prices from the Industrial Minerals Pricing Database may be viewed in Table 1.

### 4. Investor interest

Investor interest in REE remains substantial after the correction and many projects being planned in 2010 remain active. Over 50 deposits are in advanced stages of development (Technology Metals Research, 2015). Examples of active REE projects include Mountain Pass, Bear Lodge, Bokan Mountain, Round Top, Ngulla, Browns Range, Kvanefjeld and Ashram.

The REE industry remains highly fluid and is prone to disruption by technological advancement, which is less common in more established markets. As a highly complex set of chemical products with distinct uses and markets, project viability assessment is more complex for REE than for many other materials. Some of the parameters critical to understanding economic viability are: proprietary or licensed processing technologies; the relative proportion of each rare earth in a deposit and thus projected rare earth basket prices; overall grade; and mineralogy (Bogner, 2014; Hatch, 2010).

### 5. Lanthanum and Cerium oversupply

Lanthanum (used in polishing powders and catalysts) and

**Table 1.** Industrial Minerals Prices Database: Prices for selected REO as of 27 August, 2015. Minimum grade 99%, free on board China, in US\$/kg bulk (Industrial Minerals, 2015).

Industrial Minerals REE prices	Low	High
Cerium oxide, min 99%, FOB, China, \$/kg, Bulk	2	2.5
Dysprosium oxide, min 99%, FOB, China, \$/kg, Bulk	235	250
Europium oxide, min 99%, FOB, China, \$/kg, Bulk	200	225
Lanthanum oxide, min 99%, FOB, China, \$/kg, Bulk	2.1	2.5
Neodymium oxide, min 99%, FOB, China, \$/kg, Bulk	41	46
Praseodymium oxide, min 99%, FOB, China, \$/kg, Bulk	57	62
Samarium oxide, min 99%, FOB, China, \$/kg, Bulk	2.1	3.1

Ce (used primarily in alloys) are both in oversupply (Kennedy, 2014; Mackowski, 2014). Many junior explorers seek to remove the two elements from the processing chain to minimize processing costs (Dickson, 2015d). They are considering stockpiling the material once in production, in anticipation of improved markets. However, in the medium term Ce and La are likely to remain in oversupply.

## 6. Processing technologies

Recognizing the technological and financial hurdles represented by on-site processing, junior companies are increasingly looking towards established REE processors and specialist chemical companies for joint venture and offtake opportunities (e.g., Rare Earth Salts, 2014; Tantalus Rare Earths, 2015). A number of innovative processing technologies are promoted by junior research and mining companies (for a review of processing methods, see Verbaan et al., 2015).

## 7. The case for development

HREE market conditions are more positive than LREE market conditions. Both of the West's new mines, Lynas's Mount Weld in Australia and Molycorp's Mountain Pass in California, are carbonatite-hosted deposits. These deposits have a high proportion of the LREE compared to HREE (Fig. 3), and have supplemented strong supply of LREE from Northern and Western China.

HREE are supplied almost exclusively by southern China and remain in tight supply. Most deposits have a LREE bias and therefore HREE continue to command better prices (Table 1).

Additionally, with venture capital flowing into batteries and high-technology companies, interest in REE permanent magnets

(mostly Nd-iron-boron (NdFeB) magnets; Fraden, 2010; Torrisi, 2014b) has resulted in the promotion of exploration projects based on Nd and Pr concentrations (Dickson, 2015a). The proportion of REE consumed in the magnet sector is rising, as is the proportion of value derived from Nd and other magnet metals (Fig. 4) Nd demand is also expected to rise (Fig. 5).

The optimism for magnet demand is tempered by reports that, despite expanding magnet industry consumption of REE, including Nd, stockpiled material is difficult to sell (Syrett, 2015). Dysprosium, used in NdFeB magnets to prevent denaturing at high temperatures, could potentially be substituted by lower-priced Ce co-doped with cobalt (Pathak et al., 2015). In percentage terms, the value of Dy consumed is likely to fall against other REE used in magnets (Fig. 6).

Europium, one of the higher-priced REE, also has the potential to recede as alternative products and processes emerge. Previously used in cathode ray tube (CRT) television sets before the appearance of modern plasma and liquid crystal display (LCD) screens, today Eu finds use in fluorescent bulbs and strip-lights to increase the warmth of the light emitted. The emergence of even more energy efficient light emitting diodes (LEDs) could see prices fall in the medium term, although supply tightening may offset this effect (Dickson, 2015e).

