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Rare Earth Elements: Industrial Applications and Economic Dependency of Europe

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Abstract

Rare Earth Oxides are used in mature markets (such as catalysts, glassmaking and metallurgy), which account for 59% of the total worldwide consumption of rare earth elements, and in newer, high-growth markets (such as battery alloys, ceramics, and permanent magnets), which account for 41% of the total worldwide consumption of rare earth elements. China currently controls completely the mining activity, the enrichment technologies and metallurgy, and end-metal products of rare earths, resulting for both Europe and the U.S.A. in full industrial dependency. Due to high demand and limited availability of rare earth elements (REEs), Europe is unable to meet its industrial needs today for the manufacturing sector. Therefore the EU has included them in the group of 14 critical minerals. The balance of demand and supply in the world market of Rare Earth Metals was always rather unstable. The most significant increase of prices took place during the years 2009-2011, followed by a sudden and substantial fall in prices due mainly to the actual, persistent heavy economic crisis of the industrialized countries. The EU, in order to limit the dependency of REE imports, would have to employ alternative measures to secure REE supply security by adopting an admixture of trade policies, industrial adjustment and innovation and budget allocations in the member states.

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Keywords: Rare Earths Elements; applications; ;economic value; European dependency

1. Introduction

Rare earth elements (REEs) include the 14 lanthanides: Cerium (Ce), Praseodymium (Pr), Neodymium (Nd), Promethium (Pm), Samarium (Sm), Europium (Eu), Gadolinium (Gd), Terbium (Tb), Dysprosium (Dy),

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Holmium (Ho), Erbium(Er), Thulium(Tm), Ytterbium (Yb), and Lutetium (Lu). Moreover, Lanthanum (La) belongs to the REEs; often Yttrium (Y) is included as well. Their average abundance in the earth's crust varies from 66 *ppm* in Ce, 40 *ppm* in Nd, and 35 ppm in La to 0.5 ppm in Tm, disregarding the extremely rare Pm. Several of the REEs are thus not very "rare" and occur widely dispersed in a variety of forms, especially as accessory minerals in granites, pegmatites, gneisses and related metamorphic igneous rocks (Greenwood and Earnshaw, 1984). The abundance of Ce is almost the same as environmentally much more studied elements, such as Cu and Zn; the most scarce lanthanides, Lu and Tm, are actually more abundant in the Earth's crust than Cd and Se. No other group of elements in the periodic system displays such a great self-similarity as the REEs. They all usually form trivalent cations, though the divalent or the tetravalent oxidation state is known for most of them in chemical compounds. The effective ionic radius of the trivalent ions decreases gradually from La^{+3} (1.031 Å) to Lu^{+3}, (0.861Å) (Tyler, 2004).

The REEs are found, usually several together, in a variety of accessory minerals, such as phosphates, carbonates, fluorides and silicates. They rarely form more continuous ore bodies.

REEs do not occur as native elemental metals in nature, only as part of the host mineral's chemistry. For this reason, the recovery of rare earth minerals (REMs) must be accomplished through complex processing methods to chemically break down the minerals containing the REEs.

Despite the abundance of more than 200 known REE-bearing minerals, only three of them are considered to be the principal REE mineral ores most feasible for the extraction of REMs: bastnäsite, xenotime, and monazite (Tyler, 2004).

China's lead in total world mine production and reserves in 2010 stands at 97%; India with 2%; Brazil with 1% (USGS, 2010). In terms of total global mining reserves in REEs, China represents almost half of the total at 48%; the Commonwealth of Independent States 17%; the US 12%; India 3%; Australia 1%; and others 19%.

This may give the US and the EU confidence in pursuing further cases. Nevertheless, some voices in the US have also highlighted the defence and strategic elements of the debate, given that many military components are dependent on Chinese sourced REE inputs (USGAO, 2010). For example, the US Secretary of Defence has been given the task of reporting on the long-term availability of REEs for US defence and natural security (USCRS, 2010). The World Trade Organization (WTO) has also recognised that «fears of inadequate access to supplies in resource scarce countries and of inappropriate exploitation in resource-rich regions could lead to trade conflict or worse» (WTO, *World Trade Report 2010*).

