



# Rare Earth Elements: The Global Supply Chain

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September 6, 2011

**Congressional Research Service**

7-5700

[www.crs.gov](http://www.crs.gov)

R41347

## Summary

The concentration of production of rare earth elements (REEs) outside the United States raises the important issue of supply vulnerability. REEs are used for new energy technologies and national security applications. Is the United States vulnerable to supply disruptions of REEs? Are these elements essential to U.S. national security and economic well-being?

There are 17 rare earth elements (REEs), 15 within the chemical group called lanthanides, plus yttrium and scandium. The lanthanides consist of the following: lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium. Rare earths are moderately abundant in the earth's crust, some even more abundant than copper, lead, gold, and platinum. While more abundant than many other minerals, REEs are not concentrated enough to make them easily exploitable economically. The United States was once self-reliant in domestically produced REEs, but over the past 15 years has become 100% reliant on imports, primarily from China, because of lower-cost operations.

There is no rare earth mine production in the United States. U.S.-based Molycorp operates a separation plant at Mountain Pass, CA, and sells the rare earth concentrates and refined products from previously mined above-ground stocks. Neodymium, praseodymium, and lanthanum oxides are produced for further processing but these materials are not turned into rare earth metal in the United States. Molycorp anticipates reopening its Mountain Pass mine (as a low-cost producer) in 2012.

Some of the major end uses for rare earth elements include use in automotive catalytic converters, fluid cracking catalysts in petroleum refining, phosphors in color television and flat panel displays (cell phones, portable DVDs, and laptops), permanent magnets and rechargeable batteries for hybrid and electric vehicles, and generators for wind turbines, and numerous medical devices. There are important defense applications, such as jet fighter engines, missile guidance systems, antimissile defense, and space-based satellites and communication systems.

World demand for rare earth elements is estimated at 136,000 tons per year, with global production around 133,600 tons in 2010. The difference is covered by previously mined above-ground stocks. World demand is projected to rise to at least 185,000 tons annually by 2015. Additional mine capacity at Mt. Weld Australia is expected to come onstream later in 2011, to help close the raw materials gap in the short term. Other new mining projects could easily take 10 years to reach production. In the long run, however, the USGS expects that global reserves and undiscovered resources are large enough to meet demand.

Several legislative proposals have been introduced in the 112<sup>th</sup> Congress in the House and Senate to address the potential of U.S. supply vulnerability and to support domestic production and supply chain development of REEs because of their applications for national security/defense systems and clean energy technologies. The House Committee on Natural Resources approved H.R. 2011, the *National Strategic and Critical Minerals Policy Act of 2011*, on July 20, 2011.

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## Introduction

The concentration of rare earth elements (REEs) production in China raises the important issue of supply vulnerability. REEs are used for many commercial applications including new energy technologies, electronic devices, automobiles, and national security applications. Is the U.S. vulnerable to supply disruptions? Are these elements essential to U.S. national security and economic well-being?

The examination of REEs for new energy technologies reveals a concentrated and complex global supply chain and numerous end-use applications. Placing the REE supply chain in the global context is unavoidable. The current goal of U.S. mineral policy is to promote an adequate, stable, and reliable supply of materials for U.S. national security, economic well-being, and industrial production. U.S. mineral policy emphasizes developing domestic supplies of critical materials and encourages the domestic private sector to produce and process those materials.<sup>1</sup> But some raw materials do not exist in economic quantities in the United States, and processing, manufacturing, and other downstream ventures in the United States may not be cost competitive with facilities in other regions of the world. However, there may be public policies enacted or executive branch measures taken to offset the U.S. disadvantage of its potentially higher cost operations. The private sector may achieve lower cost operations with technology breakthroughs. Based on this policy framework, the Congress and the Administration are discussing the impact of China's near-monopoly position in rare earth elements and a range of potential federal investments that would support the development of a vertically integrated rare earth supply chain in the United States.

Aside from a small amount of recycling, the United States is 100% reliant on imports of REEs and highly dependent on many other minerals that support its economy. For example, the United States is more than 90% import-reliant for the following minerals: manganese (100%), bauxite (100%), platinum (94%), and uranium (90%). While import reliance may be a cause for concern, high import reliance is not necessarily the best measure, or even a good measure, of supply risk. The supply risk for bauxite, for example, may not be the same as that for REEs due to the multiplicity of potential sources. In the case of REEs, the dominance of China as a single or dominant supplier of the raw material, downstream oxides, associated metals and alloys, may be a cause for concern because of China's export restrictions and growing internal demand for its REEs.

This report provides a discussion of the major issues and concerns of the global supply chain for REEs, their major end uses, and legislative and other policy proposals that Congress may consider to improve the U.S. rare earth position. An **Appendix** section provides a summary of rare earth-related legislation in the 112<sup>th</sup> Congress.

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<sup>1</sup> U.S. mineral policies provide a framework for the development of domestic metal mineral resources and for securing supplies from foreign sources. Specifically, the Mining and Minerals Policy Act of 1970 (30 U.S.C. §21a) declared that it is in the national interest of the United States to foster the development of the domestic mining industry "... including the use of recycling and scrap." The National Materials and Minerals Policy, Research and Development Act of 1980 (30 U.S.C. 1601) declares, among other things, that it is the continuing policy of the United States to promote an adequate and stable supply of materials necessary to maintain national security, economic well-being and industrial production, with appropriate attention to a long-term balance between resource production, energy use, a healthy environment, natural resources conservation, and social needs.

## What Are Rare Earth Elements?

There are 17 rare earth elements (REEs), 15 within the chemical group called lanthanides, plus yttrium and scandium. The lanthanides consist of the following: lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium. Rare earths are moderately abundant in the earth's crust, some even more abundant than copper, lead, gold, and platinum. While some are more abundant than many other minerals, most REEs are not concentrated enough to make them easily exploitable economically.<sup>2</sup> The United States was once self-reliant in domestically produced REEs, but over the past 15 years has become 100% reliant on imports, primarily from China, because of lower-cost operations.<sup>3</sup> The lanthanides are often broken into two groups: light rare earth elements (LREEs)—lanthanum through europium (atomic numbers 57-63) and the heavier rare earth elements (HREEs)—gadolinium through lutetium (atomic numbers 64-71). Yttrium is typically classified as a heavy element.<sup>4</sup>

## Major End Uses and Applications

Currently, the dominant end uses for rare earth elements in the United States are for automobile catalysts and petroleum refining catalysts, use in phosphors in color television and flat panel displays (cell phones, portable DVDs, and laptops), permanent magnets and rechargeable batteries for hybrid and electric vehicles, and numerous medical devices (see **Table 1**). There are important defense applications such as jet fighter engines, missile guidance systems, antimissile defense, and satellite and communication systems. Permanent magnets containing neodymium, gadolinium, dysprosium, and terbium are used in numerous electrical and electronic components and new-generation generators for wind turbines. About 75% of permanent magnet production is concentrated in China. See **Table 1** for selected end uses of rare earth elements.

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<sup>2</sup> U.S. Department of the Interior (DOI), Geological Survey (USGS), *Minerals Yearbook, Volume 1*, 2007, Rare Earths (Advance Release).

<sup>3</sup> DOI/USGS, Rare Earth Elements—Critical Resources for High Technology, Fact Sheet 087-02.

<sup>4</sup> DOI/USGS, Principal Rare Earth Elements Deposits of the United States—A Summary of A Domestic Deposits and a Global Perspective, Scientific Investigations Report 2010-5220.

Table I. Rare Earth Elements (Lanthanides): Selected End Uses

Light Rare Earths (more abundant)	Major End Use	Heavy Rare Earth (less abundant)	Major End Use
Lanthanum	hybrid engines, metal alloys	Terbium	phosphors, permanent magnets
Cerium	auto catalyst, petroleum refining, metal alloys	Dysprosium	permanent magnets, hybrid engines
Praseodymium	magnets	Erbium	phosphors
Neodymium	auto catalyst, petroleum refining, hard drives in laptops, headphones, hybrid engines	Yttrium	red color, fluorescent lamps, ceramics, metal alloy agent
Samarium	magnets	Holmium	glass coloring, lasers
Europium	red color for television and computer screens	Thulium	medical x-ray units
		Lutetium	catalysts in petroleum refining
		Ytterbium	lasers, steel alloys
		Gadolinium	magnets

Source: DOI, U.S. Geological Survey, Circular 930-N.

## Demand for Rare Earth Elements

The demand for mineral commodities is a derived demand which differs from consumer goods demand. Minerals are used as inputs for the production of goods and services. Consumers have no direct need for the commodity itself as a consumer good. The demand for rare earth elements is derived from the production of their end use products, such as flat panel displays, automobiles, catalysts, etc. As a result, the demand for REEs (as with other minerals) depends on the strength of the demand of the final products for which they are inputs. An increase in the demand for the final product will lead to an increase in demand for REEs.

In the case of derived demand, when prices rise, the extent to which the quantity of a material declines depends largely on the degree to which its price increase can be passed on to the final consumer, as well as the proportion of the final good's price that is accounted for by the mineral/metal commodity. That is, it might depend on the amount of REEs used per unit of output. For commodities that are characterized by derived demand, the demand conditions for the final consumer goods to which they contribute are key factors. The major variables that determine the growth in demand for consumer goods are price and income growth.<sup>5</sup>

World demand for REEs is estimated at 136,100 tons in 2010,<sup>6</sup> with global production around 133,600 tons annually.<sup>7</sup> The difference is covered by above-ground stocks or inventories. By

<sup>5</sup> Theory of Mineral Demand, Gary A. Campbell, *Economics of the Mineral Industries*, American Institute of Mining, Metallurgical, and Petroleum Engineering, Inc. 1985.

