# Chapter 6
# Economic Aspects of the Rare Earths

**Abstract** In this chapter, the global production of the rare earths is discussed, expected shortages and surpluses for certain rare earths (the "balance problem") are indicated, and it is explained how China came to be the largest producer of rare earth elements in the world. Of course, the so-called Rare Earth Crisis of 2009–2013 is also addressed.

## 6.1 Introduction

The rare earths are used world-wide, and the availability and price of these metals has therefore world-wide effects. It happened that, from approximately the year 2000, production came largely from China. In 2009 the prices of the rare earths rose enormously (the so-called "Rare Earth Crisis"). This made the production by other countries worthwhile, or, in the case of the American Mountain Pass mine, made production again viable. This chapter explains more about these matters.

## 6.2 Global REE Production

The global production of the rare earth elements prior to 2010 is summarized in Fig. 6.1, and was approximately 110,000 tons per year in 2010.

Before 1960, the production of the rare earth elements was approximately 2 ktons per year. Production was mainly from monazite (and xenotime) from placer deposits (Geschneider 2011). The start of the growth of the rare earth industry began in the early 1960s, when it was discovered that the element europium (Eu) gave an intense red luminescence when exited by electrons. This was very quickly utilized in the development of color TV's (Geschneider 2011).

Looking at Fig. 6.1, it appears that industrial demand is in fact low in terms of ton. In 2012, the annual primary production was about two orders of magnitude less

J.H.L. Voncken, *The Rare Earth Elements*, SpringerBriefs in Earth Sciences,
DOI 10.1007/978-3-319-26809-5_6

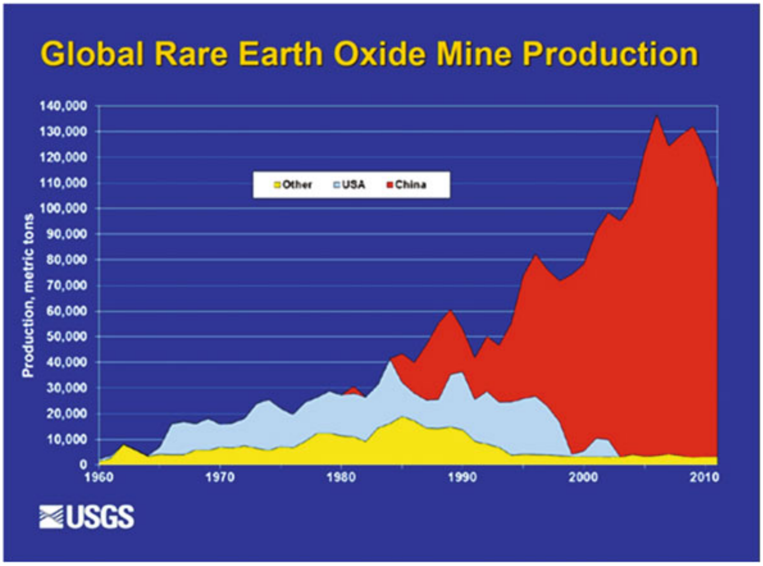

**Fig. 6.1** Global rare-earth-oxide production trends. *Source* USGS (2015)

than copper and four orders of magnitude less than iron (Alonso et al. 2012). However, the commercial significance of the rare earth elements does not match the amount used. Several of the REEs are important because they are critical in a wide variety of applications. Also they are used in key technologies undergirding mobility and energy supply (Alonso et al. 2012).

The production of rare earth oxides from the Mountain Pass mine started in 1964 and remained the main source of light rare earths in the west until approximately the middle of the 1990s (Castor 2008). In approximately 1985, China began to export rare earth element concentrates, and by 1990, China was producing more than the USA (Geschneider 2011).

Since the middle of the 1990s, China has had a near monopoly in all aspects of the REE supply chain, including, production, processing, consumption, and R&D. Although small amounts of REE continued to be produced in Russia, India, and Brazil, by 2005. China supplied 97 % of the world's REE resources.