China has the largest reserves of REEs in the world (80%) and is a major producer of REEs for the world market.

The value of rare earth metals (REMEs) is increasingly rising due to their uses in many modern technologies, including the production of catalytic filter-neutralizers of exhaust gases of cars, fiber optics, lasers, oxygen sensors, phosphors, and superconductors. Therefore, the REME market, which is the youngest goods market, rises violently. From 1964 to 1997, it increased by a factor of 17 and, from 1997 to 2007, it has increased by a factor of 20.5 (www.metalltorg.ru).

This paper reviews the current literature on industrial applications of REEs and studies on economic value of REMEs and Europe's dependence on them.

2. World Reserves and Production of Rare Earth Oxides

The global Rare Earth Reserves by country are given in Figure 1. The reserve is defined by the USGS (2010) as "*the part of the reserve base which could be economically extracted or produced at the time of determination*". On the contrary, the reserve base not only comprises the resources that are currently economic (= reserves) but also marginally economic reserves, and some of those that are currently sub-economic.

Figure 1: The possible global Rare Earth reserves, by country, as they are estimated by USGS (2014).

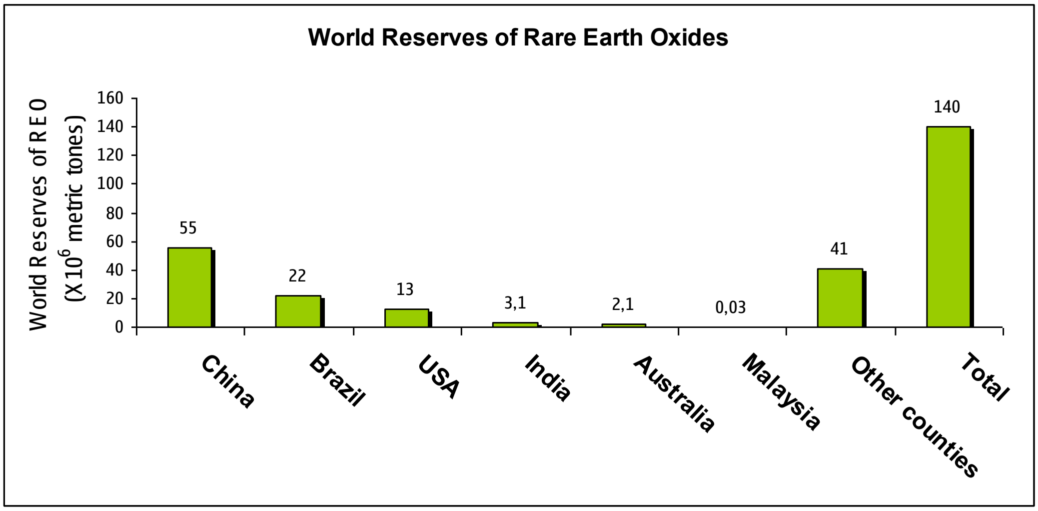
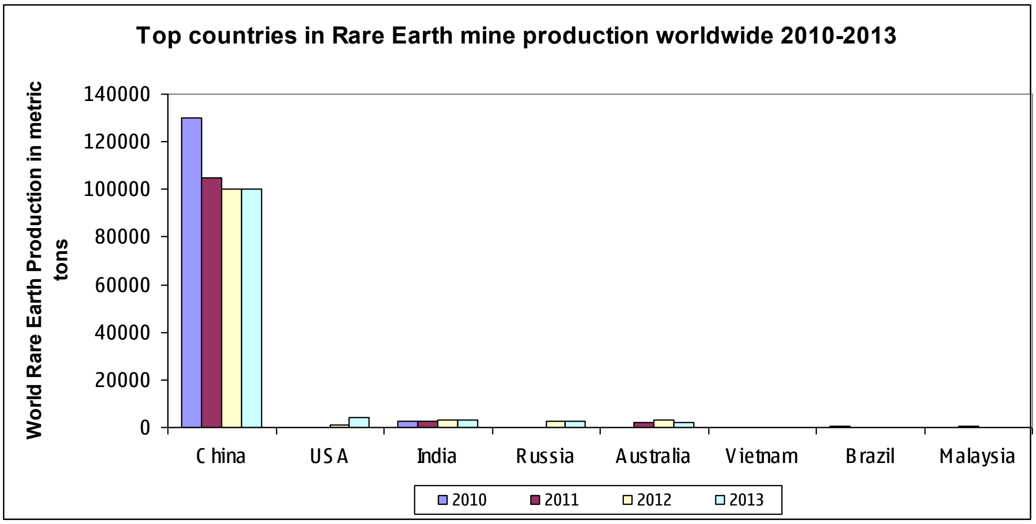


