Synopsis

There is currently very minimal rare earth mine production and processing in the U.S., with most necessary rare earth materials being obtained from foreign sources, almost exclusively China. Meanwhile, the demand for rare earth materials continues to grow dramatically, primarily fueled by the continued development and implementation of emerging technologies. A supply disruption of essential rare earths to the U.S. could clearly threaten the economic status and national security of the country. The situation is exacerbated by the fact that in recent years China has been reducing its export quotas in order to satisfy domestic demand and further develop an integrated vertical supply chain in the rare earth industry. Although recently some companies have attempted to address this issue (Molycorp is a noted example), rare earth elements continue to be an issue of national concern. The purpose of this document is to provide timely information in sufficient detail to allow policy makers to make strategic decisions.

The rare earth elements group consists of seventeen chemical elements, typically categorized into two groups – light and heavy. Heavy rare earth elements can be further divided into middle rare earth elements and heavy rare earth elements (Table 1). Rare earth materials, including ores, oxides, metals, and alloys, consist of one or more rare earth elements. Rare earth metals are generally lustrous in appearance, with a color range from iron grey to silver, and they are characteristically soft, malleable, ductile and typically reactive. Many rare earth elements are strongly paramagnetic, have strong magnetic anisotropy, and can be difficult to separate from one another, as they share some common properties.

Trillions of dollars' worth of modern devices depend on rare earths. The two most important commercial end uses for rare earths in the U.S.

Table 1: Rare Earth Elements

	Element	Symbol	Atomic Number	Atomic Weight	Density (gcm-3)	Melting Point (^{o}C)	Vicker's Hardness (10kg load, kg/mm^2)
Light	Lanthanum	La	57	138.90	6.146	918	37
	Cerium	Ce	58	140.11	8.160	798	24
	Praseodymium	Pr	59	140.90	6.773	931	37
	Neodymium	Nd	60	144.24	7.008	1021	35
	Promethium	Pm	61	145.00	7.264	1042	-
	Samarium	Sm	62	150.36	7.520	1074	45
Middle	Europium	Eu	63	151.96	5.244	822	17
	Gadolinium	Gd	64	157.25	7.901	1313	57
	Terbium	Tb	65	158.92	8.230	1356	46
	Dysprosium	Dy	66	162.50	8.551	1412	42
	Holmium	Ho	67	164.93	8.795	1474	42
Heavy	Erbium	Er	68	167.26	9.066	1529	44
	Thulium	Tm	69	168.93	9.321	1545	48
	Ytterbium	Yb	70	173.04	6.966	819	21
	Lutetium	Lu	71	174.97	9.841	1663	77
	Scandium	Sc	21	44.95	2.989	1541	85
	Yttrium	Y	39	88.90	4.469	1522	38

are automotive catalytic converters and petroleum refining catalysts, which together account for almost half of total rare earth usage. Metallurgical additives and alloys are ranked a close third in rare earth applications. Other major end uses for rare earths include permanent magnets and rechargeable batteries for both hybrid and full electric vehicles, phosphors for lighting and flat panel displays, glass polishing and ceramics, and numerous medical devices. Many of these are referred to as rare earth dependent technologies, as without rare earth materials, they would not be commercially viable. In addition to widespread applications in commercial products, rare earth materials are also widely used in defense and dual-use systems. Examples of such applications include precision guided munitions, lasers, communication systems, radar systems, avionics, night-vision equipment, and satellites. In these applications, rare earth materials are very difficult to replace without losing performance. Examples of emerging rare earth applications include sub-light-speed computer processors, advanced superconductors (materials through which electricity flows with zero resistance), magnetic refrigeration, and water treatment. In addition, rare earths continue to be utilized in agriculture, mainly in China.

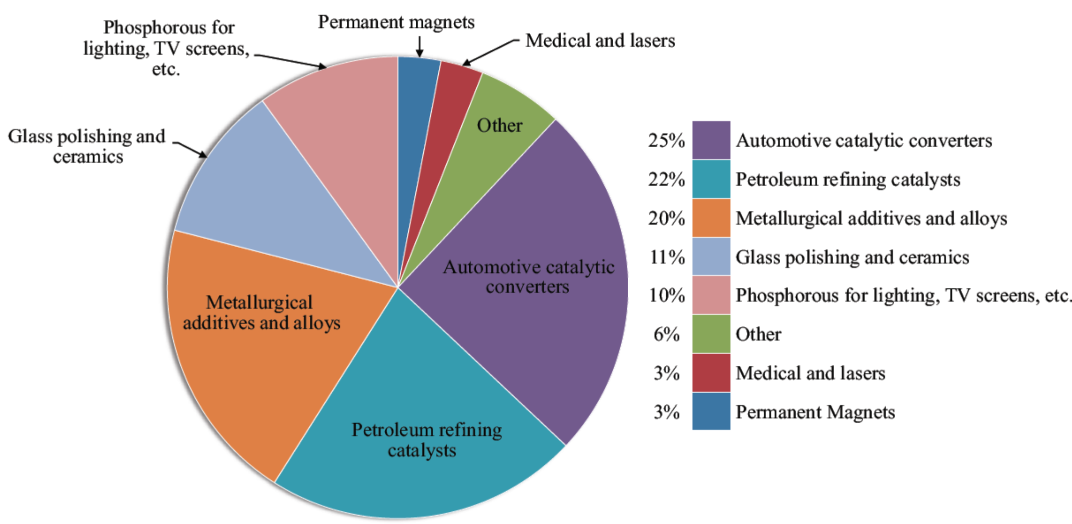

Figure 1: Rare Earth Use in Common Commercial Products in the U.S.

Major global rare earth deposits can be classified into igneous, sedimentary and secondary types. The largest rare earth deposit in the world, Bayan Obo, located in Inner Mongolia, China, is the only deposit in this group formed by hydrothermal replacement of carbonate rocks of sedimentary origin. Carbonatite deposits constitute many of rest of the world's rare earth resources, such as Mountain Pass in the United States, Mount Weld in Australia and Maoniuping in China.