<sup>6</sup> "Lynas Says Rare Earths Demand to Grow at 9% a Year," bloomberg.com/news, October 25, 2010.

<sup>7</sup> U.S. Geological Survey (USGS), Mineral Commodity Summaries, January 2011.

2015, global demand for rare earth elements may reach 210,000 tons per year, according to one estimate.<sup>8</sup> The Industrial Minerals Company of Australia (IMCOA) estimates demand will be 185,000 metric tons in 2015. China's output may reach 140,000 tons per year (up from 130,000 tons in 2010) in 2015 as China's annual demand is estimated to rise from 73,000 metric tons (mt)<sup>9</sup> to 111,000 mt, according to the IMCOA.<sup>10</sup> But the Chinese Rare Earth Industry Association estimates China's demand increasing to 130,000 metric tons by 2015. Based on the above estimates, the non-China annual output would need to be between 45,000 mt to 70,000 mt to meet global demand for REEs. Although new mine production may be able to make up the difference for some lighter elements (there may be an excess supply of the lighter elements such as cerium, lanthanum, and praseodymium), several forecasts show that there will likely be shortfalls of other light rare earths (LREEs) and several heavier rare earth elements (HREEs), such as, dysprosium, terbium, neodymium, europium and erbium. This potential shortfall has raised concerns in the U.S. Congress.

While the Lynas Corp. Mt Weld project and Molycorp's Mountain Pass operation are projected to come on-stream in 2011 and 2012 respectively, with annual capacity to produce a total of 40,000 mt by 2013 (and additional potential annual capacity of 20,000 mt from Molycorp's Mountain Pass mine by the end of 2013), most new (greenfield) mining projects could easily take 10 years for development. In the long run, however, the USGS expects that global reserves and undiscovered resources are large enough to meet global demand.

As world demand continues to climb, U.S. demand for rare earth elements is also projected to rise, according to the USGS.<sup>11</sup> For example, permanent magnet demand is expected to grow by 10%-16% per year over the next several years. Demand for rare earths in auto catalysts and petroleum cracking catalysts is expected to increase between 6% and 8% each year over the same period. Demand increases are also expected for rare earths in flat panel displays, hybrid vehicle engines, and defense and medical applications. The 2010 composition of U.S. and world demand is shown in **Figure 1**. The anticipated composition of demand in 2015 is shown in **Figure 2**.

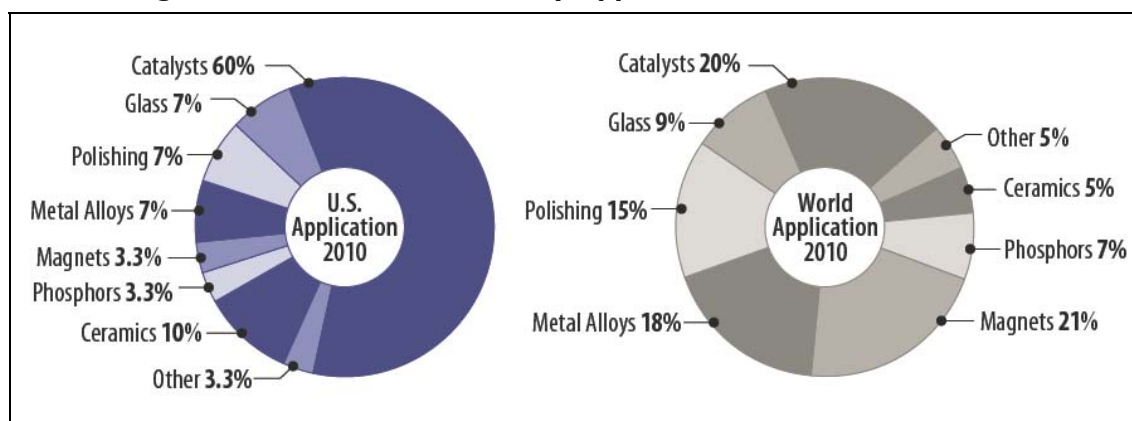
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<sup>8</sup> "Global Rare Earth Demand to Rise to 210,000 Metric Tons by 2015," October 18, 2010, Bloomberg News. Estimate provided by Wang Caifeng, Secretary General of the Chinese Rare Earth Industry Association.

<sup>9</sup> A metric ton equals 2200 lbs., or 1.1 short tons.

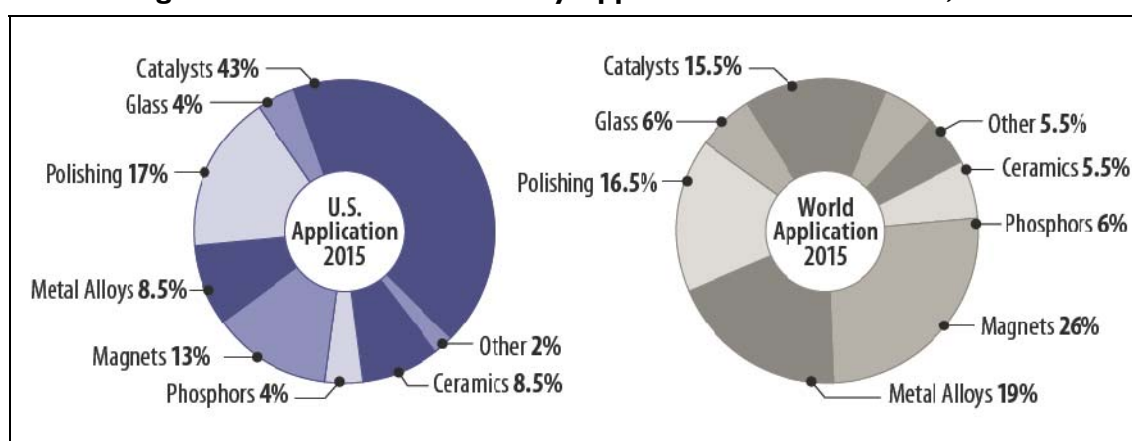
<sup>10</sup> IMCOA, *Meeting Rare Earth Demand in the Next Decade*, March 2011.

<sup>11</sup> DOI/USGS Minerals Yearbook, Volume 1, 2007.

**Figure 1. Rare Earth Demand by Application-U.S. and World, 2010**

Source: IMCOA, 2011

Note: Figure created by CRS.

**Figure 2. Rare Earth Demand by Application-U.S. and World, 2015**

Source: IMCOA, 2011

Note: Figure created by CRS.

## Rare Earth Oxide Prices

Prices of rare earth oxides and metals are rising rapidly and most rare earth experts would agree that the most recent restrictions on Chinese exports and lack of capacity elsewhere has led to the sharp price rise. **Figure 3** illustrates recent price increases of selected rare earth oxides. With a surge in demand and export restrictions it will take time for global supply to catch up. Prices may remain high in the short-term but, typically, tend to fall back to the industry's marginal cost of production after supply increases.<sup>12</sup>

However, there are likely structural shifts taking place in the global economy. Well over half the world's population is now part of emerging economies, led by China (population 1.3 billion) and

<sup>12</sup> Comment: "Unravelling the causes of the mineral price boom," David Humphreys, *Resources Policy*, v. 34, 2009.

India (population 1.0 billion) and followed by Africa (population nearly 1 billion), South America (population 400 million), and other parts of Asia (nearly 1.5 billion people). Their economies are expected to grow in the coming years which could keep prices under pressure even as new supply comes on-stream.

It is unclear where rare earth prices will plateau because this rate of growth suggests a structural shift in demand. Emerging economies' growth is usually more materials-intensive than developed economies because of the huge materials need for new infrastructure projects. If REE producers have a difficult time catching up to the expected sustained growth in the industry, prices may likely remain high for some time, particularly for the less available HREEs. Prices will depend on the long-term strength of demand in the emerging economies. History shows, however, that the long-run supply curve does adjust to meet demand.<sup>13</sup>

In general terms, costs of mineral extraction are increasing because of lower ore grades and increasing capital costs. China's costs of production are likely to rise as environmental and social costs and the potential for rising labor costs begin to be incorporated into China's REE production and processing operations. China would likely be unable to increase production significantly to drive prices down, as they have done in the past, because of higher costs, internal demand for domestic consumption, and the value-added export market. Byproduct REEs could also be impacted by rising downstream processing costs.<sup>14</sup>

Manufacturing costs of consumer goods that contain REEs may continue to decline per unit of output even as raw material costs continue to rise. Prices for many consumable goods have come down so that households are likely to have multiple units of a variety of products such as cell phones, laptops, flat panel televisions, and iPods, etc. Even with materials efficiencies, where less metal is used per unit of output, there is upward pressure on mineral prices because of overall demand growth and lack of supply capacity.<sup>15</sup> Because the materials intensity (small amounts per unit output) of REEs are relatively low for most end-use applications, low-cost manufactured goods may contain high-cost materials.

Recent non-specific export quotas in China have led to suppliers exporting more of the higher-valued HREEs. This practice has led to major price spikes of LREEs because of reduced availability. The overall price may be difficult for some buyers to absorb, even though many of the end-use applications use small amounts per unit of output.