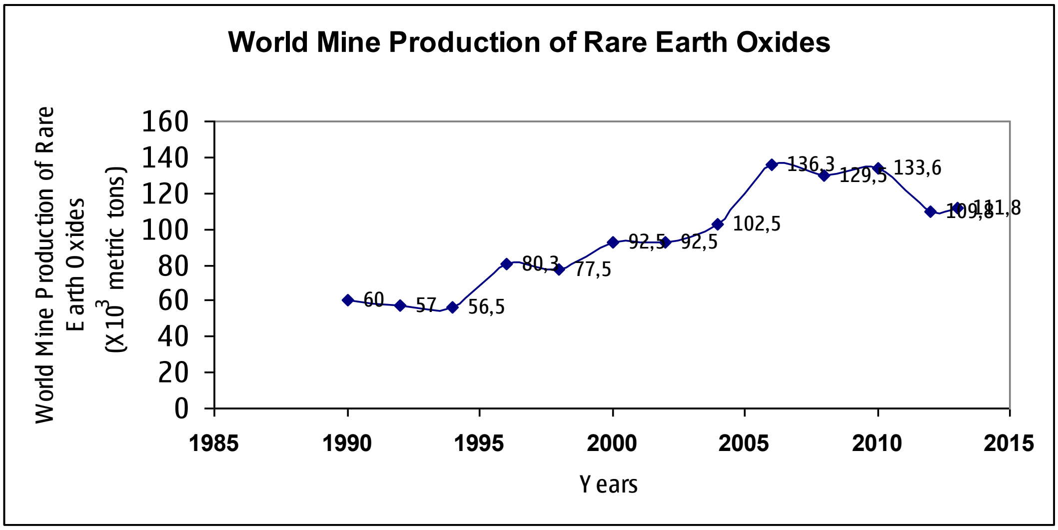
Figure 2: Top countries in Rare Earth Mine Production worldwide during 2010-2013 (after USGS, 2014 & http://www.statista.com/statistics/268011/top-countries-in-rare-earth-mine-production/)



It is to be expected that both the reserve base and the reserve will increase in the years ahead because the steep increases in Rare Earth Oxide (REO) prices lead to the exploration of new deposits. For example, the Chinese Ministry of Commerce announced in October 2010 that a new large rare earth deposit was found in Central China (MOFCOM 2010a). Figure 2 displays the top countries in Rare Earth mine production worldwide 2010-2013 (USGS, 2014).

On the other hand the trend of world production of RRE was increasing in recent decade (Figure 3) as compared the figures of the period 1990 to 2013, where the main contribution comes from China, which holds about 90% of world production, reaching 2013 to 111.8 million t. The figure points out the steady increase in the rare earth production due mainly to continuous increase of the Chinese market share, particularly since 2002, when the American mine was closed due to environmental problems and low competitiveness because of low Chinese prices (The Greens/EFA Group, 2011). Though the fact that China produces more than 95% of the global production, their share of the reserves is much lower at 38 %. Large deposits are also found in the USA, Australia and states of the former Soviet Union.