Most rare earth reserves are located throughout the world in deposits of bastnaesite and monazite. Bastnaesite deposits in the U.S. and China account for the largest concentrations of rare earths, while monazite deposits in Australia, South Africa, China, Brazil, Malaysia, and India account for the second-largest concentrations of rare earths. Apatite, cheralite, eudialyte, loparite, phosphorites, rare earth-bearing (ion-adsorption) clays, secondary monazite, spent uranium solutions, and xenotime make up most of the remaining resources. While China produces approximately 97 percent of the rare earths consumed globally, the country has only 48 percent of worldwide economically exploitable rare earth reserves, according to the USGS. Although many reserves have already been discovered, the USGS reports that undiscovered resources are still thought to be very large relative to expected future demand.

The first rare earth mineral, ytterbite, was discovered in 1787 in Ytterby, Sweden. Yttrium, Terbium, Erbium and Ytterbium were all subsequently named after the original location in Sweden, with Holmium, Scandium, Lutetium and Europium also named after the surrounding regions. Later rare earth elements were discovered in minerals from Sweden and Russia, after which most of the world's rare earth supply came from placer sand deposits in Brazil and India, until the 1940s, when Australia and Malaysia began production of monazite. In the 1950s, South Africa became the primary source, with U.S. supplies ramping up from the 1960s and topping the world's suppliers in the late 1980s. Rare earth minerals were discovered in Bayan Obo in the western region of Inner Mongolia, China in 1935, and by the 1950s the Baotou Iron and Steel Company began operation of a mine at the site, harvesting Bayan Obo's significant iron deposit. By the late 1950s the company began the process of recovering rare earth ores as a by-product of the iron and steel production process. The Bayan Obo iron, REE and niobium deposit is now considered to be the largest rare earth deposit in the world.

Due to the quality and availability of resource data, there is not an accurate surveyed figure for global rare earth resource distribution. The USGS, however, has estimated the total world reserves of rare earth oxides (REOs) as of January 2012 at approximately 114 million metric tons (Table 2). China currently dominates world reserves with 48.3 percent, followed by the Commonwealth of Independent States (CIS) with 16.7 percent, the U.S. with 11.4 percent and India with 2.7 percent.

Five of the world's richest rare earth deposits include the Bayan Obo deposit in China, the Mountain Pass deposit in U.S., the Mount Weld carbonatite deposit in Australia, placer deposits in Australia and the Seven Provinces ion adsorption clay deposit in Southern China.

The Bayan Obo deposit, located 84 miles northwest of Baotou in the Inner Mongolia Autonomous Province, is the largest rare earth deposit in the world. According to Kanazawa and Kamitani, as of 2006 the total reported reserves at Bayan Obo were "at least 1.5 billion tonnes of iron (average grade 35%), at least 48 million tonnes of RE Oxides (REO) (average grade 6%), and about 1 million tonnes of niobium (average grade 0.13%). Recent statistics show 89 million tonnes of REO in China." Rare earth elements in the deposit mainly occur as REE fluorcarbonate series minerals: bastnaesite, parisite, cordylite, huanghoite, and cebaite and monazite hosted in dolomite marbles. Carbonate rocks found at Bayan Obo fall into one of four categories: sedimentary limestone and dolostone, deformed mineralized coarse-grained dolomite marble, fine-grained dolomite marble and carbonatite dikes.

Table 2: Estimated Exploitable Global REO Reserves

Country	**Reserves (metric tons)**	**Percentage**
China	55,000,000	48.3%
Commonwealth of Independent States	19,000,000	16.7%
United States of America	13,000,000	11.4%
India	3,100,000	2.7%
Australia	1,600,000	1.4%
Brazil	48,000	0.04%
Malaysia	30,000	0.03%
Other Countries	22,000,000	19.3%
World Total (rounded)	**113,778,000**	**100%**

Note: Reserves are defined by the USGS as that part of the reserve base that could be economically extracted or produced at the time of determination. The term reserves need not signify that extraction facilities are in place and operative. Reserves include only recoverable materials.

The Mountain Pass carbonatite deposit in the United States is the second largest rare earth deposit in the world, located near the border between the southern California and Nevada, where Precambrian metaphoric rocks are widely distributed. The main deposit, a carbonatite body dubbed “the Sulphide Queen,” is approximately 0.62 miles long and 820 feet in width, and is composed mainly of dolomite and calcite. From 1965 to 1995, this deposit supplied most of the world’s rare earth metal needs, before mining at the site closed in 2002. Remaining reserves at the site are calculated at 20 million metric tons, with an average grade of 8.9 percent rare earth oxides based on a 5 percent cut-off grade.

The Mount Weld carbonatite deposit, approximately 1.9 miles in diameter, is located some 21 miles south of Laverton, Western Australia, and is owned by the Lynas mining corporation. Rare earth elements occur in this deposit at highly concentrated grades, mainly within the mineral bastnaesite. Also in Australia, placer deposits, a sedimentary accumulation of rare earth minerals, are distributed widely along the coastline. Monazite and xenotime are the most common rare earth minerals found in placer sand deposits.

The “Seven Provinces in South of China” refer to a widely distributed collection of small ion adsorption clay rare earth deposits, located in southern China. Ion adsorption clay type deposits are typically rich in the less common heavy rare earth elements, and are estimated to contain approximately 80 percent of the world’s resources of heavy rare earths, in an easily exploitable form.

In July 2011, a Japanese team discovered deep-sea mud containing high concentrations of rare-earth elements at numerous sites throughout the eastern South and central North regions of the Pacific Ocean. The team estimated the size of the discovery at around 80-100 billion metric tons, almost a thousand times greater than 2012 USGS estimates of proven reserves of approximately 114 million metric tons of rare earth oxides worldwide. However, proving the commercial viability of mining rare earth minerals from 2 to 3 miles below the surface of the Pacific Ocean will be a significant challenge.

In South Korea, rare earth deposits exist within Hongcheon, in the Ganwon Province, and Chungju, in the North Chungcheong Province. However, these areas were not exploited commercially due to low mineral grades and difficult locations near residential areas. Full-scale production at the site is expected to begin in 2012.

Afghanistan’s Helmand Province is believed to contain a major deposit of light rare earths in carbonatite, including lanthanum, cerium and neodymium. The country’s rare earth resources were surveyed under difficult wartime conditions from 2009 to 2011 by USGS researchers for

Business and Stability Operations (TFBSO). The survey uncovered an estimated 1 million metric ton deposit at Khanneshin, which is considered “comparable in grade to world-class deposits like Mountain Pass, CA, and Bayan Obo in China.”

