

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/303140029>

# An outlook on the rare earth elements mining industry

Article · April 2016

CITATIONS

14

READS

2,907

3 authors:



**George Barakos**

Technische Universität Bergakademie Freiberg

28 PUBLICATIONS 61 CITATIONS

[SEE PROFILE](#)



**Helmut Mischo**

Technische Universität Bergakademie Freiberg

213 PUBLICATIONS 106 CITATIONS

[SEE PROFILE](#)



**J. Gutzmer**

Helmholtz-Zentrum Dresden-Rossendorf

300 PUBLICATIONS 4,048 CITATIONS

[SEE PROFILE](#)

Some of the authors of this publication are also working on these related projects:



Mining-RoX: Autonomous Robots in Underground Mining [View project](#)



ARIDuA - Autonomous robots and Internet of Things in underground mining [View project](#)

POSTED APRIL 2016

# An outlook on the rare earth elements mining industry

---

**By George Barakos MAusIMM, Research Associate, Helmholtz Institute Freiberg for Resource Technology, Germany; Professor Helmut Mischo University Professor, TU Bergakademie Freiberg, Germany; Professor Jens Gutzmer, Director, Helmholtz Institute Freiberg for Resource Technology, Germany and University Professor, TU Bergakademie Freiberg, Germany**

---

## How learning from the mistakes of the past can contribute to building a strong global rare earth elements supply chain

The rare earth elements (REEs) are a group of 16 chemical elements consisting of the 15 lanthanides plus yttrium. The term 'rare earths' is misleading, as it does not refer to their abundance in the earth's crust, but to the inconspicuous appearance of the minerals from which they were originally isolated. Almost all REEs in the earth's crust are more abundant than gold, silver or platinum, while Cerium (Ce) is the most abundant of all REEs and is more common in the Earth's crust than copper or lead. Admittedly, rare earths are not present in equal amounts in REE ores. They are generally divided into the light rare earth elements (LREEs) and the heavy rare earth elements (HREEs), with the HREEs being much less abundant and thus much more valuable. The attributions to these groups are not distinct, but in general Lanthanum to Gadolinium are called LREEs while Terbium to Lutetium are called HREEs.

REEs have gained visibility to the general public through the crisis of 2010 and the price spike of 2011 (Massari and Ruberti, 2013). Numerous headlines about REEs have appeared in the media, and suddenly the world became alarmed that China was about to crush high-tech industries of Western economies due to imposition of export restrictions. China at the time was holding a share of 95 per cent of global production of REEs.

The crisis did not last for long. Nonetheless, this short-lived alarm was sufficient to initiate a treasure hunt by way of exploration for REE deposits all over the world. The continuously growing demand on the one hand, and the Chinese sovereignty of the REE-market on the other, led the rest

of the world to explore their own REE resources. In just a few years, more than 400 projects were initiated to explore REE deposits outside China. But the flurry of exploration did not solve the vital problems of the REE market. Indeed, little has changed in the conditions that govern the REE-industry.