Adequate mine capacity is only a part of the solution to any REE supply shortfall. Additional processing, refining, and manufacturing capacity is necessary to meet growing demand. Some raw material dependence will be addressed in the near term but the longer-term challenge is building out the entire supply chain outside China to meet growing global demand. While sustained high prices may attract some investors, the technology and skills must also be available to carry out the work.

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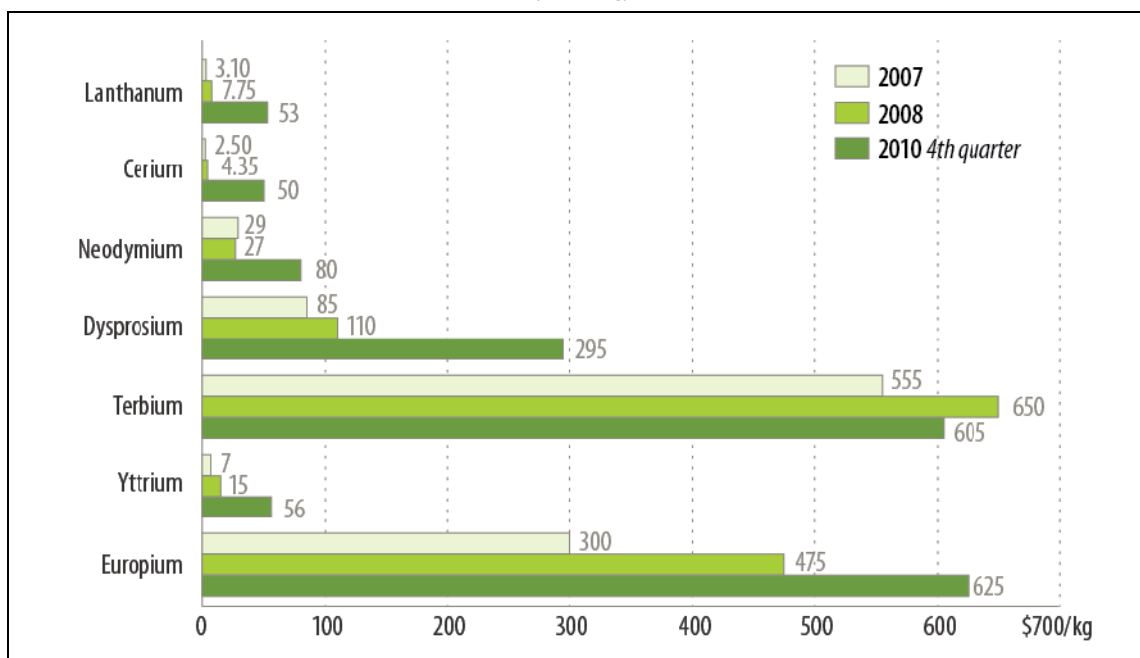
<sup>13</sup> Ibid.

<sup>14</sup> Byproducts are materials produced as a result of production of a primary product for which the mine was developed. The costs of production are assigned to the production of the primary product.

<sup>15</sup> "The great metals boom: A perspective," David Humphreys, *Resources Policy*, v. 35, 2010.

**Figure 3. Selected Rare Earth Oxide Prices, 2007-2010**

(US \$/kg)



Source: IMCOA, 2011 and METI, 2011.

Notes: According to the Ministry of Economy Trade and Industry (METI) of Japan, prices for dysprosium and neodymium metals rose dramatically. The price for dysprosium metal rose from \$250/kg in April 2010 to \$2,840/kg by July 2011, while the price for neodymium rose from \$42/kg in April 2010 to \$334/kg in July 2011.

## The Application of Rare Earth Metals in National Defense<sup>16</sup>

It has been estimated that the Department of Defense (DOD) uses less than 10% of domestic consumption of rare earths. However, no firm estimates are available at this time.<sup>17</sup> Rare earth elements used for defense purposes are primarily found in two types of commercially available, permanent magnet materials. They are samarium cobalt (SmCo), and neodymium iron boron (NdFeB). NdFeB magnets are considered the world's strongest permanent magnets and are essential to many military weapons systems. SmCo retains its magnetic strength at elevated temperatures and is ideal for military technologies such as precision-guided missiles, smart bombs, and aircraft. The superior strength of NdFeB allows for the use of smaller and lighter magnets in defense weapon systems. Permanent magnets containing neodymium, gadolinium,

<sup>16</sup> This section was prepared by Valerie Grasso, CRS Foreign Affairs, Defense, and Trade Division. For more details, see CRS Report R41744, *Rare Earth Elements in National Defense: Background, Oversight Issues, and Options for Congress*, by Valerie Bailey Grasso.

<sup>17</sup> Gopal Ratnam, "Pentagon Is 'Myopic' over China's Rare Earths Monopoly, U.S. Lawmaker Says," Bloomberg, November 1, 2010, <http://www.bloomberg.com/news/2010-11-01/pentagon-is-myopic-over-china's-rare-earths-monopoly-us-lawmaker-says.html>.

dysprosium, and terbium are also used in numerous electrical and electronic components and generators for wind turbines.

With the exception of small amounts of yttrium, rare earths have yet to be included in the strategic materials stockpile for national defense purposes. Generally, strategic and critical materials have been associated with national security purposes. In the Strategic Materials Protection Board's (SMPB) last report (December 2008), the SMPB defined critical materials in this way: "the criticality of a material is a function of its importance in DOD applications, the extent to which DOD actions are required to shape and sustain the market, and the impact and likelihood of supply disruption."<sup>18</sup> DOD's current position on strategic materials was largely determined by the findings of the SMPB.<sup>19</sup> Many scientific organizations have concluded that certain rare earth metals are critical to U.S. national security and becoming increasingly more important in defense applications.<sup>20</sup>

Some experts are concerned that DOD is not doing enough to mitigate the possible risk posed by a scarcity of domestic suppliers. As an example, the United States Magnet Materials Association (USMMA), a coalition of companies representing aerospace, medical, and electronic materials, has recently expanded its focus to include rare earth metals and the rare earth magnet supply chain. In February 2010, USMMA unveiled a six-point plan to address what they describe as the "impending rare earth crisis" which they assert poses a significant threat to the economy and national security of the United States.<sup>21</sup> However, it appears that DOD's position assumes that there are a sufficient number of supplier countries worldwide to mitigate the potential for shortages.

## Rare Earth Resources and Production Potential

Rare earth elements often occur with other elements, such as copper, gold, uranium, phosphates, and iron, and have often been produced as a byproduct. The lighter elements such as lanthanum, cerium, praseodymium, and neodymium are more abundant and concentrated and usually make up about 80%-99% of a total deposit. The heavier elements—gadolinium through lutetium and yttrium—are scarcer but very "desirable," according to USGS commodity analysts.<sup>22</sup>

Most REEs throughout the world are located in deposits of the minerals bastnaesite<sup>23</sup> and monazite.<sup>24</sup> Bastnaesite deposits in the United States and China account for the largest

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<sup>18</sup> 2010, <http://www.bloomberg.com/news/2010-11-01/pentagon-is-myopic-over-china-s-rare-earths-monopoly-u-s-lawmakersays>.

<sup>19</sup> U.S. Government Accountability Office, *Rare Earth Materials in the Defense Supply Chain*, GAO,-10-617R, April 1, 2010.

<sup>19</sup> Green Jeffrey A. Defense, Energy Markets Should Brace for Shortages of Key Materials. *National Defense Industrial Association*, October 2009; U.S. Lacks Data on Supply of Minerals Critical to Economy, National Security; Defense Stockpile is Ineffective. National Academy of Sciences, October 5, 2007, at <http://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=10052007>.

<sup>21</sup> Magnet Materials Supply Chain Players Propose Six-Point Plan to Address Impending Rare Earths Crisis, *USMMA*, February 4, 2010, at <http://www.usmagnetmaterials.com/?p=74>.

<sup>22</sup> DOI/USGS Fact Sheet 087-02, Rare Earth Elements-Critical Resources for High Technology.

<sup>23</sup> Bastnaesite is mineral with the formula (Ce, La)CO<sub>3</sub>(F,OH) that may contain other rare earth elements.

<sup>24</sup> Monazite is a mineral with the formula (Ce, La, Nd, Th)PO<sub>4</sub> that may contain other rare earth elements.

concentrations of REEs, while monazite deposits in Australia, South Africa, China, Brazil, Malaysia, and India account for the second largest concentrations of REEs. Bastnaesite occurs as a primary mineral, while monazite is found in primary deposits of other ores and typically recovered as a byproduct. Over 90% of the world's economically recoverable rare earth elements are found in primary mineral deposits (i.e., in bastnaesite ores).<sup>25</sup>

Concerns over radioactive hazards associated with monazites (because it contains thorium) have nearly eliminated it as a REE source in the United States. There are high costs associated with thorium disposal. Bastnaesite, a low-thorium mineral (dominated by lanthanum, cerium, and neodymium) is shipped from stocks in Mountain Pass, CA. The more desirable HREEs account for only 0.4% of the total stock. Monazites have been produced as a minor byproduct of uranium and niobium processing. Rare earth element reserves and resources are found in Colorado, Idaho, Montana, Missouri, Utah, and Wyoming. HREEs dominate in the Quebec-Labrador (Strange Lake) and Northwest Territories (Thor Lake) areas of Canada. There are high-grade deposits in Bayan Obo, Inner Mongolia, China (where much of the world's REE production is taking place) and lower-grade deposits in South China provinces providing a major source of the heavy rare earth elements.<sup>26</sup> Areas considered to be attractive for REE development include Strange Lake and Thor Lake in Canada; Karonga, Burundi; and Wigu Hill in Southern Tanzania.