In October 2011, the U.S. mining company Molycorp announced the discovery of a new heavy rare earth deposit near the company’s Mountain Pass mine in California. In December 2011, the company was given permission by the U.S. Bureau of Land Management to begin exploratory drilling at the site, with results due in the second quarter of 2012.

Global demand for rare earth materials grew steadily by between 8–12 percent per year until 2008 before falling due to the global recession. Demand levels then recovered and continued to follow a similar growth trend from mid-2009 onwards, and demand has been projected to continue to steadily grow out to 2016. China is not only the world’s leading producer of rare earth materials, but also consumed 70,000 metric tons of global production in 2011, and this figure is forecast to continue to rise to 80,000 metric tons in 2012. Japan and northeast Asia are the second-largest consumers of rare earth materials, accounting for approximately 22 percent of world consumption, and the U.S. follows as the third leading consumer, at about 12 percent. Some experts predict that China's internal needs for rare earths will continue to take up the majority of its production. Concurrently, global needs for rare earths outside China are also projected to grow dramatically, fueled by the growth of emerging green energy technologies such as HEVs, wind power, and energy-efficient lighting.

The global rare earth supply situation has been caused by unbalanced global supply and production – China produced 94% of the world supply of REEs in 2011, leaving only 6% available from ROW facilities, despite sizable deposits worldwide. China is facing growing domestic demand, and as such its supply to ROW will be limited to what is left over after satisfying internal needs. China’s drive to build its downstream REE industries will only decrease the ROW supply, resulting in shortages if ROW producers do not step in to fill the gap.

All indices place rare earths, (including yttrium) at the top of all mineral commodities in terms of concentration of world production. According to the USGS, a high concentration of supply raises issues related to the reliability of supply as well as to price manipulation – a single source of supply is inherently more risky than multiple sources. The National Research Council has recommended a criticality matrix as a tool for assessing mineral supply risk, in which rare earths are ranked high for supply risk and moderately high for the effect on supply restriction.

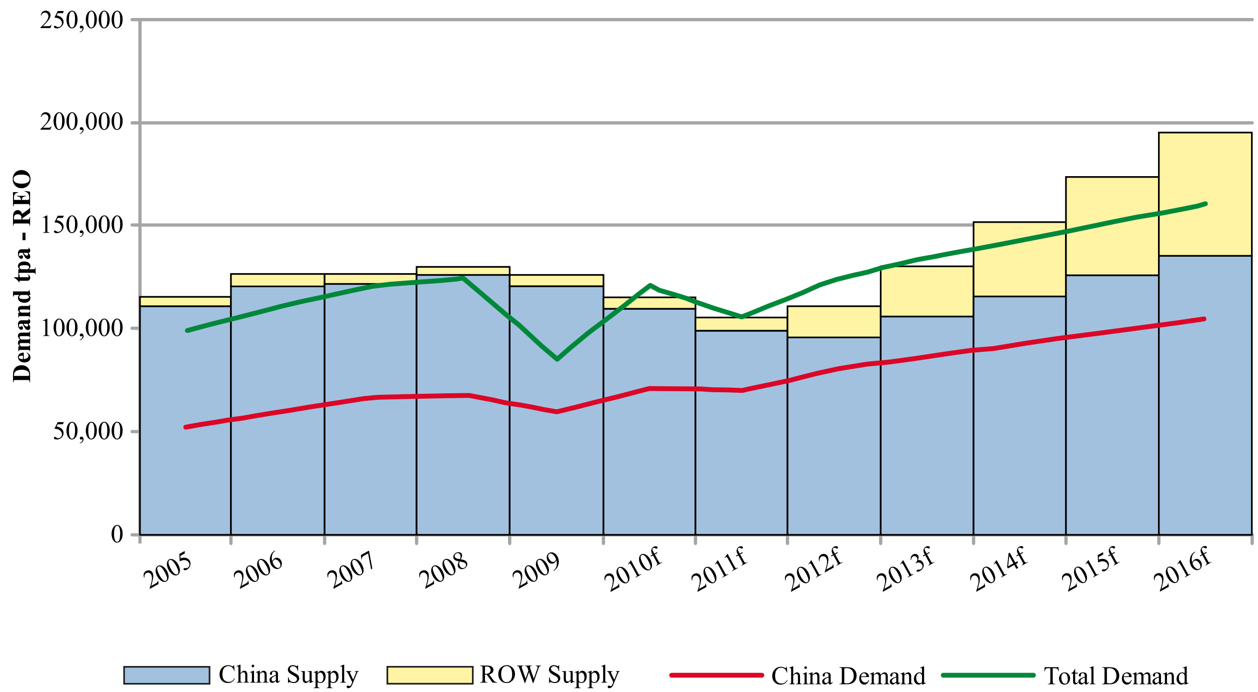

Figure 2: 2012 REO Current and Forecast Demand Trend 2005-2016
(Note: “f” denotes forecast)

According to a November 2011 British Geological Survey report on rare earths, the two dominant importers of both rare earth compounds and metals as of 2009 were the U.S., at 16,500 metric tons, and Japan, with 13,500 metric tons. Germany imported 8,200 metric tons, followed by France at 7,000 metric tons, and Austria at 4,500 metric tons. Regarding rare earth metal imports alone, Japan leads the group by more than tenfold at 4,800 metric tons, followed by France with 400 metric tons. India, Belgium and Austria imported approximately 300 metric tons, with the U.S., Brazil and China importing approximately 200 metric tons each. Rare earth compound exports for 2009 were led by China, at 38,500 metric tons, followed by Austria at 10,000 metric tons, Japan with 6,000 metric tons, and Russia with 4,600 metric tons. China also leads rare earth metal exports at 5,300 metric tons, followed by the U.S. at 4,100 metric tons, Hong Kong at 460 metric tons, Belgium at 270 metric tons and Austria at 240 metric tons.

There are currently no exchanges where rare earth metals are traded, a situation that is not uncommon as they are considered to be minor metals. Specialist companies trade in rare earth metals and oxides, where producers set prices and oxides are often supplied on long-term confidential contracts. Due to limited data available on rare earth pricing, the numbers reported are spot transaction prices where the buyer or seller has disclosed the amounts to a third party, and in some cases they may be as much as 100% higher than prices actually being paid in rare earth transactions. As an example of rapidly rising prices, the quoted price for europium metal was US$485 per kg in January 2010; the quoted price as of August 2011 was US$6,620 per kg, an approximate increase of 1,364 percent.