## **The global market of rare earth elements**

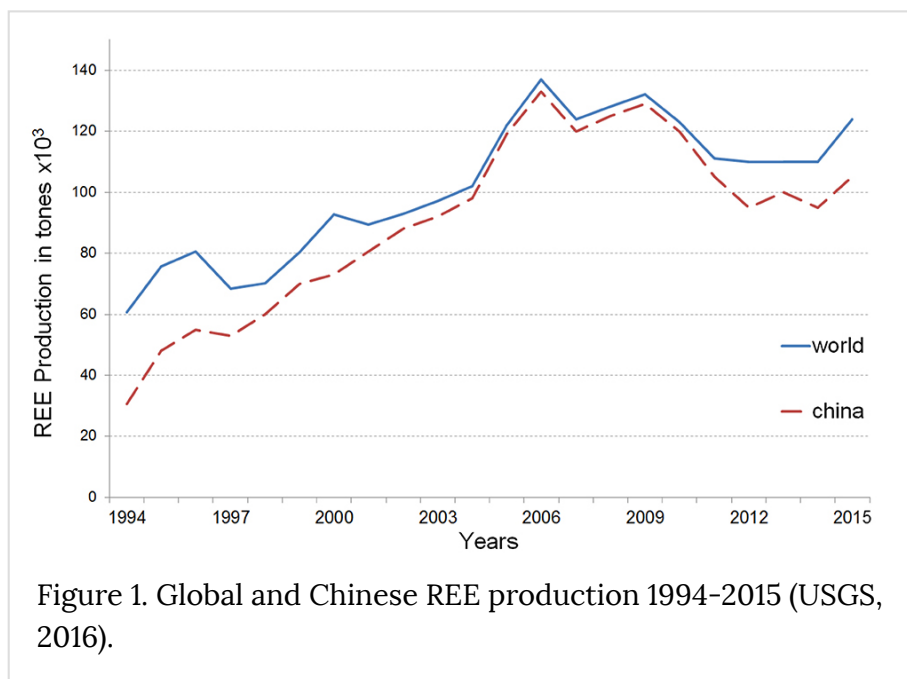
### **Supply and demand**

Rare earths are vital to some of the world's fastest growing markets: catalysts, magnets, ceramics and electronics. REEs underpin technologies that are critical for clean energy, transport and communication (Haque et al, 2014). Their application in nuclear energy is significant, while the variety of uses in defence applications is remarkable too. Their chemical similarity justifies their combined use or reciprocal substitution in some applications, yet the end uses of the individual REEs are diverse. This is one of the factors that determine the criticality of some of the elements compared to others.

The importance of REEs to the modern world is undeniable and it is certain that global demand will continue to grow. In contrast to this growth, however, the REE market remains small. In fact it could be said that there is no global 'rare earths market'. There are local and regional markets for individual REEs, and due to the fact that trading is restricted to a few suppliers who have no long-term contracts, it is almost impossible to predict the potential prices with any certainty. Big mining companies are deterred from getting involved into the REE industry. There are fewer than twenty large companies that trade REEs, and these are distributed to a handful of countries: China, Canada, Australia, USA, Russia, India and Japan. China is the biggest supplier of REEs in the world, while United States, Japan and Germany are the biggest importers (Roskill, 2015).

Several market analysts had forecasted that demand for some REEs would soon exceed supply (Alonso et al, 2012; Humphries, 2012). Indeed, there is a shortage of some certain rare earths; nevertheless there is no disruption of the supply chain. Since China is dominating the market, the supply of REEs to the world outside China almost coincides with the export quotas set by the Chinese government. Consequently, the fast growing domestic demand for REEs from their booming industry is crucial in terms of supplies to the rest of the world. However, despite the restrictions, global supply of REEs is still sufficient.

### **The role of China**



China has been leading the REE market for 20 years (Figure 1); this can be attributed to a series of factors. A significant fraction of global REE reserves that are economically advantageous in terms of exploitation are located in China. However, the Chinese dominance is not only a matter of reserves, but rather the result of a well-thought out, carefully crafted dynamic long-term strategic plan.