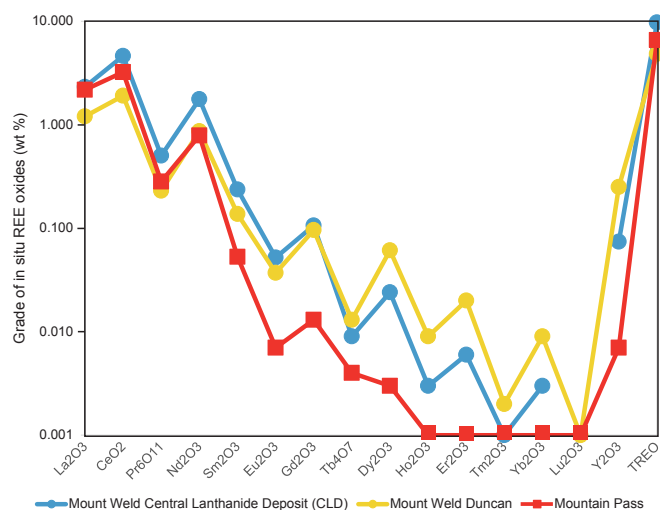
## 8. Recent developments in China

Toward the end of the 2000s, China began to plan and implement a policy of consolidation to dampen the environmentally damaging effects of REE production in China (Folger, 2011), simplify regulation of the sector (Rubenstein, 2015; Sylvester, 2015), and conserve a non-renewable natural resource (Morrison and Tang, 2012). By the end of the consolidation, the only companies permitted to mine REE in China, including via their subsidiaries, will be: China Northern Rare Earth Group High-Tech Co. Ltd. (formerly Baotou Steel Rare Earth Group High-Tech Co. Ltd.); China Minmetals Corp.; Aluminum Corp. of China (Chalco, via its subsidiary China Rare Earth Holdings); Ganzhou Qiongdong Rare Earth Group; Guangdong Rising Nonferrous Metals Group Co. Ltd.; and Xiamen Tungsten Co. Ltd. (Torrisi, 2014b). China Northern is by far the largest of the planned groups, accounting for 57% of Chinese production quotas alone (Dickson, 2015b). However, its Baotou, Inner Mongolia production base contains mainly LREE (Sylvester, 2015), minimizing potential returns.

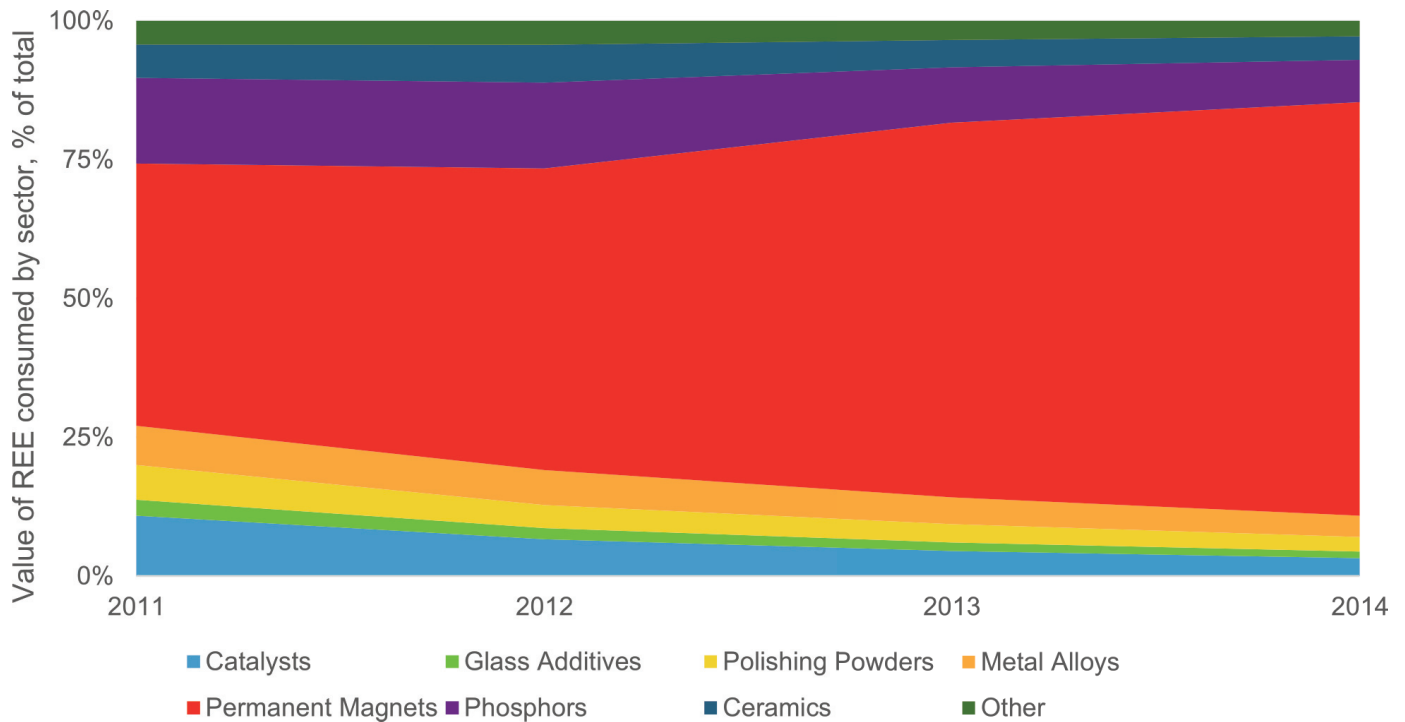
The Chinese government also hopes that consolidation, stronger local government regulations, and the elimination of illegal mining and smuggling will reduce REE oversupply (Jacobsen, 2014).