Heavy rare earth prices have risen fairly steadily since 2003 due to the rising domestic demand in China and escalating export controls. Although recent reductions in export quotas were for total rare earths, an unexpected drop in the supply of light rare earths occurred due to producers focusing their output on the more profitable heavy rare earths. As a result, a much greater increase in price was observed for light rare earths than for heavy rare earths.

As a result of the extraordinary price growth of many rare earths during 2011, rare earth consumers began to scale back purchasing, with some retreating to private stockpiles to avoid affecting cost-sensitive downstream businesses with higher material costs. The Japanese tsunami of March 2011 also temporarily halted a number of high tech manufacturing facilities, the aftereffects of which meant that many companies had little immediate need for new rare earth supplies. The result was that rare earth prices began to fall in the second half of 2011 almost as quickly as they ascended in the first half.

The Chinese government responded by shutting down certain operations within the domestic rare earth industry in late 2011, to both curb overproduction and to perform comprehensive validation of rare earth production facilities and practices. This shutdown has lasted into early 2012, and saw almost half of the country's production capacity sitting idle "as inspection teams scour the country to enforce the quotas and industry consolidation targets, as well as new environmental regulations." The shutdown included China's largest producer, Inner Mongolia Baotou Steel Rare-Earth Group, and as of February 2012, the company still had not been granted an export license for the year under the auspices of environmental infractions, placing an artificial restriction in supply of rare earths to the outside world.

Until the 1990s, most of the world's rare earths were supplied from the United States, from Mountain Pass in California. By 2003, Mountain Pass was closed, and the level of rare earth output in the U.S. had dropped to zero. Plenty of rare earth supply remained in the ground, but it no longer made financial sense to continue mining deposits when cheap rare earths were available from Chinese producers. They were able to take advantage of significantly lower labor costs, less stringent environmental regulations, and the fact that they were mining rare earths as part of an already profitable iron mining process. The history of rare earths in the U.S. will be discussed, as well as the issues that the U.S. is facing today in the rare earth crisis, and strategies being employed to redevelop the country's rare earth industry.

Aside from California's Mountain Pass, another important U.S. rare earth resource is at the Bear Lodge property in northeast Wyoming (shown in Figure 3.1), currently being explored by Rare Element Resources Ltd. The Bear Lodge property contains significant quantities of high-grade rare earth elements in carbonatite dikes, as well as extensive gold resources within the same deposit. In February 2012, mineral resource estimates of rare earth deposits showed an indicated resource of 6.8 million tons @ 3.75% REO and an inferred resource of 24.2 million tons @ 2.75% REO.

The Bokan Mountain project in Alaska is another significant U.S. rare earth deposit, currently being explored by Ucore Rare Metals, Inc. The company's 19 square mile property includes the site of the former Ross Adams uranium mine, with an estimated untapped resource of approximately 11+ million pounds of U_3O_8, and a USGS estimated deposit of 374 million pounds of rare earth oxides. Bokan has been described by Ucore as having "near term production potential, and is located in an area of Alaska specifically set aside for natural resource development, with no residential or indigenous populations in proximity."

Rare earth resources are also present in the United States within Wyoming, Utah, New York, Idaho, Missouri and Montana. Mill tailings from historic processing of magnetite deposits at Mineville, New York are a rare earth resource of moderate size, due to 11 percent REO concentrations within apatite, including approximately 2 percent yttrium oxide. The Pea Ridge iron deposit in Missouri (shown in Figure 3) contains "a variety of lanthanide-bearing minerals, including the principal ore minerals monazite and xenotime" also within apatite. Additional estimates include a possible 600,000 metric tons of REE-bearing material at the site, at an REO concentration of approximately 12 percent.

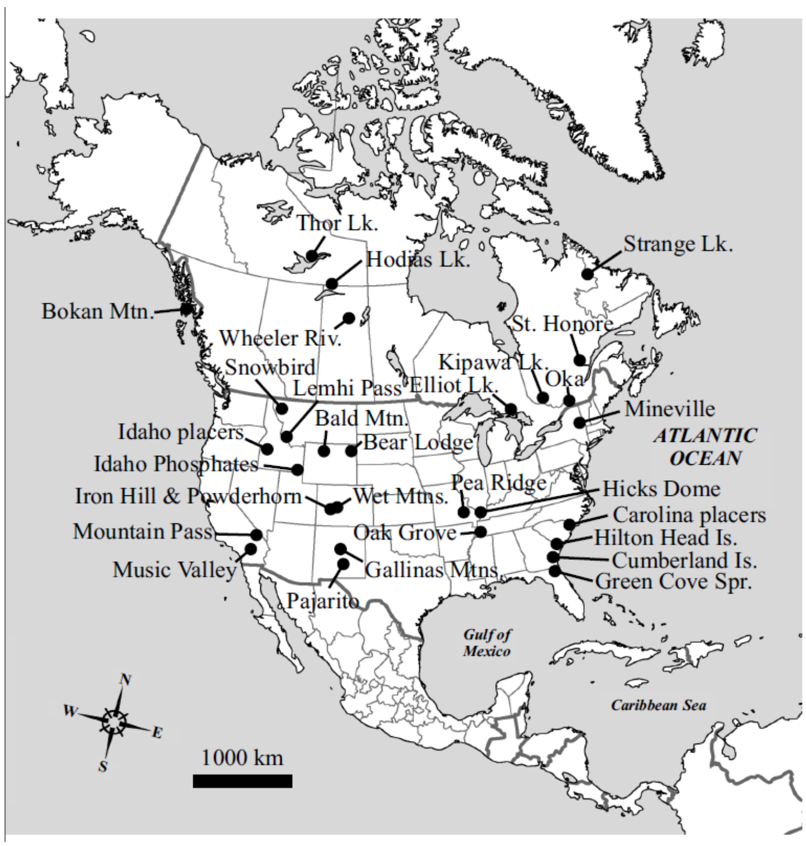

Figure 3: Locations of Rare Earth Deposits in North America

Beginning in 1954, the Mountain Pass mine in California was exclusively mined for rare earths by the Molybdenum Corporation of America, who changed their name to Molycorp in 1974. From 1965 to

1985, the mine produced the majority of the world's supply of rare earth materials (Figure 4). However, in the early 1990s, cheaper Chinese imported rare earth materials caused a steady decline in prices, and the mine's market share began a steady decline. At the same time, environmental problems raised production costs at Mountain Pass, and as a result production ceased in 2002. In 2008, the mine was sold to a private group named Molycorp Minerals LLC, headquartered in Greenwood Village, Colorado, who plans to restart rare earth oxide production at the site. Molycorp expects to achieve full-scale production of praseodymium, cerium, neodymium and lanthanum oxides in Q4 2012.