**Table 2** and **Figure 4** illustrate China's near-monopoly position in world rare earth production. However, REE reserves and the reserve base are more dispersed throughout the world. China holds 50% of the world's reserves (55 million metric tons out of 110 million metric tons) and the United States holds about 13% according to the most recent USGS estimate.<sup>27</sup> South Africa and Canada (included in the "Other" category) have significant REE potential, according to the USGS. REE reserves are also found in Australia, Brazil, India, Russia, South Africa, Malaysia, and Malawi.

According to some geologists, careful consideration should be given to the feasibility of mining and processing of REEs as a byproduct of phosphorus deposits and from titanium and niobium mines in Brazil and elsewhere in the world.<sup>28</sup> Canadian, Chinese, and U.S. firms have recently assessed various REE deposits associated with development of primary minerals such as gold, iron ore, and mineral sand projects in the United States.

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<sup>25</sup> DOI/USGS Circular 930 N, International Strategic Minerals Inventory Summary Report—Rare Earth Oxides, by Wayne Jackson and Grey Christiansen, 1993.

<sup>26</sup> Dr. Anthony N. Mariano, *The Nature of Economic REE and Y Minerals on a World Level*, presented at the MIT Energy Initiative Workshop, April 29, 2010.

<sup>27</sup> USGS Mineral Commodity Summaries, January 2011.

<sup>28</sup> Ibid.

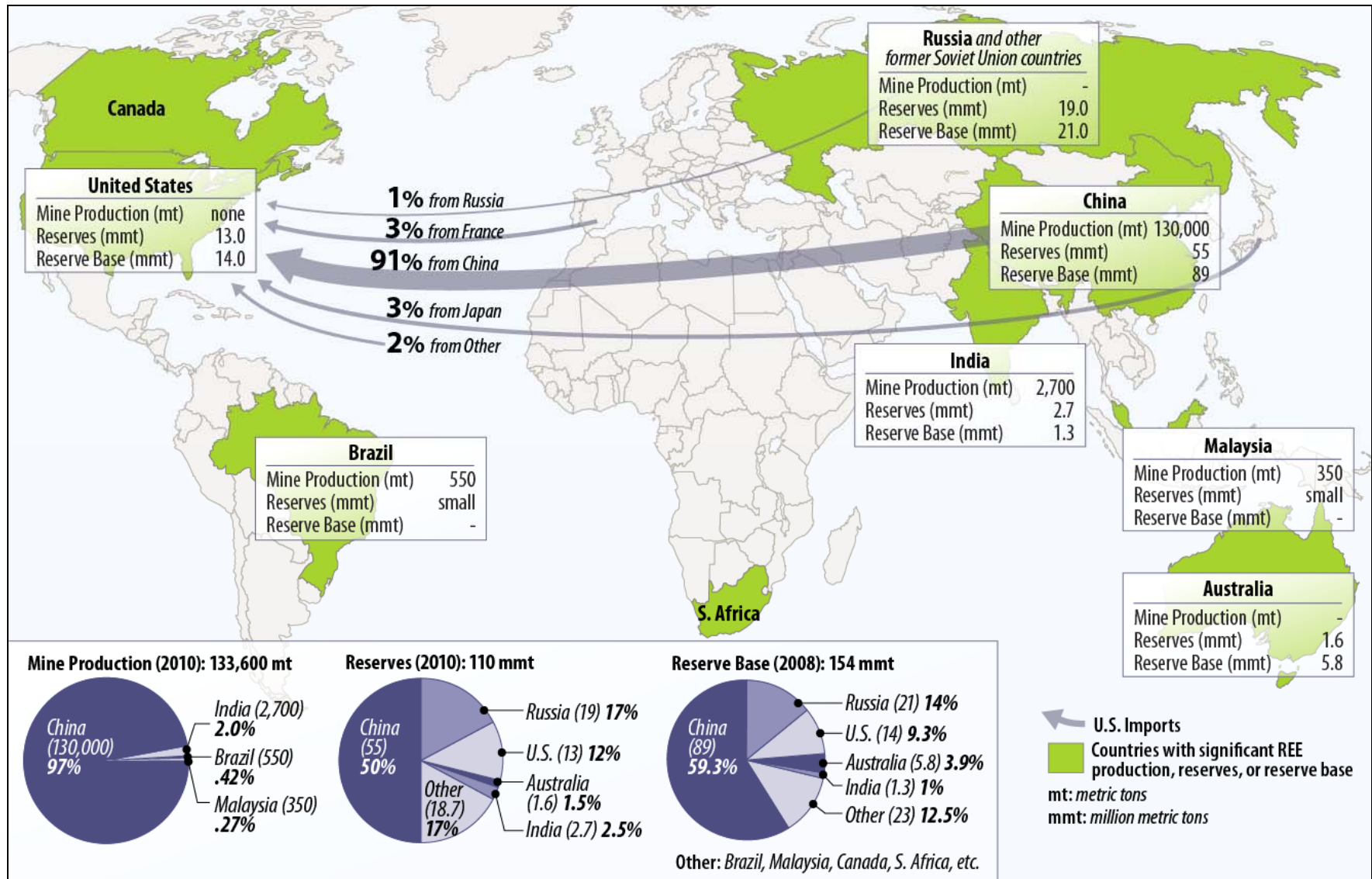
Table 2. Rare Earth Elements: World Production and Reserves—2010

Country	Mine Production (metric tons)	% of total	Reserves (million metric tons)	% of total	Reserve Base <sup>a</sup> (million metric tons)	% of total
United States	none		13.0	13	14.0	9.3
China	130,000	97.3	55.0	50	89.0	59.3
Russia			19.0	17	21.0	14
(and other former Soviet Union countries)						
Australia			1.6	1.5	5.8	3.9
India	2,700	2	3.1	2.8	1.3	1
Brazil	550	0.42	Small			
Malaysia	350	0.27	Small			
Other	NA		22.0	20	23	12.5
Total	133,600		110.0		154	

**Source:** U.S. Department of the Interior, Mineral Commodity Summaries, USGS, 2010.

- a. Reserve Base is defined by the USGS to include reserves (both economic and marginally economic) plus some subeconomic resources (i.e., those that may have potential for becoming economic reserves).

Figure 4. Rare Earth Elements: World Production, Reserves and U.S. Imports



Source: U.S. Geological Survey, Mineral Commodity Summaries, 2008-2011. (Figure created by CRS.)

There is currently no rare earth mine production in the United States. U.S.-based Molycorp operates a separation plant at Mountain Pass, CA, and sells the rare earth concentrates and refined products from previously mined above-ground stocks. Neodymium, praseodymium, and lanthanum oxides are produced for further processing, but these materials are not turned into rare earth metal in the United States. While the United States exports much of its REE stocks to Japan, that material is not counted in the trade equation for import reliance because the material is not produced from a primary source.

Molycorp, which has an exploration program underway to further delineate its rare earth mineral deposits, has plans for full mine production in the second half of 2012 and has plans to modernize its refinery facilities. Molycorp's Mountain Pass deposit contained an estimated 30 million tons of REE reserves and once produced as much as 20,000 tons per year.<sup>29</sup> Mountain Pass cut-off grade<sup>30</sup> (below which the deposit may be uneconomic) is, in some parts, 5.0%, while the average grade is 9.2%.<sup>31</sup> Molycorp anticipates becoming the low cost producer. U.S. Rare Earth (another U.S. based company), in the pre-feasibility stage of mine development, has long-term potential because of its large deposits in Idaho, Colorado, and Montana.<sup>32</sup>

Molycorp's deal with Sumitomo for additional financing is expected to be complete sometime in August or September 2011 according to Molycorp's CEO Mark Smith. Sumitomo would provide \$130 million in equity and debt financing and gain access to some raw materials from the Mountain Pass mine for a buyer in Japan.

Canadian deposits contain the heavy rare earth elements dysprosium, terbium, and europium, which are needed for magnets to operate at high temperatures. Great Western Minerals Group (GWMG) of Canada and Avalon Rare Metals have deposits with an estimated high content (7% and 20% respectively) of heavy rare earth elements.<sup>33</sup> Avalon is developing a rare earth deposit at Thor Lake in the Northwest Territories of Canada. Drilling commenced in January 2010. Thor Lake is considered by some in the industry to contain one of the largest REE deposits in the world with the potential for production of heavy REEs.<sup>34</sup> GWMG owns a magnet alloy producer in the U.K. When GWMG begins production in Canada and elsewhere, they plan to have a refinery near the mine site allowing greater integration and control over the supply chain. GWMG's biggest competitive advantage could be its potential for a vertically integrated operation. The Japan Oil, Gas, and Metals National Corporation (JOGMEC) signed an agreement with Midland Exploration Inc. for development of the Ytterby project in Quebec, Canada. JOGMEC is under the authority of the Japanese Ministry of Economy, Trade, and Industry with a mandate to invest in projects worldwide to receive access to stable supplies of natural resources for Japan.