Figure 3: World Mine Production of Rare Earth Oxides (REOs), as it was estimated by US Geological Survey (modified after USGS, 2010 and USGS, 2014).



3. Applications of REEs in Industry

Rare earth elements (REEs) are not particularly “rare” in terms of abundance, but for many years remained rarely separated from each other owing to their similar chemical characteristics (Hurst, 2010). Although REEs are widely distributed geographically, they are chiefly mined, concentrated, and separated in China.

China continued efforts to restrict the supply of REOs and consolidate its rare earth industry. China’s rare earth production and export quotas for 2013 were 93,800 tons and 31,000 tons, respectively.

They are used in mature markets (such as catalysts, glassmaking, lighting, and metallurgy), which account for 59% of the total worldwide consumption of rare earth elements, and in newer, high-growth markets (such as battery alloys, ceramics, and permanent magnets), which account for 41% of the total worldwide consumption of rare earth elements. In mature market segments, lanthanum and cerium constitute about 80% of rare earth elements used, and in new market segments, dysprosium, neodymium, and praseodymium account for about 85% of rare earth elements used. Regardless of the end use, rare earth elements are not recycled in large quantities, but could be if recycling became mandated or very high prices of rare earth elements made recycling feasible.

In 2008, 129,000 metric tons (t) of REOs was consumed worldwide (Cordier and Hedrick, 2010). Mature applications (catalysts and the glass, lighting, and metallurgical industries, sectors that grow at the rate of growth for the general economy) consumed about 60% of the total, and the remaining 40% was consumed in developing, high-growth technologies (battery alloys, ceramics, magnets, and other sectors that grow at 4 to 10% per year) (USGS, 2011).

The mature REO end-use markets (catalysts, glass industry, metallurgy excluding battery alloy, and phosphors) consume mainly cerium (45%), lanthanum (39%), and yttrium (8.0%) oxides. Dysprosium, gadolinium, neodymium, and praseodymium oxides and other REOs contribute the remaining 7.0% of total REOs consumed in these sectors. The main industrial applications of REE are briefly listed in Table 1 (Naumov, 2008).

Catalysis: In 2008, 27,400 t of REOs were used as catalysts for fluid cracking (72%) and automobile catalytic converters (28%), of which lanthanum oxide contributed 66%, cerium oxide 32%, neodymium oxide

0.8%, and praseodymium oxide 0.6% (Table 2).

Glass: REOs are added to glass to perform such functions as absorbing ultraviolet light, altering the refractive index, and colorizing or decolorizing (USGS, 2011). Yttrium is used with garnet to form yttrium-aluminum-garnet (YAG) lasers. Neodymium and other REEs are used as dopants to alter the properties of the YAG lasers (Anscombe, 2002, Table 2). Neodymium is used for the production of YAG lasers. No REE-bearing scrap material is recycled for use in this crystal-growing process.

Table 1: Main industrial applications of REEs (after Naumov, 2008)

REE	Symbol	Application
Scandium	Sc	High-strength Al-Sc alloys, electron beam tubes
Yttrium	Y	Capacitors, phosphors, microwave filters, glasses, oxygen sensors, radars, lasers, superconductors
Lanthanum	La	Glasses, ceramics, car catalysts, phosphors, pigments, accumulators
Cerium	Ce	Polishing powders, ceramics, phosphors, glasses, catalysts, pigments, misch metal, UV filters
Praseodymium	Pr	Ceramics, glasses, pigments
Neodymium	Nd	Permanent magnets, catalysts, IR filters, pigments for glass, lasers
Promethium	Pm	Sources for measuring devices, miniature nuclear batteries, phosphors
Samarium	Sm	Permanent magnets, microwave filters, nuclear industry
Europium	Eu	Phosphors
Terbium	Tb	Phosphors
Dysprosium	Dy	Phosphors, ceramics, nuclear industry
Holmium	Ho	Ceramics, lasers, nuclear industry
Erbium	Er	Ceramics, dyes for glass, optical fibers, lasers, nuclear industry
Ytterbium	Yb	Metallurgy, chemical industry
Lutecium	Lu	Single crystal scintillators
Thulium	Tm	Electron bean tubes, visualization of images in medicine
Gadolinium	Gd	Visualization of images in medicine, optical and magnetic detection, ceramics, glasses, crystal scintillators