Figure 4: Molycorp's Mountain Pass Mine, California

Mountain Pass has faced environmental issues in the past; including a 1998 incident where the EPA suspended chemical processing due to multiple wastewater spill incidents. Molycorp has stated that they are now investigating pathways that are environmentally friendly and are not covered under intellectual property rights owned by foreign companies. By going public in July 2011, Molycorp raised US$379 million of the $511 million the company estimated was necessary for operations through 2012. Also, bills in the House and Senate would have offered loan guarantees for Molycorp and other investors in rare earth mines.

However, these bills never became law. Molycorp also applied to the Department of Energy (DoE) for loan guarantees in 2010 and currently awaits a decision in the second round of the process.

U.S. industry used to be involved in all stages of the rare earth material supply chain. Approximately 20 years ago the U.S. had twelve rare earth oxide magnet factories employing 6,000 workers, participating in a global market valued at US$600 million. As of 2010, only four factories remained, with approximately 600 workers, while the global market had grown to a value of over US$7 billion. The U.S. currently does not have manufacturing facilities of an appropriate scale to refine oxides into metals in large quantities, and is considered weak at each of the five stages of mining, separation, refining oxides into metal, fabrication of alloys, and manufacturing magnets and other components (Figure 5). Currently in the U.S. there is limited production of mine rare earth ores, REOs are processed into metals in only extremely small quantities, and only limited processing of metals into alloys exists. Therefore, even if rare earth production ramps up in the U.S., many of the processes in the supply chain would still occur in China and other countries in the short term.

There are a few companies participating in the rare earth supply chain and sharing the smaller non-Chinese market. Electron Energy Corporation (EEC) in Landisville, PA is the only U.S. company producing SmCo permanent magnets, while there are currently no producers of the more desirable NdFeB magnets. EEC uses small amounts of gadolinium, for which there is currently no U.S. production. In addition, the EEC imports magnet alloys from China for use in magnet production. Santoku America, Inc., of Tolleson, Arizona is the only listed U.S. producer of NdFeB alloys, and it does not produce NdFeB magnets, only alloys. There were 11 distributors and/or fabricators of magnets in the U.S. as of 2010, indicating a large demand for NdFeB and SmCo magnets, with distributors and fabricators typically importing overseas materials to resell them to their domestic customers.

In March 2012 a deal was announced between Molycorp Inc. and Neo Material Technologies, a global producer of rare earth engineered materials and applications, including NdFeB magnetic powders under the Magnequench brand and other rare earth metals under the Performance Materials division. Neo Material Technologies has 1,375 employees at 19 locations across 10 countries, and Molycorp plans to purchase the company for US$1.3 billion, completing Molycorp's supply chain and greatly strengthening its mine-to-magnets strategy. The deal has great significance for ROW supply, particularly in the U.S., as now Molycorp will have access to the magnetic alloy patents and more advanced processing technology it needs to make better use of the output of its

Mountain Pass rare earths facility. Molycorp would be in the unexpected position of both importing some REEs from China and supplying rare earth element products to China, a strange turn of events given the company's drive to secure U.S. supplies. The company will also absorb Neo Material Technologies' production facilities in China, Thailand and the U.S., joining Molycorp's existing facilities in the U.S. and Estonia.

According to the USGS, import dependence upon a single country raises serious concerns about supply security. In a global context, U.S. rare earth resources are modest and of uncertain value; hence, securing resources from traditional trading partners such as Canada and Australia is of great interest for diversifying sources of supply. However, Molycorp Inc. states that the "best route to ensuring security of rare earth magnet supply for the needs of American industry and defense purposes is to follow the example of China and develop a strong domestic rare earth industry from mining to final magnet production, based on the responsible exploitation of America's own strategic rare earth reserves." There are many factors that constrain the rebuilding of the U.S. supply chain. First, the U.S. does not have a substantial amount of heavy rare earths, such as dysprosium, a rare earth element that provides heat resistance for permanent magnets and is used in both commercial and defense applications. Second, the mining industry lacks the manufacturing assets and facilities to process rare earth ore into finished products, such as permanent magnets. Large capital investments need to be secured to build processing facilities. However, investors are concerned that China will continue to undercut U.S. prices and negatively affect their return on investment. Third, there are significant environmental concerns related to rare earth mining. Radioactive elements, such as thorium and radium, often accompany rare earth materials in mineral deposits, and this not only raises significant environmental concerns but also makes the extraction of rare earths difficult and costly.

In March 2012, President Barack Obama announced that the U.S., Japan, and the E.U. would be jointly filing a case with the WTO contesting China's export and trade policies on rare earths, citing the importance of China's adherence to global trade rules. The case may take several years to conclude and have no effect on China's policies for some time, even if the WTO were to eventually rule against them. Continued appeals to the WTO reflect growing outside pressure on China, due to its restrictive policies on rare earth exports in the face of global demand, as well as the country's status as the dominant global supplier. A combination of export taxes and quotas characterizes the Chinese government's efforts to prevent over-exploitation and to direct