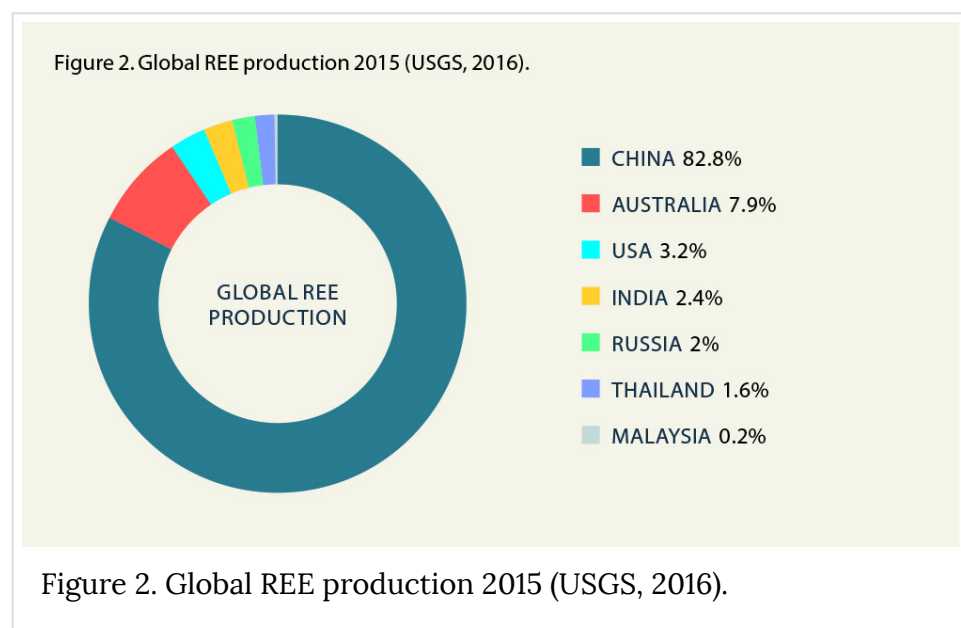
Until the late 1990s, most REEs were produced by the United States, but mining companies, confronted with rising costs, began to scale-back and shut down (<http://www.technologyreview.com/featuredstory/423730/the-rare-earth-crisis/>) operations. Mining operations at Mountain Pass in California were suspended in 2002 due to environmental issues (Ali, 2014). Therefore, as REE production in the United States gradually declined, China seized the opportunity and has since become the world's leading producer. The Chinese strategy, combined with lax environmental regulations, tax rebates and cheap labour, quickly yielded results and operations in China were able to scale-up in a relatively short period of time. There was also significant effort to develop the intellectual capital needed for the REE industry in China. It is exactly the intellectual capacity that the rest of the world is now lacking.

By 2009, US policy-makers had begun to worry about whether this would have larger implications for the economy and national security (Kennedy, 2015). The Chinese embargo against Japan verified these worries and alerted the Western world. As a result of this uncertainty and in response to the spreading of worrisome news, the prices of REEs soared in mid-2011. Prices for most of the elements declined significantly in 2012, but China had successfully demonstrated the power that comes with monopolistic control of an important raw material class. The Chinese Government issued export quotas for both local-owned and foreign-owned REE exporting companies. A dispute was settled in the World Trade Organisation (WTO) from the EU, Japan and United States against China, who was forced to compromise and change its export policies. The current situation could be described as temporarily stable, yet opaque and fragile.

## Current status of rare earth element mining

Despite the spur in exploration activities, global production of REEs remains relatively small and still heralds predominantly from China (Figure 2). World production for 2015 was estimated at 124 000 tons of rare earth oxides (USGS, 2016). According to Chen Zhanheng, vice-secretary general of the Association of China Rare Earth Industry (ACREI) an additional 30 000–40 000 tons of rare earth oxides are estimated to have been supplied to the global market by illegal mining and smuggling out of China (Stanway, 2016). Restriction of illegal mining is also one of the likely reasons why production in China has decreased slightly in recent years (Kiggins, 2015). Moreover, the depletion of national reserves, combined with health and environmental impacts, has forced the domestic REE industry in China to put limits on production.

Major investments made by Molycorp in the United States and Lynas in Australia and Indonesia were expected to be the counterweight to the monopoly position of China – at least for LREE production. However, since prices for REEs declined dramatically and Chinese export restrictions were loosened, the REE market went from undersupplied to oversupplied, especially regarding LREEs. Consequently, Molycorp filed for bankruptcy in mid-2015 and sealed the mine a couple of months later, indicating that rushing to fill the market needs without careful evaluation of the market conditions was not the appropriate step to take. Thus Lynas remains currently the biggest REE producer in the Western world. Lynas sources its ore from the Mt Weld deposit in Western Australia and processes it at the Lynas Advanced Materials Plant (LAMP) in Malaysia.



Other significant REE producers outside China are Russia and India. Indian REE reserves occur mainly in extensive heavy mineral sand deposits along its eastern and western coasts. Heavy mineral sand deposits are extracted by three government-owned companies in the states of Tamil Nadu (Manavalakurichi), Kerala (Chavara) and Odisha (Zepf, 2013; Roskill, 2015). Russia has several large REE deposits, of which the most important ones are located on the Kola Peninsula territory: the Khibiny and the Lovozero deposits (Walters, Lusty and Hill, 2011).