Metallurgy (Excluding Battery Alloy): REEs are added to aluminum, iron, steel, and other host metals in small quantities in order to improve selected physical properties of the resulting alloys. The rare earths are added as ferroalloys, master alloys, mischmetal (a mix of mostly cerium and lanthanum oxides), or metals.

In 2008, 11,500 t of REOs were used in this category (Table 2), of which cerium oxide accounted for 52%, lanthanum oxide 26%, neodymium oxide 17%, and praseodymium oxide 5.5%.

Ceramics: REEs are added to ceramic glazes for colour control (Campbell and Keane, 2010). Barium titanate powder, which is used in electronic applications, is doped with lanthanides to modify the properties of the titanate. Yttrium is used to make ferrites for high frequencies and to stabilize zirconia in oxygen sensors.

In 2008, 7,000 t of REOs were used in this category, of which yttrium oxide accounted for 53%, lanthanum oxide 17%, cerium and neodymium oxides 12% each and praseodymium oxide 6.0% (Table 2).

Neodymium-Iron-Boron Magnets: Because of their superior magnetic flux density, neodymium-iron-boron magnets are in high demand for small and large motors and generators. In 2008, 26,300 t of REOs were used in this category, of which neodymium oxide accounted for 69%, praseodymium oxide 23%, dysprosium oxide 5.0%, gadolinium oxide 2.0% and terbium oxide 0.2% (Table 2).

Table 2: The distribution of Rare Earth Oxides (REOs) consumption within important industry market sectors, 2008 (modified after USGS, 2011; La_2O_3: Lanthanum oxide, CeO_2: Cerium oxide; Nd_2O_3: Neodymium oxide; Pr_6O_{11}: Praseodymium oxide; Y_2O_3: Yttrium oxide; $D_{y2}O_3$: Dysprosium oxide; Gd_2O_3: Gadolinium oxide;

Tb_6O_7: Terbium oxide; SmO: Samarium oxide).

Chemical formulas of REOs	Catalysts Consumption	Glass Industry Consumption	Metallurgy Industry Market Sector Consumption	Ceramics Market Sector Consumption	Permanent Magnet Market Sector Consumption	Battery Alloy Market Sector Consumption	Unspecified Market Sectors Consumption
	Tones (t)	Tones (t)	Tones (t)	Tones (t)	Tones (t)	Tones (t)	Tones (t)
La_2O_3	18,200	8,050	2,990	1,190	-	6,050	1,430
CeO_2	8,820	18,600	5,980	840	-	4,040	2,930
Nd_2O_3	228	360	1,900	840	18,200	1,210	1,130
Pr_6O_{11}	152	694	633	420	6,140	399	300
Y_2O_3	-	240	-	3,710	1,310	-	1,430
$D_{y2}O_3$	-	-	-	-	-	-	-
Gd_2O_3	-	-	-	-	525	-	75
Tb_6O_7	-	-	-	-	53	-	-
SmO	-	-	-	-	-	399	150
Other	-	-	-	-	-	-	75
Total	27,400	28,424	11,503	7,000	26,228	12,098	7,510

Battery Alloys: The negative electrode of nickel-metal-hydride (NiMH) rechargeable batteries comprises a variety of materials whose principal function is to store hydrogen within the lattice of the electrode. Some of these materials have REOs participation.

In 2008, 12,100 t of REOs were used in this category, of which lanthanum oxide accounted for 50% (6,050 t), cerium oxide 33% (4,040 t), neodymium oxide 10% (1,210 t) and praseodymium and samarium oxides 3.3% (399 t) each (Table 2).