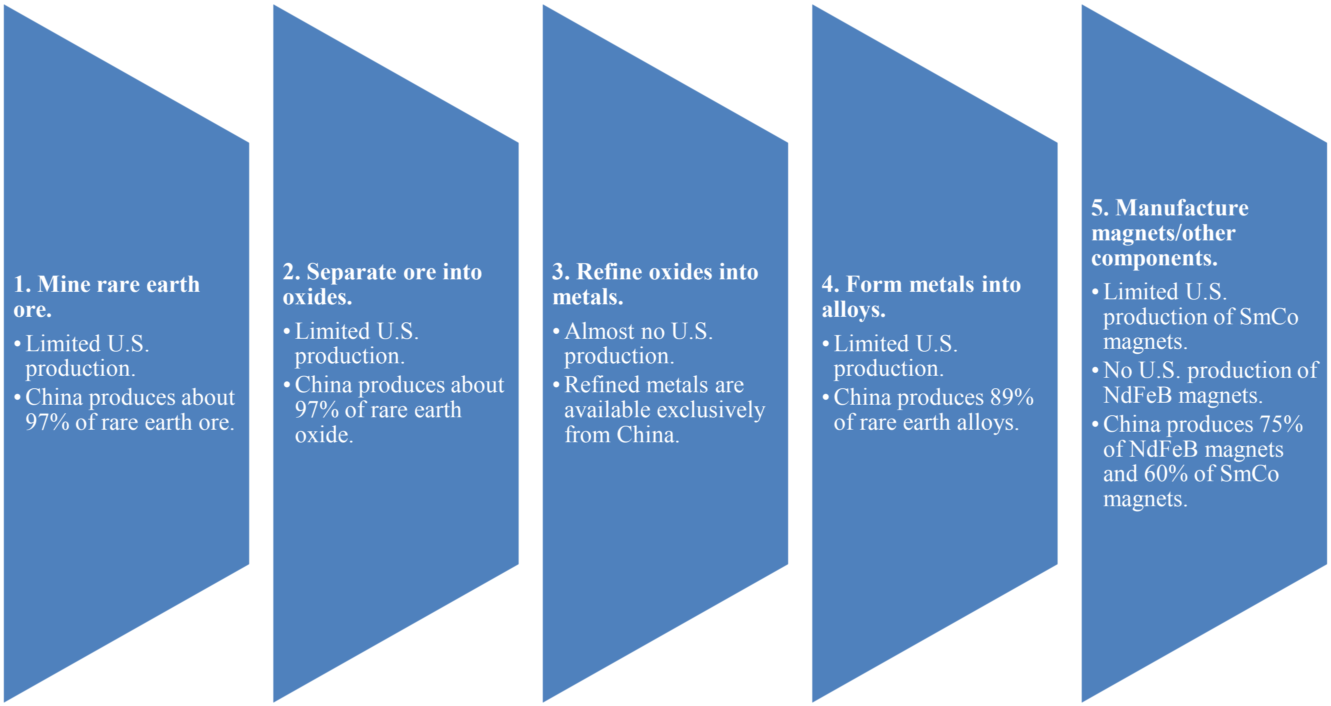

Figure 5: Example of Permanent-magnet Rare Earth Supply Chain

resources as needed for domestic applications, despite global demand for rare earths.

These developments in rare earth trade highlight the current level of U.S. dependence on foreign resources. It is clearly in the best interest of the country to develop domestic rare earth resources and to conduct R&D into areas related to the use of rare earths. The scientific community is currently researching new processes and technologies for mining rare earths, developing recycling methods for consumer goods that contain rare earths, and creating more efficient uses for rare earth minerals. The current level of dependence on China for a supply of rare earths puts the U.S. at a disadvantage. As Pecht and Zuga have pointed out, "with foreign control of rare earths now estimated at 97% and the realization that America's electronics production — and thus its ability to produce hybrid electric cars and alternative energy systems — could come to a halt should China decide to curtail access to these materials, it is clear that the U.S. must be proactive and make up ground in terms of developing industrial policy aimed at protecting its industrial base." To effectively provide for its future energy needs, it is critical that the U.S. has a strategic plan to address the acquisition and efficient utilization of rare earths.

There are several activities underway that begin to address the rare earth crisis in the US. In December 2010, the DoE developed three pillars to address critical materials that are at risk of supply disruptions in the short term (rare earth materials were a major component), where a disruption would also impact clean energy technologies – including wind turbines, electric vehicles, photovoltaic cells and fluorescent lighting[15]. The three pillars specified in the DoE's *Critical Materials Strategy* report are that (1) it is essential to have a diversified global supply chain, (2) substitutes must be developed, and we must focus on (3) recycling, reuse and more efficient use of critical materials. To address key materials risks, constraints and opportunities across the supply chain (rare earths being a major component), the DoE's report compiled programs and policies in eight broad categories, as shown in Figure 6. These eight categories include: (1) research and development, (2) data collection, (3) permits for domestic production, (4) financial assistance for domestic production and processing, (5) stockpiling, (6) recycling, (7) education, and (8) diplomacy.

The Advanced Research Projects Agency-Energy (ARPA-E) funded two initial rare earth projects in 2010 totaling $6.6 million to develop substitutes for rare earth magnets. The goal of the first $4.4 million project was to develop materials to allow the U.S. to fabricate the next generation of permanent magnets, with an energy density up to twice that of the strongest available NdFeB magnets. The agency further funded 14