The Lynas Corp., based in Australia, has immediate potential for light rare earths development, according to investor analyst Jack Lifton. Development of Lynas's Mt. Weld deposit in Australia

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<sup>29</sup> The Jack Lifton Report, *The Rare Earth Crisis—Part I*, by Jack Lifton, October 2009.

<sup>30</sup> Defined by the Department of the Interior's Dictionary of Mining, Mineral, and Related Terms, as the lowest grade of mineralized rock qualified as ore in a given deposit and the lowest assay that is included in an ore estimate.

<sup>31</sup> Industrial Minerals Company of Australia (IMCOA), *Meeting Rare Earth Demand in the Next Decade*, March 2011, p. 7.

<sup>32</sup> *Rare Earth Strategic Supplies More Important Than Price*, Industrial Metals/Minerals Interview of Jack Lifton by The Gold Report, December 14, 2009.

<sup>33</sup> IMCOA, p.7.

<sup>34</sup> Ibid.

is underway and there is potential to reopen the rare earth mine Steenkampskraal in South Africa. An agreement between GWMG and Rare Earth Extraction Co. Ltd. of Stellenbosch to develop the mine is in progress.

Access to a reliable supply to meet current and projected demand is an issue of concern. In 2010, China produced 97% of the world's rare earth elements (measured in rare earth oxide content) and continues to restrict exports of the material through quotas and export tariffs. China has plans to reduce mine output, eliminate illegal operations, and restrict REE exports even further. China has cut its exports of rare earth elements from about 50,000 metric tons in 2009 to 30,000 metric tons in 2010—a 60% reduction from 2009. The Chinese Ministry of Commerce announced export quotas of about 30,000 mt for 2011.

While limited production and processing capacity for rare earths currently exists elsewhere in the world, additional capacity is expected to be developed in the United States, Australia, and Canada within two to five years, according to some experts.<sup>35</sup> Chinese producers are also seeking to expand their production capacity in areas around the world, particularly in Africa and Australia. There are only a few exploration companies that develop the resource, and because of long lead times needed from discovery to refined elements, supply constraints are likely in the short term.

A Department of Energy report highlights mines that could potentially come on-stream in the next five years. These include Mt. Weld (Australia) in 2011; Mountain Pass (USA) in 2012 and 2013; Eastern Coast (Brazil); Nolans bore (Aus); Nechalacor (Canada); Domng Pao (Vietnam); Hoidas Lake (Canada); and Dubbo Zirconia (Aus).<sup>36</sup>

## **Supply Chain Issues**

The supply chain for rare earth elements generally consists of mining, separation, refining, alloying, and manufacturing (devices and component parts). A major issue for REE development in the United States is the lack of refining, alloying, and fabricating capacity that could process any future rare earth production. One U.S. company, Electron Energy Corporation (EEC) in Landisville, PA, produces samarium cobalt (SmCo) permanent magnets, while there are no U.S. producers of the more desirable neodymium iron-boron (NdFeB) magnets needed for numerous consumer electronics, energy, and defense applications. EEC, in its production of its SmCo permanent magnet, uses small amounts of gadolinium—an REE of which there is no U.S. production. Even the REEs needed for these magnets that operate at the highest temperatures include small amounts of dysprosium and terbium, both available only from China at the moment. EEC imports magnet alloys used for its magnet production from China.

The underinvestment in U.S. supply chain capacity (including processing, workforce development, R&D) has left the United States nearly 100% import dependent on all aspects of the REE supply chain and dependent on a sole source for much of the material. An April 2010 Government Accountability Office (GAO) report illustrates the lack of U.S. presence in the REE global supply chain at each of the five stages of mining, separation, refining oxides into metal, fabrication of alloys and the manufacturing of magnets and other components. According to the GAO report, China produces about 95% of the REE raw materials, about 97% of rare earth

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<sup>35</sup> Jack Lifton, "Is The Rare Earth Supply Crisis Due to Peak Production Capability or Capacity," michaelperelman.worldpress.com, September 6, 2009.

<sup>36</sup> U.S. Department of Energy, *Critical Materials Strategy*, December 2010.

oxides, and is the only exporter of commercial quantities of rare earth metals (Japan produces some metal for its own use for alloys and magnet production). About 90% of the metal alloys are produced in China (small production in the United States) and China manufactures 75% of the NeFeB magnets and 60% of the SmCo magnets. A small number of SmCo magnets are produced in the United States. Thus, even if U.S. rare earth production ramps up, much of the processing/alloying and metal fabrication would occur in China.

According to investor analyst Jack Lifton, the rare earth metals are imported from China, then manufactured into military components in the United States or by an allied country. Lifton states that many investors believe that for financing purposes, it is not enough to develop REE mining operations alone without building the value-added refining, metal production, and alloying capacity that would be needed to manufacture component parts for end-use products. According to Lifton, vertically integrated companies may be more desirable. It may be the only way to secure investor financing for REE production projects.<sup>37</sup> Joint ventures and consortiums could be formed to support production at various stages of the supply chain at optimal locations around the world. Each investor or producer could have equity and offtake commitments. Where U.S. firms and U.S. allies invest is important in meeting the goal of providing a secure and stable supply of REEs, intermediate products, and component parts needed for the assembly of end-use products.

Most experts have predicted where new mining capacity for rare earths is likely to come on-stream, but it is just as important to know where new downstream capacity (processing, refining, and metals alloying) is being built or likely to be built in the world as well as the likely investors in downstream capacity for rare earths. Additional questions that could be addressed by Congress include how long would it take to develop the skill set in the United States for downstream production activities? Would an international educational exchange program with those countries already involved in rare earth refining and recycling be appropriate?

### **Molycorp’s “Mine to Magnet” Vertical Integration Approach for Rebuilding the U.S. Rare Earth Supply Chain**

From the mid-1960s through the 1980s, Molycorp’s Mountain Pass mine was the world’s dominant source of rare earth oxides. The ramp up in production had been driven primarily by Molycorp’s higher grade, its relatively low cost, and a rapid rise in the demand for the LREEs, particularly europium used for red phosphors in television and computer monitors, and cerium for glass polishing.<sup>38</sup> However, by 2000, nearly all of the separated rare earth oxides were imported, primarily from China. Because of China’s oversupply, lower cost production, and a number of environmental (e.g., a pipeline spill carrying contaminated water) and regulatory issues at Mountain Pass, Molycorp ceased production at its mine in 2002. Since then, the United States has lost nearly all of its capacity in the rare earth supply chain, including intellectual capacity. However, under new ownership since 2008, Molycorp has embarked upon a campaign to change the rare earth position in the United States with its “mine to magnet” (vertical integration) business model.

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<sup>37</sup> Op. cit., Lifton Interview by The Gold Report, December 14, 2009.

<sup>38</sup> DOI/USGS, Rare Earth Elements—Critical Resources for High Technology, Fact Sheet, 087-02.

After major energy producer Chevron purchased Union Oil Company of California (UNOCAL), which included the rare earth mine at Mountain Pass, Chevron wanted to focus on its energy business. They were willing to sell-off its non energy Molycorp Mountain Pass asset.

When investor groups purchased Molycorp from Chevron in 2008, they did not inherit the environmental liability that resulted from the pipeline spill. Chevron continued the cleanup that resulted from an earlier ruptured water disposal pipeline carrying some chemical contaminants from the oxide separation facility. Since its purchase by the new owners, Molycorp CEO and engineers have been adamant about minimizing their environmental footprint during the separation phase of the process. Molycorp designed a proprietary oxide separation process that would use fewer reagents and recycle the waste water, thus doing without a disposal pond. Molycorp recently broke ground for their new separation facility at the Mountain Pass mine. This complex process separates out the individual elements which follows the mining of the raw material. Molycorp is in the process of reopening the mine in 2012 as the lowest-cost operator, according to their calculation. They expect production costs at around \$2.77/kg versus an estimated \$5.58/kg in China and a potentially much higher cost operation at Lynas at about \$10.11/kg. Molycorp engineers suggest that they will use one-half the amount of ore to get the same amount of usable end product. In addition, they will use fewer reagents, use “full loop” recycling, and no evaporation ponds.<sup>39</sup>

All permits are in place to commence mining with the exception of a permit to transport natural gas that will be used to power the separation facility. The rights of way for a pipeline must be approved by the Bureau of Land Management (BLM) and the pipeline permit by Federal Energy Regulatory Commission (FERC). In the meantime, Molycorp will truck in liquid natural gas for its energy source until the pipeline is approved.<sup>40</sup>

Molycorp recently acquired the Japanese subsidiary Santoku America in Tolleson, AZ, and renamed it Molycorp Metals and Alloys (MMA). This acquisition is part of the firm’s strategy to become a vertically integrated company. It produces both NdFeB and SmCo alloys used in the production of permanent magnets. Molycorp Metals and Alloys is the sole U.S. producer of the NdFeB alloy. Their intention is to modernize the facility and expand metals and metal alloy production.<sup>41</sup> Molycorp also recently purchased a majority interest in AS Silmet, an Estonian-based rare earth element and rare metals processor, which will double its capacity for rare earth oxide and metal production (separation) in the near-term, according to Molycorp officials.