Unspecified: The "unspecified" category includes use of REEs in chemicals, military weapons and delivery systems, and satellite systems. In 2008, 7,500 t of REOs were used in this category, of which cerium oxide accounted for 39% (2,930 t), lanthanum and yttrium oxides 19% (1,430 t) each; neodymium oxide 15% (1,130 t), praseodymium oxide 4.0% (300 t), samarium oxide 2.0% (150 t) and gadolinium oxide and other REOs, 1.0% (75 t) each (Table 2).

4. Economic value of Rare Earth Metals (REMEs)

The balance of demand and supply in the world market of REMEs was always rather unstable. After a rapid increase in demand in the 1980s by developed countries, it somewhat decreased in 1991–1993. In that moment, the REME market was affected, first, by a tremendous increase in their production in China and, second, by the presence of large reserves in countries of the former Soviet Union.

From 1990 to 2000, the total output of REMs increased from 33 to 81 t, or, by a factor of 2.45, while the demand by the producers of the Nd–B magnets for oxides of neodymium and dysprosium oxides increased in this period by a factor of 9–10. In 2000, the demand for neodymium reached its peak, which caused an abrupt increase in its production in China in both the metal and oxide forms. Simultaneously, this led to considerable excess supplies of other rare earth metals, which decreased their prices.

In March–April 2000, the Chinese government, with the intent to improve the situation in the world market of REMEs, took measures to restrict their mining, reduce their exports, and revoke government support from a series of unprofitable enterprises. This caused a decrease in the total supplies of REMEs to the world market and an increase in their prices (USGAO, 2010).

The period from 2000 to 2007 was characterized by a large variety of tendencies, though namely by a gradual decrease; however, in 2007, an increase was observed in prices for the most widespread REMEs, including yttrium, cerium, and most of the light elements, as well as a stable increase for dysprosium, terbium, and other heavy elements (USCRS, 2010).

As regarding the historical trends of REOs prices, since the early years to the present, we can identify two distinct phases. In the period 1991–2007, the production of these raw materials changed from about 50,000 t/year to almost 130,000 t/year, while the average prices fell, by less than 13 US$/t to a little more than 5 US$/t. From 2007 onwards, the produced quantities started to be 134,000 t/year (2010) while the prices of all REOs have been soaring. These developments, both of produced quantities and prices, are mostly due to the role of China: at first, this country used to have an exclusive role of producer, while in the last period, it has also become an important consumer itself and, thanks to its hegemony, controls market prices policies and enacts export control quotas (Papp et al., 2008).

The most significant increase of prices took place during the years 2009-2011 as it is shown by the Table 3. More recently (2012), according to the Metal-Pages quotations (Metalpages Inc., 2011–2012), there was a sudden and substantial fall in prices. These changes of trend are likely due to different reasons: the actual, persistent heavy economic crisis of the industrialized countries; the contraction of hi-tech consumption; the placing on the market of large stocks of REOs by some Chinese private operators fearful of possible inspections and confiscations by the Chinese Government (Lian and Stanway, 2011).

5. Economic Dependence of Europe on Rare Earth Elements

According to the United States Geological Survey (USGS) there are a total of 70 REE mines in China, with 19 active, 16 potential, and the status of 35 unclear (Orris, G.J. and Grauch, R.I., 2002).

The formation of prices for commodities such as REEs occurs in a partially transparent manner through direct negotiation between buyer and seller. Prices are formulated in terms of the quality or purity, supply, demand, current inventories, transportation costs and other externalities such as storage costs. As yet, the practice of derivates trading and hedging does not apply to REEs. International prices for REEs have been relatively low because of a number of factors including the number of extraction enterprises in operation and illegal mining activities.

Table 3: Prices of REEs (in US$/kg) for the four-years period 2009 – 2012, showing a significant increase between 2009-2011, and thereafter a sudden and substantial fall for 2012, with the corresponding percentage lost (data based on Metalpages Inc., 2011–2012).