The three major mining areas in China are in Baotou, Sichuan and Jiangxi, which together host 88 per cent of the Chinese resources. Located in Baotou, Bayan Obo is a giant Fe-REE-Nb deposit, where 83 per cent of the Chinese REE reserves are concentrated. The unique advantage of this deposit is its

exceptional grade and the fact that REEs are exploited as a by-product of iron ore mining. A further important LREE mine is situated in Maoniuping in the Sichuan province, while in Jiangxi there are HREE deposits of great economic importance (eg Longnan). However, there are concerns about these HREE deposits as they are expected to be depleted by 2025 or even earlier (Zepf, 2013).

## Rare earth element potential

When REE prices were high, investments appeared to be temptingly easy. Of the hundreds of potential REE projects, very few are in an advanced stage and may commence mining operations within the foreseeable future (Table 1). To our knowledge there are no REE mining projects – and in particular HREE producers – close to entering mine construction or exploitation. Nevertheless, a few remarkable projects are mentioned below. The current situation in the REE industry is constantly subject to changes. Nevertheless, active rare earth mines and exploration projects are mentioned in this article as well as some more significant resources all over the world (Figure 3).

The HREE-rich Bear Lodge deposit in the United States is at an advanced exploration stage, currently preparing the environmental impact statement. The Bokan-Dotson Ridge REE project deals with the largest HREE deposit in the United States and is currently in evaluation stage; however, it is uncertain when mining operations could start. In South Africa Zandkopsdrift is estimated to be one of the largest REE resources outside of China and the owner company filed a prefeasibility study in 2015. The Lofdal REE deposit in Namibia is believed to be potentially exploitable with an unusually high grade in HREEs. In Canada, the Hoidas Lake project has advanced to prefeasibility, while Avalon – who is running the Nechalacho HREE project in Thor Lake – announced that the expenditures for this project will remain minimal in 2016 and the company will focus on other projects. Nolans Bore is another significant mining project in Australia that plans to enter production in 2019. The Nora Karr deposit in Sweden has been widely touted as the most important REE resource in the EU and production is estimated to begin in 2018. Finally, Greenland holds some interesting exploration projects: Kvanefjeld and Motzfeldt, which are both in early exploration stage.

Figure 3. Global REE production 2015 (USGS, 2016)

| Country      | Active mines                         | Significant projects           |
|--------------|--------------------------------------|--------------------------------|
| Australia    | Mount Weld                           | Nolans Bore                    |
| Canada       |                                      | Hoidas Lake                    |
| China        | Bayan Obo, Weishan Lake, Maoniuping, |                                |
| Greenland    |                                      | Kvanefjeld, Motzfeldt          |
| India        | Odisha, Chavara, Manavalakurichi     |                                |
| Namibia      |                                      | Lofdal                         |
| Russia       | Khibiny, Lovozero                    |                                |
| South Africa |                                      | Zandkopsdrift                  |
| Sweden       |                                      | Nora Karr                      |
| USA          | Mountain Pass (Until mid-2015)       | Bear Lodge, Bokan-Dotson Ridge |