Molycorp has entered into a cooperative research and development agreement (CRADA) with U.S. Department of Energy’s Ames Laboratory to study new methods to create commercial-grade permanent magnets used in commercial applications. Development of downstream activities such as refining, rare earth metals alloying, and permanent magnet manufacturing will require a large amount of financing, a skilled workforce, and a sizeable U.S. market, all of which could be more completely developed in the long term. A potential barrier to entry to permanent magnet manufacturing, in the short term, is the intellectual property rights for permanent magnet manufacturing held by two firms: Hitachi in Japan and Magnequench (formerly a U.S. firm) which is owned by the Chinese. Months-long talks between Hitachi and Molycorp to jointly pursue permanent production in the United States were suspended in August 2011. Some investor

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<sup>39</sup> Briefing at Mountain Pass mine site by various Molycorp Engineers, August 8, 2011.

<sup>40</sup> Ibid.

<sup>41</sup> Briefing at Molycorp Metals and Alloys by Managing Director Randall Ice, on August 9, 2011.

analysts believe that establishing permanent magnet production on U.S. soil may not happen soon because of the intellectual property rights issue.

The management at MMA is also examining ways to improve metal recycling. Much of their recycling research is focused on the magnets and the highly valued HREEs. They want to probe into the commercial feasibility of recycling materials contained in permanent magnets used in consumer goods. Sourcing sufficient quantities of end-use materials and understanding the metallurgical processes for extracting the heavy rare earth elements such as the dysprosium and terbium is an important part of the research. Testing the quality of the recyclable material and evaluating the economics will determine the project's success. Molycorp is also evaluating near-term opportunities to recycle energy efficient light bulbs for the phosphors.<sup>42</sup>

Keeping and recruiting top talent (in engineering, science, and finance) that can help Molycorp achieve its mine-to-magnet mission is one of the company's top priorities, according to company officials. Their aim is to consistently invest in the right people and the right training to accomplish its goal.

### **Other Recent Supply Chain Developments**

The Great Western Mineral Group will form a joint venture with China's Ganzhou Qiandong Rare Earth Group to build an oxide separation facility in South Africa. The raw material for the separation facility will be produced at GWMG's Steenkampskraal mine in South Africa. Construction of the processing plant is expected to begin in 2012.

Frontier Rare Earths, based in Luxemburg, along with Korea Resources Corp. formed a joint venture to build a separation facility also in South Africa. Frontier Rare Earths owns the nonproducing rare earth Zondkopsdrift mine in South Africa.

Lynas and Siemens have entered into a joint venture for the manufacturing of magnets used in wind turbine generators. Lynas (45% stake) will provide raw material to Siemens (55% stake) from their Mt. Weld mine in Australia, which is expected to begin production sometime in 2011. Lynas expects to process the raw material at its Malaysian processing facility after receiving approval from the Malaysian government. There are concerns in Malaysia over the proper disposal of thorium, which is contained in the mineral deposit and produced alongside the rare earth elements.

### **Role of China**

State-run ("State-Key") labs in China have consistently been involved in research and development of REEs for over fifty years. There are two State-Key labs: (1) Rare Earth Materials Chemistry and Applications, which has focused on rare earth separation techniques and is affiliated with Peking University, and (2) Rare Earth Resource Utilization, which is associated with the Changchun Institute of Applied Chemistry. Additional labs concentrating on rare earth elements include the Baotou Research Institute of Rare Earths, the largest rare earth research institution in the world, established in 1963, and the General Research Institute for Nonferrous

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<sup>42</sup> Ibid.

Metals established in 1952.<sup>43</sup> This long term outlook and investment has yielded significant results for China's rare earth industry.

Major iron deposits at Bayan Obo in Inner Mongolia contain significant rare earth elements recovered as a byproduct or co-product of iron ore mining. China has pursued policies that would use Bayan Obo as the center of rare earth production and R&D. REEs are produced in the following provinces of China: Baotao (Inner Mongolia) Shandong, Jiangxi, Guangdong, Hunan, Guangxi, Fujian, and Sichuan. Between 1978 and 1989, China's annual production of rare earth elements increased by 40%. Exports rose in the 1990s, driving down prices. In 2007, China had 130 neodymium-iron boron magnet producers with a total capacity of 80,000 tons. Output grew from 2,600 tons in 1996 to 39,000 tons in 2006.

Spurred by economic growth and increased consumer demand, China is ramping up for increased production of wind turbines, consumer electronics, and other sectors, which would require more of its domestic rare earth elements. Safety and environmental issues may eventually increase the costs of operations in China's rare earth industry as domestic consumption is becoming a priority for China. REE manufacturing is set to power China's surging demand for consumer electronics—cell phones, laptops and green energy technologies. According to the report by Hurst, China is anticipating going from 12 gigawatts (GW) of wind energy in 2009 to 100 GW in 2020. Neodymium magnets are needed for this growth.<sup>44</sup>

China's policy initiatives restrict the exports of rare earth raw materials, especially dysprosium, terbium, thulium, lutetium, yttrium, and other heavy rare earths. It is unclear how much the export restrictions affect exports of downstream metal and magnets. According to Hurst, China wants an expanded and fully integrated REE industry where exports of value-added materials are preferred (including consumer products). It is common for a country to want to develop more value-added production and exports if it is possible.<sup>45</sup> China's goal is to build-out and serve its domestic manufacturing industry and attract foreign investors to participate by locating foreign-owned facilities in China in exchange for access to rare earths and other raw materials, metals and alloys, as well as access to the emerging Chinese market.

Some foreign investors are hesitant to invest in China because of the concerns related to technology sharing. Also, the September 2010 maritime conflict between China and Japan in which Japanese officials claimed that China held up rare earth shipments to Japan (denied by Chinese officials) has heightened the urgency among many buyers to seek diversity in its sources of rare earth materials.

Some have urged the U.S. Trade Representative to bring a dispute resolution case against China in the WTO, similar to a case the United States brought against China in 2009 over its export restrictions (such as export quotas and taxes) on certain raw materials (including, bauxite, coke, fluorspar, magnesium, manganese, silicon metal, silicon carbide, yellow phosphorus, and zinc). The United States charges that such policies are intended to lower prices for Chinese firms (especially the steel, aluminum, and chemical sectors) in order to help them obtain an unfair competitive advantage. China claims that these restraints are intended to conserve the

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<sup>43</sup> China's Rare Earth Elements Industry: What Can the West Learn? by Cindy Hurst, Institute for the Analysis of Global Security, March 2010.

<sup>44</sup> Ibid.

<sup>45</sup> Ibid.

environment and exhaustible natural resources. According to some press reports, a WTO panel in April 2011 ruled that China's export restraints on raw materials violated WTO rules.

According to a press account, a letter written by four U.S. Senators in March 2011 urged the Obama Administration to instruct the U.S. Executive Director at each multilateral bank, including the World Bank, to oppose the approval of any new financing to the Chinese government for rare earth projects in China.<sup>46</sup> The letter also urged the Administration to impose the same types of restrictions on Chinese investment in mineral exploration and purchases in the United States as China imposes on foreign investment in rare earth in China.<sup>47</sup>

The Chinese government announced in 2010 that it intends to restructure the rare earth mining industry under the umbrella of a few world-class mining and metal conglomerates for greater efficiencies and to reduce environmental degradation. In addition to the consolidation of the industry and environmental cleanup efforts, investor analyst Jack Lifton reports that China is building strategic stockpiles of rare earths and other critical materials that could meet domestic demand for several years. South Korea and Japan are also building strategic stockpiles.<sup>48</sup> The level of stockpiling could have a dramatic impact on the market, particularly for HREEs.<sup>49</sup>

**Table 3. China's Rare Earth Production and Exports, 2006-2011**

	2006	2007	2008	2009	2010	2011
Official Chinese production quota	86,520	87,020	87,620	82,320	89,200	93,800
USGS reported production	119,000	120,000	120,000	129,000	130,000	112,500 (estimated by IMCOA)
Chinese export quota	61,560	60,173	47,449	50,145	30,259	30,246

**Source:** China Ministry of Land and Resources. U.S. Geological Survey. Ministry of Commerce of China.

**Note:** USGS production data exceeded Chinese quotas, some of which is attributed to illegal mining.

The value of U.S. rare earth imports from China rose from \$42 million in 2005 to \$129 million in 2010, an increase of 207.1%. However, the quantity of rare earth imports from China fell from a high of 24,239 metric tons in 2006 to 13,907 metric tons in 2010, a 42.6% decline.

<sup>46</sup> Letter to Secretary of Treasury Timothy Geitner and Secretary of the Interior Ken Salazar from Senators: Hon. Charles Schumer; Hon. Debbie Stabenow; Hon. Bob Casey and; Hon. Sheldon Whitehouse, March 15, 2011, <http://insidetrade.com//index.php?option=comiwppfile&file=mar2011/wto2011.0620.pdf>.

<sup>47</sup> For more details on U.S. trade with China see CRS Report RL33536, *China-U.S. Trade Issues*, by Wayne M. Morrison.

<sup>48</sup> "Implications for Investors of the Dramatically Increasing Chinese Demand for Rare Earths," Jack Lifton, Technology Metals Research, June 15, 2011, <http://www.techmetalsresearch.com>.

<sup>49</sup> Op. cit, Technology Metals Research June 15, 2011.

## Japan's Interests

Japan has expressed a sense of urgency to secure new non-Chinese supplies of REEs since the September 2010 maritime incident with China and the claim of a Chinese supply embargo of REEs and other materials. Japan's primary end use application of REEs include polishing (20%), metal alloys (18%), magnets (14%), and catalysts (12%)—much different than that of the United States. Japan receives 82% of its REEs from China. Forty percent of China's REE exports go to Japan and 18% to the United States.