The global demand for REE in the year 2010 was approximately 110,000–130,000 tons per year (Fig. 6.1). The clear rise in demand for REE since 2000 is due to the value of REE in the fields of clean energy and high-technology products (Canadian Institute of Mining, Metallurgy and Petroleum 2015). Not all REEs are as high in demand as others. The highest commercial interest is for eight rare earth elements: lanthanum, cerium, neodymium, praseodymium, samarium, dysprosium, europium and terbium (Massari and Ruberti 2013).

Japan is the largest importer of REE, which amounts to about 73 % of the global demand outside of China. The European Union countries collectively import roughly 13 % and the United States imports roughly 3 % of China's REE production (Canadian Institute of Mining, Metallurgy and Petroleum 2015).

In the future, when the global supply/demand is projected out to 2020, a shortage of HREE (Tb, Dy, Er, Y) is expected. In 2016, the global demand for these HREEs is expected to be 14,500 tons, while production is expected to be 7000 tons (Canadian Institute of Mining, Metallurgy and Petroleum 2015).

Furthermore, the abundances of LREE and HREE are not similar. The LREEs are much more common. And within the lanthanide series, due to the Oddo-Harkins rule (see Chap. 3), the REEs with an even atomic number are more common than the REEs with an odd atomic number. In a chart of the abundance, this is clearly visible as a saw tooth pattern (Chap. 1, Fig. 1.3).

Then there is also the so-called "balance problem". The rare earths are found in nature as mixtures. The mixture found depends on the ore mineral, the type of ore, and the location of the deposit. Bastnaesite and monazite are minerals which are rich in the LREEs, whereas xenotime and the South-Chinese ion-adsorption clays are rich in the HREEs. Also, the REEs decrease in abundance with increasing atomic number Z. Now the "balance problem" is the balance between the abundance of the rare earth elements in ores and the demand on the economic markets (Binnemans et al. 2013).

A market in balance is very difficult to achieve because the demand for specific rare earths is different, due to different applications and technological innovations. This causes a sometimes very high demand for one REE, which is a minor element in the ore (for instance dysprosium), whereas the demand for another one, which is a major constituent in the ore (for instance yttrium) is much lower. To help solve this, one may tune the production of REEs in general to meet the high demand of a particular REE, and stockpile the other REEs with a lower demand. The latter leads to a price increase, due to the costs for stockpiling. Moreover, taking into account the operational margins of a producer, this leads to shortages of some REEs and surpluses of others (Binnemans et al. 2013).

It would be a preferable situation if the demand for elements that are very abundant would control the REE market. Unfortunately, this is not the case. The most wanted elements at this time are neodymium and dysprosium (Binnemans et al. 2013). Cerium, praseodymium, and the heavy REEs holmium, gadolinium, thulium, ytterbium and lutetium are produced in excess, and are stockpiled.

There are basically five solutions to the problem (Binnemans et al. 2013; Binnemans 2014).

1. Find new high-volume applications for the elements that are available in excess,
2. Find substitutions for those that are high in demand, but available in limited amounts.
3. Diversify the types of rare-earth ores mined, and use less common REE-minerals such as eudialyte or loparite. In the latter minerals, the concentration of REEs and the ratio of REEs occurring are different from what is found in the "common" ore minerals monazite, bastnaesite and xenotime.

4. REE-recycling. This is studied currently (2015) on a larger scale than before, due to the dependence on one major supplier (China). The main waste streams that are under consideration are REE permanent magnets, nickel-metal-hydride batteries, and lamp phosphors.
5. Reduced use. In a number of applications, smart engineering can make it possible to diminish the use of critical REEs, whereas performance is not reduced. A good example is NdFeB-magnets, which contain dysprosium to prevent demagnetization at higher temperatures. It has been established that dysprosium can diffuse to the grain boundaries of a sintered NdFeB-magnet. Due to this effect, while keeping a similar effect of dysprosium, less than 50 % of this metal is needed (Binnemans 2014).