The shift towards resource taxes, mining quota, and consolidation may help the Chinese government to exert further control over the industry, possibly making it more opaque while changing little (e.g., data may become scarce owing to centralization and professionalization of the industry production quota could become an export quota equivalent Dickson and Syrett, 2015; Wallace, 2015).

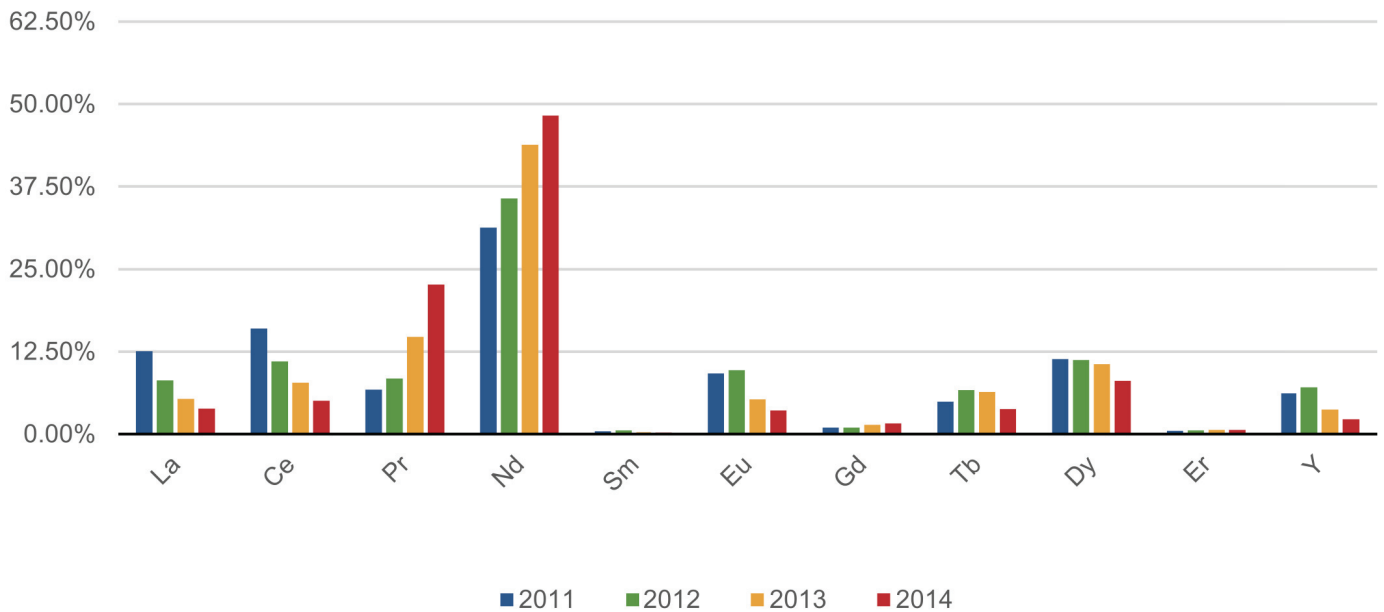
The World Trade Organization's October 2014 decision,



**Fig. 3.** The grade of in situ REO at Lynas's Mount Weld Duncan and Lanthanide deposits, and Molycorp's Mountain Pass mine, revealing the compositional bias of the two mines towards light REO. From Technology Metals Research (2015). Some REO register only trace concentrations, hence the cluster of data points at the base of the chart. Only Lu at Mountain Pass is below the detection limit.