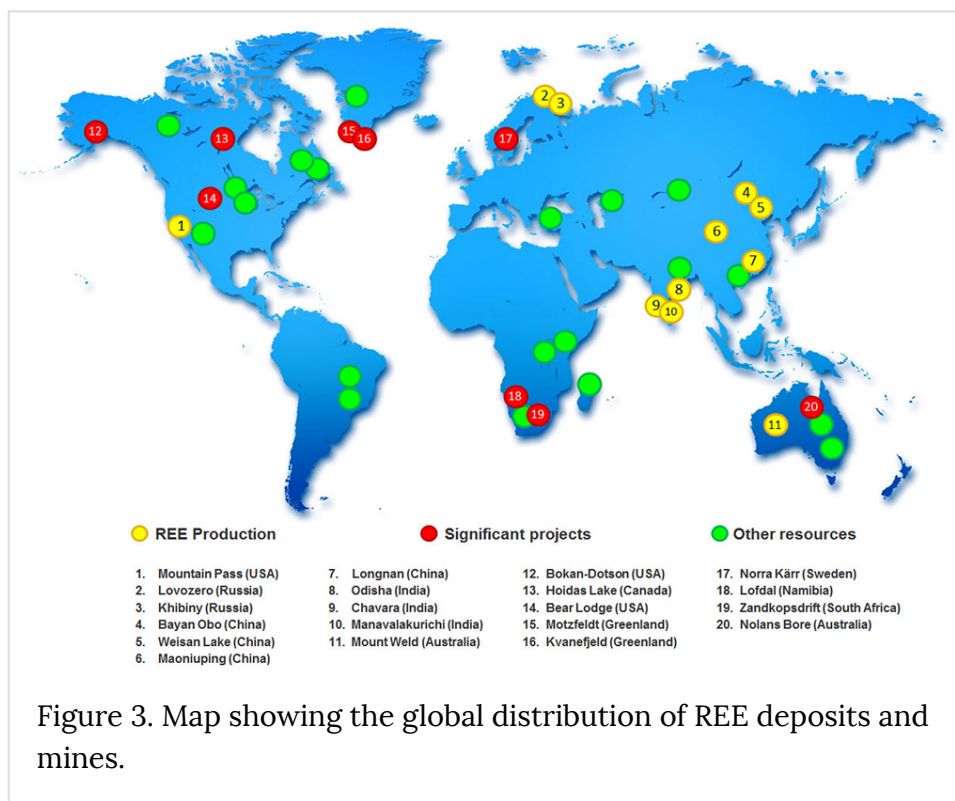
Table 1. Active rare earth mining projects and significant exploration projects worldwide.

## The future

Similar to other commodities covered only by the junior exploration and mining domain, the spike in REE prices in 2011 did not solve the supply problem. The REE market will remain small – and market analysts need to focus on the particular boundary conditions that govern the REE industry and which can determine the mineability of any REE deposit. The goal is to build a better understanding of REE supply and demand, deal with fluctuations in the market and set the basis for secure investments.

The dependency on China's export policies deters analysts from forecasting REE prices and future trends. In 2009, when China was found to violate international trade rules, the WTO was asked to intervene. However, the WTO did not resolve this conflict in a timely manner. It was 2014 when a decision was finally made and China was forced to compromise. The time and trade lost during mediation of this dispute contributed to the intensity of the 2010 crisis and 2011 price spike. Such issues call for the need to quicken the decision-making procedures in international trade disputes. Moreover, long-term agreements and the establishment of a REE stock exchange, which would set prices in a transparent manner, may be required and are being demanded by an increasing number of REE importing parties (European Commission, 2014).

But even if prices were to remain stable, the balance problem of REEs should be carefully assessed (Binnemans et al, 2013). If the REEs in higher demand have a lower abundance within a particular deposit, the minimum quantity that needs to be mined, processed and separated must be at least the amount required for critical applications as defined by the consumer market. As a consequence, elements of higher abundance and lower criticality will be produced in larger than required quantities and due to the surpluses they will have to be stockpiled, thus increasing the costs of mining, processing and storing. This is the main reason why the Mountain Pass project seems to have failed despite high expectations. A global diversification of the rare earth resources with respect to the demand and supply of the individual REEs may address such supply balance issues.



REEs may possibly also be extracted from alternative sources, such as industrial wastes, and by recycling end-of-life REE-bearing products such as consumer products or lighting. Substitution especially of the less common REEs is another important option. An entirely different but equally relevant issue concerns the environmental impact of REE mining and beneficiation. Of particular concern is the common association of REE with thorium and uranium and thus the need to strictly control the dispersion of radioactive elements into the environment (Barakos et al, 2015). This pertains in particular to the treatment and disposal of tailings. Rather lax legislation in China has resulted in significant pollution, especially related to illegal mining (Kiggins, 2015). The arguments against the LAMP facilities in Malaysia show that people are already prejudiced against REE mining development and processing, despite the fact that the public engagement experience on this industry sector is limited outside of China (Ali, 2014). In some cases, however, an abundance of thorium and uranium may have a positive impact on the feasibility of a REE deposit, since both may be exploited as by-products. The REE industry needs to convince the public that REE mining development should not be considered as a threat, but that rare earth elements are essential ingredients for clean energy and a green economy.