Japan-based firms and the Japanese government are making a number of joint venture agreements and potential partnerships around the world to secure supplies of REEs, particularly at the raw material stage. Sumitomo Corp. and the Kazakhstan National Mining Co. – Kazatomprom – formed a joint venture to produce LREEs. Toyota Tsusho and Sojitz are partnering with Vietnam's Dong Pao project to produce LREEs. Japan's JOGMEC is partnering with India to explore for REEs and establish a processing facility. JOGMEC also had decided to seek investments in Australia's Lynas Corporation.

The Japanese government has expressed an interest in making investments in the United States as well as the potential investment by Sumitomo into Molycorp's Mountain Pass mining operation. The role of the Japanese government is to reduce exploration risk of the Japanese mining industry by becoming an exploration partner in potential mining projects around the world, while increasing R&D investments into material use efficiencies and finding substitutes for HREEs in magnets. The Japanese government is also establishing a "recycling-based society" with major efforts in urban mining (i.e., the recovery of materials from end use applications, such as laptops and cell phones).

The Japanese government and the private sector have expressed concerns over the export controls Chinese have placed on ferroalloys that contain dysprosium and other HREEs and mining quotas for the southern region where most of the HREEs are mined. A number of meetings have been held between Chinese and Japanese government officials to address the rare earth situation. Japan's access to REEs is vital to their vast manufacturing industry which produces a variety of parts and consumer goods imported by the United States.

## Selected Possible Policy Options

This section provides a discussion of selected policy options that are included in legislation that has been introduced in the 112<sup>th</sup> Congress. The **Appendix** section of this report summarizes much of the rare earth related legislation.

## Research and Development

Investment in R&D is considered by many experts (e.g., DOE, MIT, and elsewhere) to play a critical role in the support for and development of new technologies that would address three areas primarily: greater efficiencies in materials use; substitutes or alternatives for rare earths; and recycling of rare earth elements. While a small investment is underway at DOE (described below), larger investments in R&D are being discussed.

## **Authorize and Appropriate Funding for a USGS Assessment**

Congress could authorize and appropriate funding for a USGS comprehensive global assessment to identify economically exploitable REE deposits (as a main product or co-product), and where REE could be exploited as a byproduct. Additionally, R&D may be necessary on how to proceed in the exploitation of high-thorium monazite deposits where REE could be produced as a byproduct.

## **Support and Encourage Greater Exploration for REE**

Supporting/encouraging greater exploration for REE efforts in the United States, Australia, Africa, and Canada could be part of a broad international strategy. There are only a few companies in the world that can provide the exploration and development skills and technology for REE development. These few companies are located primarily in Canada, Australia, China, South Africa, and the United States, and may form joint ventures or other types of alliances for R&D, and for exploration and development of REE deposits worldwide, including those in the United States. Whether there should be restrictions on these efforts in the United States is a question that Congress may ultimately choose to address.

## **Challenge China on Its Export Policy**

Challenging China on its export restrictions through the WTO would involve filing a dispute based on WTO rules that generally prohibit members from imposing restrictions (i.e., quotas) or other restraints (e.g., minimum prices or licensing) on exports. In June 2009, the United States filed a dispute over raw material exports from China, which included bauxite, coke, fluorspar, magnesium, manganese, silicon carbide, silicon metal, yellow phosphorus and zinc.<sup>50</sup> Some REE analysts assert that China sets export restrictions to meet growing Chinese demand for raw materials and to force the manufacturing of end-use products in China.<sup>51</sup>

## **Establish a Stockpile**

Establishing a government-run non-defense economic stockpile and/or private-sector stockpiles that would contain supplies of specific REE broadly needed for “green initiatives” and defense applications is a policy advocated by some in industry and government. Generally, stockpiles and stockpile releases could have an impact on prices and supply but would also help ensure supplies of REE materials (oxides, metals, etc.) during times of normal supply bottlenecks. However, an economic stockpile could be costly and risky, as prices and technology may change the composition of REEs that are needed in the economy.

According to USGS,<sup>52</sup> DOD along with USGS is examining which of the REEs might be necessary in the National Defense Stockpile (NDS). In the recent past, NDS materials were stored

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<sup>50</sup> Office of the U.S. Trade Representative, Press Release, “WTO Case Challenging China’s Export Restraints on Raw Material Inputs,” June 23, 2009.

<sup>51</sup> Irma Venter, “Investors take closer look at rare earth elements as technology, green revolution pick up pace,” *Mining Weekly Online*, <http://www.miningweekly.com>, September 18, 2009.

<sup>52</sup> Phone interview with Jim Hedrick, Rare Earth Specialist, USGS, October 1, 2009.

for wartime use based on a three-year war scenario. Some of the rare earth elements contained in the National Defense Stockpile were sold off by 1998. However, rare earth elements were never classified as strategic minerals.<sup>53</sup> DOD had stockpiled some yttrium but has since sold it off, and none of the REEs have been classified as strategic materials. Critical questions for stockpile development would be: What materials along the supply chain should be stockpiled? For example, should the stockpile contain rare earth oxides or alloyed magnets which contain the REEs, or some combination of products?

The National Research Council (NRC) has produced a report on minerals critical to the U.S. economy and states: "... most critical minerals are both essential in use (difficult to substitute for) and prone to supply restrictions."<sup>54</sup> While the NRC report is based on several availability criteria used to rank minerals for criticality (geological, technical, environmental and social, political, and economic), REEs were determined to be critical materials assessed at a high supply risk and the possibility of severe impacts if supplies were restricted. Some of the REE applications are viewed as more important than others and some are at greater risk than others, namely the HREEs, as substitutes are unavailable or not as effective.<sup>55</sup>

## Hearings on Rare Earths and Related Legislation in the 112<sup>th</sup> Congress

Four hearings were held on rare earth elements and critical materials in the spring of 2011.<sup>56</sup> Hearings were held to address potential supply risk associated with REEs, rare metals, and other critical materials. The witness testimony covered themes such as the potential impacts of supply disruption, the need for a more efficient regulatory and permitting framework for domestic minerals and downstream processing development, more complete information and analysis of the global REE space, and the role of the U.S. government. The House Committee on Natural Resources marked up and reported out H.R. 2011 on July 20, 2011. H.R. 2011 is the bill that has moved the furthest this session.

Discussion of the U. S. government role focused on investment in R& D that would examine more efficient use of raw materials, possible substitutes, and recycling. There was attention placed on the government's need to examine and support a vertically integrated rare earth supply chain in the United States. There was also some concern over whether the private sector should establish some buffer inventory and if DOD needed to establish a small-scale stockpile for defense and national security purposes. Much of the testimony concluded that there is a sense of urgency to expand education and training to achieve any build-out of a rare earth supply chain in the United States. Much of the world's expertise is now in China and Japan.

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<sup>53</sup> For a discussion of the strategic materials for defense uses, see CRS Report RL33751, *The Specialty Metal Clause: Oversight Issues and Options for Congress*, by Valerie Bailey Grasso.

<sup>54</sup> National Research Council, *Minerals, Critical Minerals, and the U.S. Economy*, National Academies Press, 2008.

<sup>55</sup> DOI/USGS, *Minerals Yearbook*, Volume 1, 2007.

<sup>56</sup> House Subcommittee on Energy and Mineral Resources, Oversight hearings on Strategic and Critical Minerals Policy, May 24 2011; House Subcommittee on Energy and Mineral Resources, Hearing on H.R. 2011 and H.R. 1314, June 3, 2011; House Committee on Science, Subcommittee on Investigations and Oversight hearing on a National Critical Materials Strategy, June 14, 2011. Senate Committee on Energy and Natural Resources, Hearing on Energy Efficiency and rare earth minerals (S. 383, S. 1113, and S. 421), June 9, 2011.

## Executive Branch Activities

Below is a summary of selected current research, development, information, and analysis activities on rare earth elements at federal agencies.

### Department of Energy<sup>57</sup>

The Office of Science (FY2011 enacted, \$4.8 billion; FY2012 request, \$5.4 billion) conducts a *Materials Science and Engineering Program* (FY2010 enacted, \$5 million) at the Ames National Laboratory, and funds its *Energy Innovation Hub Program* to conduct R&D on critical materials (FY2012 request, \$20 million).

Within the Office of Energy Efficiency and Renewable Energy (FY2011 enacted, \$1.8 billion; FY2012 request, \$3.2 billion), there is an *Applied Magnet Research Program* (FY2010, \$2 million) at Ames Laboratory and an *Alternative Motor Design Program* designing motors without rare earth permanent magnets (FY2010, \$1.4 million) at Oak Ridge National Laboratory.

The Advanced Research Projects Agency – Energy (ARPA-E) (FY2011 enacted \$179.6 million; FY2012 request, \$550 million) is conducting research on *Batteries for Electric Energy Storage* (FY2010, \$35 million) and *Substitutes for Rare Earth Magnets* (FY2009, \$6.6 million).