REEs	2009	2010	2011	2012	Price fall from 2011 to 2012 (in %)
Ce	4,5	61	158	42,5	73
La	6,25	60	151,5	36	76
Pr	14	86,5	248,5	175	30
Nd	14	87	318	154	52
Dy	100	295	2510	1500	40
Eu	450	630	5870	4010	32
Tb	350	605	4410	3400	23

REEs - whether in raw, refined or processed form - are essential to Europe’s economy. The European Commission estimates that the EU is 97% dependent on rare earth supplies from China (European Commission, 2010). This is likely to continue with the EU’s shift to a low carbon economy, with renewable technologies requiring REE inputs. While REEs are presently abundant, the EU’s strategic dependency on REEs was recently exposed when China announced that it was cutting export quotas by 35% in the first quarter of 2011

(Bloomberg, 2010). This should be seen against the backdrop of export measures imposed on raw materials by Argentina, Brazil, India and Russia which affected EU imports of raw materials worth almost 6 billion € in 2009.

On May 20, 2008 the European Parliament adopted the first significant resolution on critical raw materials entitled "*On Trade in Raw Materials and Commodities"*. This resolution was the first very essential resolution to the European economy. The Resolution recommended that the Council of the EU and the European Commission develop a coherent EU-level strategy on crucial raw materials including such measures as the promotion of investment into research and development for the recycling and efficient use of critical raw materials, including REEs (Fiott, 2011).

Germany has already made diplomatic efforts to secure a diversified supply of REEs, including with other resource rich countries such as Australia (GFMET, 2010a). Countries such as China and India "have now given a strategic orientation to their raw materials policies and have taken measures to meet their needs for raw materials", and that "in the medium term, this can impact on German and European companies' access to sources of raw materials" (GFMET, 2010b).

The EU would have to employ alternative measures to secure REE supply security. Any such response will have to be an admixture of trade policies under WTO auspices, industrial adjustment and innovation and budget allocations in the member states and at the EU-level. Inventories would only really make for a sensible strategy so long as prices remain high. However, research on REE substitutions has not yet led to the lower costs of using substitutes, and nor have these substitutes been proven as effective replacements in terms of conductivity and other variables. The EU has so far invested 17 million € in the *ProMine* project from 2009-2013 with work on geological surveys to uncover REEs in Europe. So far this is investigative research and time will be needed before the project yields results.

In Greece significant reserves of rare earth elements are found in alluvial deposits in the coastal and groundwater environment of Strymona gulf between Strymona river and Kavala region, Northern Greece. Specific ore deposits research estimates ore reserves of 485 million t with an average content of 1.7% rare earths. Detailed and systematic investigations also show that bauxites and lateritic bauxites in Central Greece contain representative concentrations, ranging overall from 3,275-6,378 g/t REE. It must be stressed that there is still an emerging interest for the red mud from the aluminum metallurgy (Arvanitidis & Papavasileiou, 2011). Generally, in Greece they occur in a number of environments and are found in igneous (primary types), sedimentary, or metamorphic rocks (secondary types) of different ages. In secondary rocks the REE have been further concentrated from a primary enrichment through sedimentary processes or weathering. Secondary types are economically the most important types in Greece (Eliopoulos et al., 2014).

In the US, through the USGS, geological surveys have already shown that 13 million metric tones of REEs exist in the US (USGS, 2010). Many of the EU member states have been slow to take the same degree of urgency in discovering new sources of REE deposits.

6. Discussion and conclusions

Due to high demand and limited availability of REEs, Europe is unable to meet today its industrial needs for the manufacturing sector. Therefore the EU has included them in the group of 14 critical minerals. Namely, China currently controls completely the mining activity, the enrichment technologies and metallurgy, and end-metal products of rare earths, resulting for both Europe and the U.S.A. in full industrial dependency, with a rate reaching 100 %. This is happening at a time when the demand and needs tend globally constantly growing at an annual rate of 8-11 %. There are large differences in market prices of rare earth oxides. Also, the prices depend on the degree of purity determined by the specifications in the applications. The price ranges from 11 \$/kg La_2O_3 to 1,600 \$/kg Eu_2O_3 (www.lynascorp.com). It has to be underlined however, that China controls 95% of world production.