## 6.3 How China Became the World's Largest REE Producer

In the 1980s, China started to develop innovative programs in science and technology. This resulted in two programs, which would accelerate the countries high-tech development. In March 1986, the leader of China at that time Deng Xiaoping approved Program 863: The National High Technology Research and Development Program. Program 863 focuses on biotechnology, space technology, information technology, laser technology, automation, energy technology, and on new materials. There are a mix of military and civilian projects in the program (Hurst 2010). Other programs are, for instance, the Nature Science Foundation of China (NSFC).

However, no programs have been so important as Program 863 and the later program 973. A very important researcher was Professor Xu Guangxian (1920–2015), who is called "*the father of rare earths in China*" (Peking University News 2015). China credits Xu with paving the way for the country to become the world's primary exporter of rare earth elements (Hurst 2010). Xu Guangxian applied his previous research in extracting isotopes of uranium to rare-earth extraction and succeeded in developing cutting-edge extraction technologies for the REEs.

Rare earths were the perfect materials to give China high profits and geopolitical influence (Bourzac 2011). Therefore, in the 1980s and 1990s, China decided it wanted to become a world leader in the production of rare earth elements. In the years 1978–1989, China increased production of REEs by an average of 40 % per year (Hurst 2010). In 1992, former vice-chairman of the CCP and vice-prime minister Deng Xiaoping said: "There is oil in the Middle East; there is rare earth in China." In 1999, President Jiang Zemin stated: "Improve the development and application of rare earths, and change the resource advantage into economic superiority" (Canadian Chamber of Commerce 2012). As China is a state lead economy, such a statement of Jian Zemin was made into reality.

While in the USA environmental regulations were very strict and labor costs relatively high, Chinese companies profited from a combination of low labor costs and lax environmental regulations. Also, the largest rare earth mine in China at Bayan Obo not only produces rare earths but also iron ore, which provides another stream of income which covers the mine's fixed costs (Gholz 2014).

In the 1990s, China's export of the rare earth elements grew, causing a significant world-wide drop in prices. As a result, other producers, such as Molycorp, became increasingly unprofitable (Hurst 2010). In 2002 the Mountain Pass mine shut down due to complaints about environmental damage. Also, the mine and associated processing plants needed capital investment, so there had been a laborious round of permit applications (Gholz 2014).

In 1990, China also started to export separated REE commodities. At the end of the 1990s, China produced not only separated REE-oxides and metals, but also produced higher value products, such as magnets, phosphors, and polishing compounds. Since approximately the year 2000, China also produces finished products, such as electric motors, computers, batteries, liquid crystal displays (LCD), mobile phones and portable music devices (Geschneider 2011).

The result of all this has been that China became one of the largest producers globally (Hurst 2010; Canadian Chamber of Commerce 2012).

Currently in China, there are two state key laboratories, which focus on rare earths. These are the State Key Laboratory of Rare Earth Materials Chemistry and Applications, affiliated with Peking University, and the State Key Laboratory of Rare Earth Resource Utilisation, affiliated with Chanchun University, and belonging to the Chinese Academy of Sciences (Hurst 2010). In 1987, the Open Laboratory of Rare Earth Chemistry and Physics was established, at the Changchun Institute of Applied Chemistry. In 2002, the laboratory was renamed, and in 2007 it became the State Key Laboratory of Rare Earth Resource Utilization (Hurst 2010).

This laboratory focusses on 3 main research fields:

- Solid state chemistry and the physics of the rare earths
- Bioinorganic chemistry and the chemical biology of rare earth and related elements
- Rare-earth separation chemistry

The laboratories and institutes each focus on a particular research area, but their research is complementary. With respect to the scientific literature, there are two journals that focus specifically on rare earths, and which originate in China: the Journal of Rare Earths (editor-in-chief was Xu Guangxian, Publisher: Elsevier), and the China Rare Earth Information Journal. These are the only two journals world-wide that focus almost exclusively on rare earths, and they are both run by scientists based in China.

## 6.4 The REE-Crisis (2009–2013)

China limited the export of rare earths in 2007, as they wanted to retain them for their own market. This was achieved by raising export duties. Export duties were originally at 10 %, but rose from 15 to 25 % in 2011. In 2011, China subjected the export of ferro-alloys, containing more than 10 % of rare earth elements, to taxes of 25 % (Stewart et al. 2011). Overall this resulted in a large drop in China's export of rare earths.