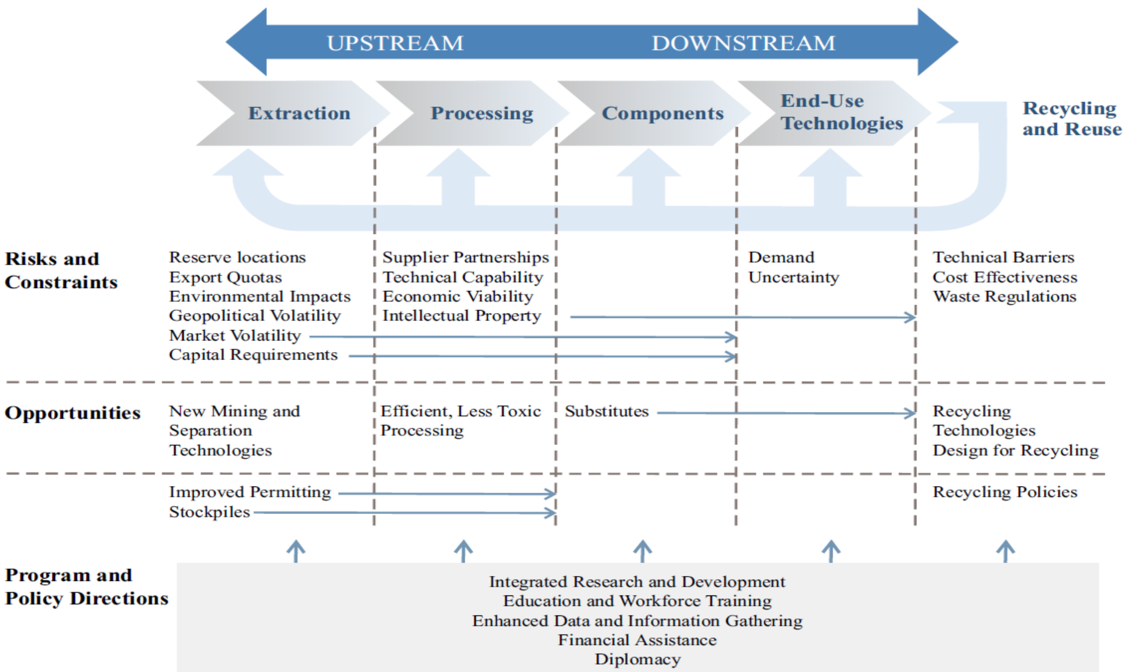

Figure 6: Future Program and Policy Directions across the Rare Earth Supply Chain

rare earth substitution projects in late 2011 under the Rare Earth Alternatives in Critical Technologies for Energy (REACT) program, at a total cost of US$31.6 million.

In the early 1990s, China became the principal producer, supplier and consumer of the rare earth industry. The country has made remarkable progress in rare earth science, technology and resource utilization while only possessing half of the world's rare earth deposits. Today, China has some of the richest deposits in the world within 21 provinces and autonomous regions – Fujian, Gansu, Guangdong, Guangxi, Guizhou, Hainan, Henan, Hubei, Hunan, Jiangxi, Jilin, Liaoning, Inner Mongolia, Qinghai, Shaanxi, Shandong, Shanxi, Sichuan, Xinjiang, Yunan and Zhejiang (Figure 7). Rare earth mines are distributed widely in China, but about 98 percent are concentrated in four

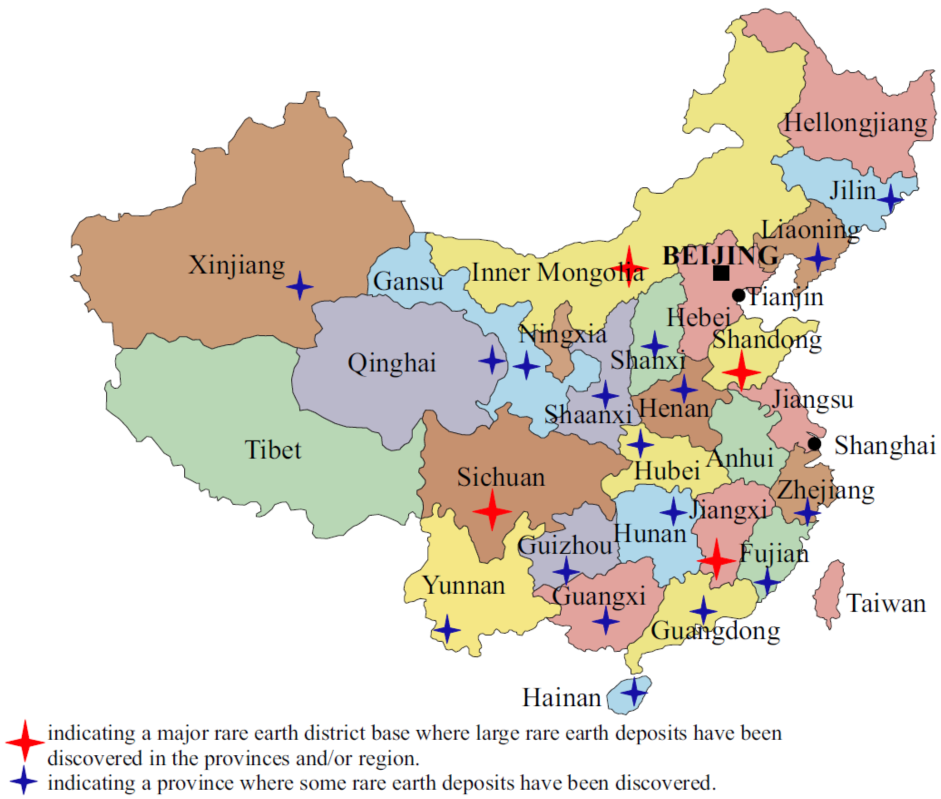

Figure 7 Discovered Rare Earth Deposits in Chinese Provinces/Regions

areas. Specifically, 80 percent are located in Baotou, Inner Mongolia; 10 percent in Shandong province; 6 percent in the seven provinces in the south of China, represented by Jiangxi province (middle and heavy rare earth deposits); and 2 percent in Sichuan province (light rare earth deposits).

In response to global demand, China's annual rare earth production grew by 40 percent from 1978 to 1989, with the country becoming one of the world's largest producers. There was a plunge in rare earth production from 1988 to 1990, due to the recession both in China and worldwide during this period. Production resumed, however, and output grew extremely quickly in the early 1990s, with an increase of over 90 percent from 1990 to 1995. During the 1990s, China's rare earth exports grew so significantly that rare earth prices worldwide plunged. This change either drove producers out of business, (particularly in the U.S.), or significantly reduced their production. In 1992, Chinese leader Deng Xiaoping made a now famous statement during a tour in Jiangxi province: "The Middle East has oil; China has rare earth". In the same year, the Chinese State Council (CSC) approved the creation of the Baotou Rare Earth Hi-Tech Industrial Development Zone. In 1999, Chinese president Jiang Zemin wrote "improve the development and application of rare earth, and change the resource advantage into economic superiority." Rare earth production in China remained relatively stable from 1998 to 2008, partially due to a rationalized exploitation policy adopted by the Chinese government in the form of production quotas.

Most Chinese rare earth enterprises are located in the vicinity of larger rare earth mines, such as those in Baotou in Inner Mongolia, Mianning in Sichuan province and Ganzhou in Jiangxi province. As of 2009 it was reported that there are 24 enterprises for rare earth concentrate production and approximately 100 rare earth enterprises for smelting separation production in China. A revised draft of China's 2009–2015 "Plans for Developing the Rare Earth Industry" simplified China's rare earth resource management by designating large districts. As seen in Figure 8, the rare earth industry in China has now been divided into three major districts, (northern, western, and southern), and two production systems (northern and southern).