The total world consumption of REOs was about 129,000 t in 2008, of which cerium, lanthanum, and yttrium are used in market sectors that are driven by the growth of the general economy. Dysprosium, neodymium, and praseodymium are used in lower growth sectors, but most of their use is in the high-growth (8–10% per year) permanent magnet sector, which can be expanded to include batteries for electric cars, motors and generators for automobiles, and wind turbine generators.

The European Commission is working to put in place various Innovation Partnerships (IP), and it is in the process of initiating one for raw materials (European Commission, 2011). To establish an IP for raw materials a number of obstacles were discussed including the lack of sustainable technologies to optimize raw material management, the lack of possibilities for substitution of materials, insufficient recycling in the value chain, lack of networking between member states on national mineral policies, lack of sufficient international cooperation, and a lack of structures to encourage a European knowledge base in raw materials. Only under the *Raw Materials Initiative* and the Europe 2020 Strategy –where resource-efficiency is considered a flagship initiative – does one read of explicit mention of REEs.

Statistical work could also do more to identifying diversified reserves of REEs within Europe itself and other parts of the world. The EU could, for example, envisage establishing an EU Geological Survey. This is something the European Economic and Social Committee recognized back in 2009 in all but name when calling for a reinforcement of "*mineral intelligence at the EU level by establishing a European geological survey and a European Mineral Resources Information System, to be built on the basis of the capacities of the Member States*" National Geological Surveys» (EESC, 2009).

The key is to instead promote efficient spending on R&D and to promote the opening up of national funding to Union-wide competition as a means of boosting the rationalization of budget spending. If these trends cannot be met by increased budgets, then the required innovation may demand enhanced collaboration between universities, research centre, industry, governments and the EU for more rationalization of spending (Wouters and Bol, 2009).

In the long-term prospects, the situation of rare earth metals seems to be uncertain. The tremendous industrial resources of deposits now in use (they are formally sufficient for 500 yr) do not guarantee protection from the appearance of problems associated with an imbalance in the supply and demand for separate REMEs. It seems likely that it is precisely this fact, rather than the monopolistic position of China in the REME market, that causes anxiety among the producers and consumers of this production. The rare earth metal industry of China long ago came to constitute an integral part of the worldwide chain of the production and consumption of REMEs.

Today, the world's consumption of rare-earth metals is ~70–75% of their total production; i.e., regular accumulation of unclaimed REMEs takes place. The data for individual mines are more impressive. For example, in 2006, official representatives of Balyunebo Iron Mine in province Baotou, China, informed that since 1958, about 12.5 million t of REME ores have been mined, of which only 1.2 million t, i.e., about 10%, were used (WTO, 2010) [www.metal-pages.com]. It seems likely that in the long-term prospects, a time may come when it will become impossible to satisfy the demand for individual REMEs via an increase in the mining of ores of today's metallurgical composition.

However, it is sure that REEs, along with the resource management of drinking water, oil and phosphorous (for fertilizers), will be crucial and decisive for the redefinition of the international global balances of the near future. Over a longer term, it is easily predictable that nanotechnology will replace various critical materials, like the REEs, in many of the current uses, by emulating their properties and thus reducing their quantities needed.

Finally, it has to be emphasized that environmental concerns must be paid attention; almost all the deposits contain the radioactive element thorium. Environmental cost is related to the market competitive force. It is very important that current rare earth market with profitable prices is greatly stimulated by the strict quota control of China and curb of smuggling to limit the supply. Therefore, all producers should pay great attention on the adjustment of future quota amount (Chen Zhanheng, 2011).

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