The separation of REEs is a primary technical issue for the global REE industry, with competency still centred mostly in China. A few separation plants are settled in the Western world, such as the Molycorp facilities in Estonia and the Rhodia plant in France. However, there are numerous current research and development projects that focus on the development of extraction and separation technologies that are resource- and energy-efficient as well as environmentally benign.

At the end of the day, extraction and primary beneficiation of REEs are likely the easy steps to take. But rare earth oxides or carbonates are still useless to original equipment manufacturers. Such companies are not equipped to convert them into metals, alloys, and magnets. What is needed to supply end customers in the Western world is a complete value chain, from mining to manufacturing.

China is currently the only country that has developed this complete value chain – comprising of hundreds of independent companies dedicated to rare earth research and production, each providing highly differentiated technologies, processing, formulation, or component-specific applications. By taking into account the economic relevance of the complete REE value chain, the economic value of the REE oxides market, which currently is less than US\$4 billion per annum globally (Roskill, 2015), turns into an industrial global market of all rare earth-dependent goods that exceeds \$7 trillion in value (Kennedy, 2015). As standalone mining companies cannot replicate a complex REE value chain, this remains the biggest challenge on the path towards a REE-industry in the Western world.

## REFERENCES

- Ali S H, 2014. 'Social and environmental impact of the rare earth industries', *Resources*, vol. 3, no. 1, pp. 123-134.
- Alonso E, Sherman A M, Wallington T J, Everson M P, Field F R, Roth R and Kirchain R E, 2012. 'Evaluating rare earth element availability: A case with revolutionary demand from clean technologies', *Environmental Science & Technology*, vol. 46, pp. 3406-3414.
- Barakos G, Mischo H and Gutzmer J, 2015. 'Rare earth underground mining approaches with respect to radioactivity control and monitoring strategies', in I B De Lima & W Leal (eds), *Rare Earths Industry: Technological, Economic, and Environmental Implications*, Elsevier, Amsterdam, pp. 121-138.
- Binnemans K, Jones P T, Van Acker K, Blanpain B, Mishra B and Apelian D, 2013. 'Rare-earth economics: The balance problem', *Journal of the Minerals, Metals & Materials*, vol. 65, no. 7, pp. 846-848.
- European Commission, 2014. *Report on critical raw materials for the EU*, viewed 8 February 2016, <http://ec.europa.eu/DocsRoom/documents/10010/attachments/1/translations/en/renditions/native>
- Haque N, Hughes A, Lim S and Vernon C, 2014. 'Rare earth elements: Overview of mining, mineralogy, uses, sustainability and environmental impact', *Resources*, vol. 3, no. 4, pp. 614-635.
- Humphries M, 2012. *Rare earth elements: the global supply chain*, CRS Report for Congress, viewed 8 February 2016, <https://fas.org/sgp/crs/natsec/R41347.pdf>.
- Kennedy J, 2015. 'Rare earth production, regulatory USA/International constraints and Chinese dominance; The economic viability is bounded by geochemistry and value chain integration', in I B De Lima & W Leal (eds), *Rare Earths Industry: Technological, Economic, and Environmental Implications*, Elsevier, Amsterdam, pp. 37-55.
- Kiggings R D, 2015. *The political economy of rare earth elements*, Palgrave MacMillan, New York.
- Massari S and Ruberti M, 2013. 'Rare earth elements as critical raw materials: Focus on international markets and future strategies', *Resources Policy*, vol. 38, pp. 36-43.
- Roskill, 2015. *Rare earths: Market outlook to 2020*, 15th Edition, Roskill, London.

Stanway D, 2015. *Fate of global rare earth miners rests on China smuggling crackdown*, viewed 8 February 2016, <http://ca.reuters.com/article/technologyNews/idCAKCN0PH2DO20150707>

United States Geological Survey, 2016. *Mineral commodity summaries 2015*, viewed 8 February 2016, <http://minerals.usgs.gov/minerals/pubs/mcs/2015/mcs2015.pdf>

Walters A, Lusty P, and Hill A, 2011. *Rare earth elements: Mineral profile series*, British Geological Survey, Nottingham.

Zepf V, 2013. *A new approach to the nexus of supply, demand and use: exemplified along the use of neodymium in permanent magnets*, Springer-Verlag, Berlin.