In December 2010, the Department of Energy issued its *Critical Materials Strategy* report. This report examines and provides demand forecasts for rare earths and other elements required for numerous energy and electronic applications.<sup>58</sup>

### Department of the Interior

The National Minerals Information Center housed within the USGS provides an annual summary of rare earth activity in its Mineral Commodities Summaries report and Minerals Yearbook.<sup>59</sup> The USGS also provides mineral resource assessments and has recently published a study on recycling of rare earths.<sup>60</sup> Its most recent resource assessment of rare earth potential in the United States was published in a November 2010 USGS report.<sup>61</sup>

### Department of Defense

The Office of Industrial Policy is currently reviewing the rare earth mineral supply chain. The Office of the Secretary of Defense reviewed its National Defense Stockpile and issued a report in

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<sup>57</sup> Budget information on DOE programs obtained from DOE Budget Highlights, FY2010-FY2012 Congressional Budget Request.

<sup>58</sup> U.S. Department of Energy, *Critical Materials Report*, December 2010.

<sup>59</sup> <http://minerals.usgs.gov/minerals/pubs/mcs2011.pdf>

<sup>60</sup> U.S. Department of the Interior, USGS, Rare Earth Elements- End Use and Recyclability, Scientific Investigations Report 2011-5094.

<sup>61</sup> U.S. Department of the Interior, USGS, The Principal Rare Earth Elements Deposits of the United States—A Summary of Deposits and a Global Perspective. USGS Scientific Investigations Report 2010-5220.

2009: *Reconfiguration of the National Defense Stockpile Report to Congress*, Washington DC, U.S. Department of Defense.

As part of the National Defense Authorization Act for FY2011b(Section 843 of P.L. 111-383), the DOD was required by Congress to prepare an “Assessment and Plan for Critical Rare Earth Materials in Defense Applications” to a number of congressional committees by July 6, 2011. Because the report is not yet available to Congress, several members of the House Armed Services Committee sent a letter on August 5, 2011, requesting an interim report from DOD by August 19, 2011.<sup>62</sup>

### **Other Federal Agencies**

Other Executive Branch agencies involved with rare earths and critical materials include the Department of Commerce and Office of the U.S. Trade Representative, which reviews global trade policy (e.g., China’s rare earth export policy) and could initiate action under World Trade Organization (WTO) rules; the Department of State, which reports on host government policies, private sector activities, and domestic markets; and the Environmental Protection Agency, which establishes federal environmental standards for numerous activities, including mining.

### **White House Office of Science and Technology Policy**

The White House Office of Science and Technology Policy (OSTP) has formed an Interagency Working Group on Critical and Strategic Minerals Supply Chains. Its participants include representatives from Department of Energy, Department of Defense, Department of the Interior, Department of Commerce, Environmental Protection Agency, Department of State, Department of Justice, and the Office of the U.S. Trade Representative. The group’s focus is to establish critical mineral prioritization and early warning mechanism for shortfalls, to establish federal R&D priorities, to review domestic and global policies related to critical and strategic minerals (e.g., stockpiling, recycling, trade, etc.), and to ensure the transparency of information.

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<sup>62</sup> Letter from the Congress of the United States, directed to The Honorable Leon E. Panetta, U.S. Department of Defense, August 5, 2011.

## **Appendix. Rare Earth-Related Legislation in the 112<sup>th</sup> Congress**

### **H.R. 1388, the Rare Earths Supply Chain Technology and Resources Transformation Act of 2011**

Introduced by Representative Mike Coffman on May 6, 2011, and referred to the House Committee on Science, Space, and Technology, Subcommittee on Energy and the Environment, and the Committees of Natural Resources and Armed Services. The bill is also referred to as the Restart Act of 2011. The bill seeks to reestablish a competitive domestic rare earths supply chain within DOD's Defense Logistics Agency (DLA).

### **H.R. 1540, the National Defense Authorization Act for FY2012**

Introduced by Representative Howard McKeon on April 14, 2011. Section 835 would require the Defense Logistics Agency Administrator for Strategic Materials to develop an inventory for rare earths materials to support defense requirements, as identified by the report required by Section 843 of the National Defense Authorization Act for FY2011 (P.L. 111-383).

### **H.R. 1314, the Resource Assessment of Rare Earths (RARE) Act of 2011**

Introduced by Representative Hank Johnson on April 1, 2011; referred on April 6 to the House Natural Resources Committee's Subcommittee on Energy and Mineral Resources. The bill would direct the Director of the U.S. Geological Survey through the Secretary of the Interior to examine the need for future geological research on rare earth elements and other minerals and determine the criticality and impact of a potential supply restriction or vulnerability.

### **H.R. 952, the Energy Critical Elements Renewal Act of 2011**

Introduced by Representative Brad Miller on March 8, 2011; referred to the Committee on Science, Space, and Technology. The bill would develop an energy critical elements program, amend the National Materials and Minerals Policy Research and Development Act of 1980, establish a temporary program for rare earth material revitalization, and serve other purposes.

### **S. 383, the Critical Minerals and Materials Promotion Act of 2011**

Introduced by Senator Mark Udall on February 17, 2011; referred to the Committee on Energy and Natural Resources. The bill would require the Secretary of the Interior to establish a scientific research and analysis program to assess current and future critical mineral and materials supply chains, strengthen the domestic critical minerals and materials supply chain for clean energy technologies, strengthen education and training in mineral and material science and engineering for critical minerals and materials production, and establish a domestic policy to promote an adequate and stable supply of critical minerals and materials necessary to maintain national security, economic well-being, and industrial production with appropriate attention to a long-term balance between resource production, energy use, a healthy environment, natural resources conservation, and social needs.

### **H.R. 618, the Rare Earths and Critical Materials Revitalization Act of 2011**

Introduced by Representative Leonard Boswell on February 10, 2011; referred to the Committee on Science, Space, and Technology. The bill seeks to develop a rare earth materials program and amend the National Materials and Minerals Policy, Research and Development Act of 1980. If enacted, it would provide for loan guarantees to revitalize domestic production of rare earths in the United States.

### **S. 1113, the Critical Minerals Policy Act of 2011**

Introduced by Senator Lisa Murkowski on May 26, 2011; referred to the Committee on Energy and Natural Resources. The bill would define what critical minerals are, but would request that the Secretary of the Interior establish a methodology (in consultation with the National Academy of Sciences, the National Academy of Engineering and various Department Secretaries) that would identify which minerals qualify as critical. The Secretary of the Interior would direct a comprehensive resource assessment of critical mineral potential in the United States, including details on the critical mineral potential on federal lands. S. 1113 would establish a Critical Minerals Working Group to examine the permitting process for mineral development in the United States and facilitate a more efficient process; specifically, that would require a performance metric for permitting mineral development and report on the timeline of each phase of the process. The Department of the Interior (DOI) would produce an Annual Critical Minerals Outlook report that would provide forecasts of domestic supply, demand, and price for up to ten years. The proposed Annual Critical Minerals Outlook would also assess critical mineral requirements for national security, energy, and economic well-being, and provide analyses of the implications of potential supply shortfalls. It would provide projections for recycling and market penetration of alternatives and international trends associated with critical minerals. Section 109 proposes greater international cooperation with allies on critical minerals and supply chain issues. If it was determined that there is no viable production capacity in the United States, a series of activities may occur with allies, led by the Secretary of State and Secretary of the Interior.

DOE would lead research and development on critical minerals and workforce development that would support a fully integrated supply chain in the United States. Title II of the bill recommends mineral-specific action (led by DOE) for cobalt, helium, lead, lithium, low-btu gas, phosphate, potash rare earth elements, and thorium. For example, there would be R&D for the novel use of cobalt, grants for domestic lithium production R&D, and a study on issues associated with establishing a licensing pathway for the complete thorium nuclear fuel cycle. Title III would repeal 1980 Minerals Policy Act and Critical Minerals Act of 1984 and would authorize for appropriation, \$106 million.

### **H.R. 2011, the National Strategic and Critical Minerals Policy Act of 2011**

Introduced by Representative Doug Lamborn on May 26, 2011; referred to the Committee on Natural Resources. The bill would direct the Secretary of the Interior to prepare a report on public lands that have been withdrawn or are otherwise unavailable for mineral exploration and development, mineral requirements of the United States, the nation's import reliance on those minerals, a timeline for permitting mineral-related activities on public lands, and the impacts of litigation on issuing mineral permits, among other things. The bill provides an authorization for appropriation, to the Secretary of the Interior, of \$1 million for fiscal years 2012 and 2013. The House Committee on Natural Resources marked up and reported out H.R. 2011 on July 20, 2011.

### **H.R. 2090, the Energy Critical Elements Advancement Act of 2011**

Introduced by Representative Randy Hultgreen on June 2, 2011. The bill would require collaboration between the Secretary of the Interior and Secretary of Energy to improve assessments of “energy critical elements throughout the supply chain, supply, demand, disposal and recycling.” Additionally it calls for more R&D on materials use substitution, recycling, and life-cycle analysis. The bill provides a list of energy critical elements.

### **H.R. 2184, the Rare Earth Policy Task Force and Materials Act**

Introduced by Representative Mike Coffman on June 15, 2011. The bill would create a Rare Earth Task Force within the DOI and be composed of the Secretary or designees from DOE, DOC, DOS, DOD, USDA, OMB, and CEQ, chaired by the Secretary of the Interior. The task force would examine impediments to domestic development of a REE supply chain. The Secretary of the Interior would prepare a Materials Program Plan of R&D that would support and help ensure long-term viability of a domestic rare earth industry. The plan would support numerous activities related to improved assessment and development technology, processing technology, and end-use applications. The bill would encourage expanding opportunities for higher education in that it would support the build-out of the rare earth supply chain.

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