The effect of this was a strong rise of the prices of REEs on the world market (Fig. 6.2). This has been termed the REE Crisis.

In fact, the export taxes were a direct violation of China's WTO commitments (Stewart et al. 2011). In 2012, the US filed a protest against China's export taxes through the WTO. Soon other industrialized countries joined. The reason for this was that the US and other industrialized countries in the world wanted to produce rare-earth-containing devices for themselves, which required access to refined rare earths (CNN 2012).

In 2014, the WTO rejected China's main argument (the alleged reason for the reduction in exports was to conserve a limited resource and to reduce mining pollution). The WTO ordered China to remove the ceiling on exports of rare earths (Ferris 2015). China was ordered to cancel its export taxes on rare earth elements on 2 May 2015, in response to the 2014-decision of the WTO on the export taxes (Argus Rare Earths 2015).

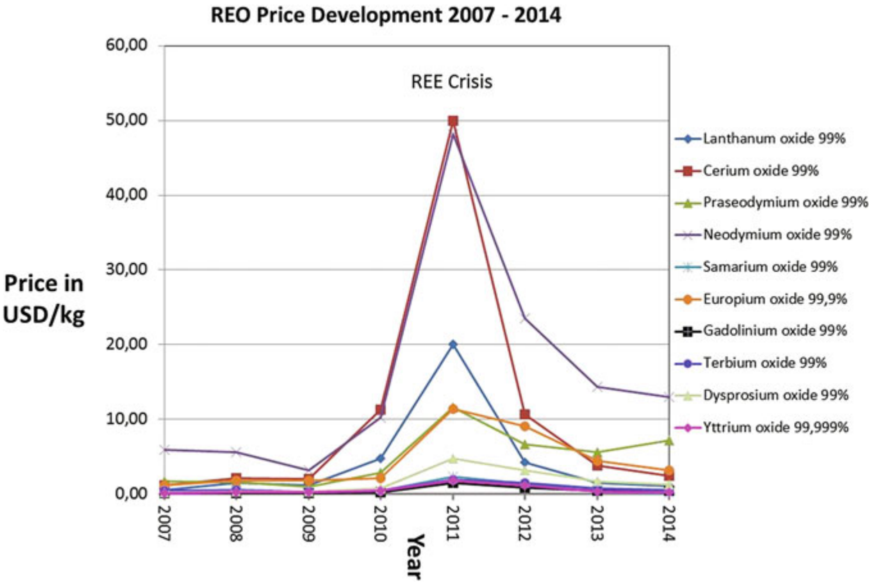

**Fig. 6.2** REO price development 2007–2014. Based on data published by Metals Pages, and Lynas Corporation. NB: these are prices for REE-oxides (REO). Prices for the pure metals were much higher

China announced on April 24, 2015 the lifting of the export taxes (BBC 2015). Indeed China has done so. "Under the new guidelines, rare earth minerals will still require an export license in China but the amount that can be sold abroad will no longer be covered by quota" (Law360 2015).

The REE-crisis actually ended, however, before this date (see Fig. 6.2). This is because other producers emerged (e.g. Lynas Corporation) since the start of the REE-crisis, and Molycorp restarted its production. However, these resources mainly comprise the LREEs, with limited HREE. Non-Chinese mines with significant amounts of HREEs are expected to come into production after 2015–2016 (Canadian Institute of Mining, Metallurgy and Petroleum 2015). Examples of the latter are Norra Kärr, Sweden, which is especially rich in the HREEs, and which makes up more than 50 % of the total REE content of the deposit (Tasman Metals 2014), and Kringlerne, SW-Greenland (Tanbreez 2014). In the meantime, China will be the sole source of HREEs (Canadian Institute of Mining, Metallurgy and Petroleum 2015). It must be realized, that the lowering in the REO-prices has had severe consequences for producing companies outside China. Lynas corporation faces bankruptcy, and Molycorp has again stopped production at Mountain Pass, and has filed for bankruptcy (Mining.com 2015; The Sydney Morning Herald 2015).

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