**Fig. 4.** The proportional value of REO consumed by various industries from 2011-2014 (Industrial Minerals Company of Australia, 2015). The permanent magnet sector is, proportionally, increasing in importance on a total consumption value basis.



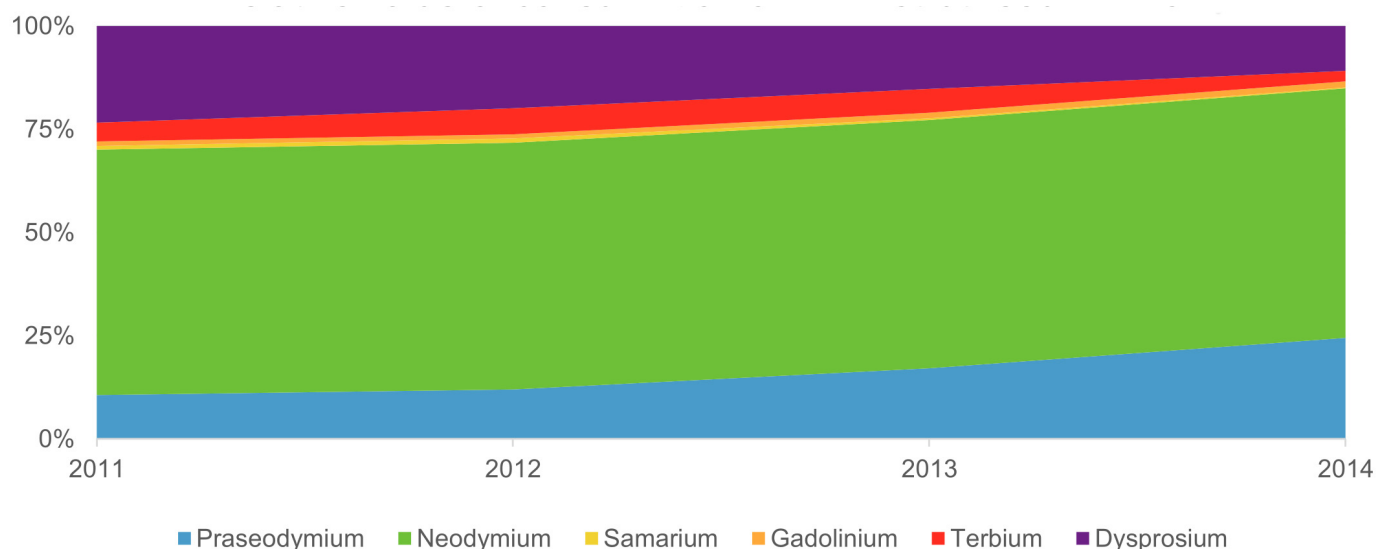
**Fig. 5.** The relative consumption value of each REO compared to the total industry consumption value from 2011-2014 (Industrial Minerals Company of Australia, 2015). The proportion of value in the Nd and Pr markets is expected to increase, primarily at the expense of La, Ce, and Eu.

which demanded that China remove its export taxes on REE resulted in a policy shift from export quota and taxes to production quota and resource taxes (Li, 2015a). On May 1, 2015, the resource tax rate for LREE was pegged at 11.5% in Inner Mongolia, 9.5% in Sichuan province, and 7.5% in Shandong province. Middle-heavy REE resource taxes were

set at 27% (Li, 2015a).

China has started to encourage value addition in its domestic REE industry. This policy resulted in a US\$157 million-equivalent grant to the Baotou region's REE industry in the summer of 2015 (Li, 2015b) and a similar subsidy of US\$72 million to Ganzhou province shortly afterwards (Dickson





**Fig. 6.** Relative value of consumption of magnet-utilised REO only from 2011-2014 (Industrial Minerals Company of Australia, 2015). Nd and Pr are set to increase in relative consumption value among all REE used in magnets.

and Li, 2015) to develop high-technology, high-return REE products.

### 9. Western woes

In the West, the REE industry is equally unstable. Lynas's debts stood at A\$650.8m at the end of 2014 (Lynas, 2015), but the business is starting to generate cash flow (Sydney Morning Herald, 2015). In contrast, Molycorp filed for bankruptcy protection in late June 2015 (Dickson, 2015f) after voluntarily deferring a number of interest payments on its loans (Lazenby, 2015). It has declared total liabilities of US\$1.7bn (Miller and Zheng, 2015).

### Acknowledgments

Suggestions and edits by Carlee Akam (British Columbia Geological Survey) greatly improved the content and clarity of this document.

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