Due to dramatically rising demand in the domestic market, the Chinese government has gradually reduced export quotas in recent years. In an effort to set sustainable levels of rare earth mining, the export quota was reduced by almost 40 percent in 2010. Chinese export quotas were reduced by a further 11 percent for the first half of 2011. However, the MOC set the rare earth quota for the second half of 2011 at 15,738 metric tons, meaning that the full-year quota was 30,184 metric tons,

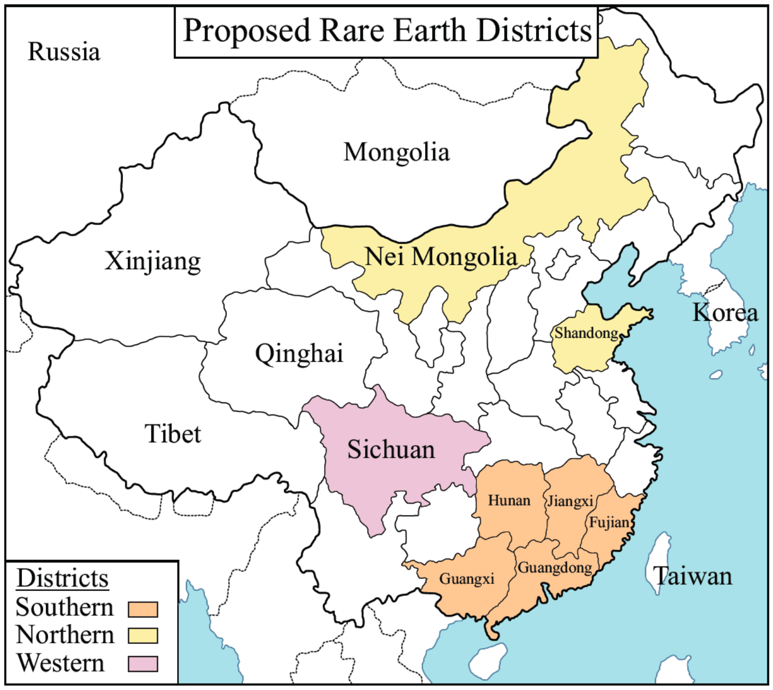

Figure 8: China's Proposed Rare Earth Districts

almost unchanged from 2010's 30,258 metric tons. The quota announcement was made two weeks after a WTO expert panel ruled that "China's export restrictions on nine raw materials were inconsistent with its WTO obligations," even though rare earths were not included in the raw materials cited in the WTO ruling.

Possibly due to skyrocketing market prices for materials and a subsequent global drop in demand, an estimated 51% of China's 2011 export quota went unused. Some companies may have also been skirting official government export quotas due to their use of rare earth "ribbons" – material comprised of 30-40% rare earth elements typically used to make magnets and sold overseas without government restrictions. According to an official from Ganzho Zhaori Rare Earth New Materials in China, as of 2012 there were almost 100 companies producing rare earth ribbons in China, and his own company had an annual production capacity of 2,000 metric tons.

On December 27, 2011, the Chinese Ministry of Commerce announced initial 2012 rare earths quotas at 24,904 metric tons. For the first time they separated heavy and light rare earths, with an allowance of 21,700 metric tons for light rare earths and 3,204 metric tons for medium/heavy rare earths. Also for the first time, they communicated their intent for the full year quota and stated it would remain unchanged from the levels seen in 2010 and 2011, with the initial quota representing 80% of the total for the year. China's total rare-earth export value between January and June of 2011 surged to $1.54 billion, an increase of 930 percent over the same period during the previous year, according to statistics from the Nonferrous Metals Society of China.

In addition to issuing production and export quotas, the Chinese government applies taxes on mineral production as part of its efforts to regulate the rare earth industry. During the early stages of the rare earth industry, China refunded the value-added tax that producers paid on exported products in an effort to encourage enterprises to export their products. This quickly led to China’s dominance of global rare earth supplies and also to the government moving from tax refunds to export duties. Since their introduction, Chinese export duty rates have increased for all rare earth export goods, with all rare earth metals and oxides at a 15 or 25 percent duty rate in 2011. While export duties and quotas are inconsistent with WTO global trading rules, China has stated publicly that it is ready to defend these policies and believes them to be necessary as part of its future plan for management of domestic resources. The intended result of these policies is a growth in numbers of higher value downstream rare earth goods exported, rather than rare earth oxides.

China showed significant interest in rare earths, particularly in R&D, even in the early years of the country’s development of its resources. In 1952, Beijing’s General Research Institute for Nonferrous Metals (GRINM) was established, becoming the largest institution in China in the field of nonferrous metals. In an effort to become a world leader in high-tech innovation, China has implemented two national programs: National High Technology Research and Development Program 863 (known simply as Program 863) and National High Technology Research and Development Program 973.

Prior to the 1990s, China's main focus was on applied research, in particular the separation of rare earths, and this resulted in weakness in the area of fundamental research. Two state laboratories in China now focus their efforts on fundamental rare earths research and have made significant contributions to rare earth technologies: the State Key Laboratory of Rare Earth Materials Chemistry and Application at Peking University, and the State Key Laboratory of Rare Earth Resource Utilization at the Changchun Institute of Applied Chemistry under the Chinese Academy of Sciences (CAS).

China also hosts the only two technical journals worldwide that are exclusively dedicated to rare earths: the *Journal of Rare Earths* and the *China Rare Earth Information Journal* (CREI). Both were launched by the Chinese Society of Rare Earths (CSRE), founded in 1980, a major rare earth science and technology research organization. The CSRE is represented by more than 100,000 registered experts, making it the world's largest rare earth-focused academic community. It serves the Chinese government and the country's researchers in the science and technology of rare earths, and it provides the ability for scientists to explore technical ideas for fundamental and applied research. The CSRE also plays an important role in the international rare earth community, organizing the International Conference on Rare Earth Development and Application once every three years, and a biennial CSRE meeting. The CSRE describes its own organization as "the most important social force in developing the rare earth science and technology in China." There are fifteen sub-committees in the CSRE covering almost every R&D field in rare earth development.

The Baotou Research Institute of Rare Earths (BRIRE), established in 1963, is now the largest rare earth R&D institute in the world, and consists of the North China Rare Earth Industry Productivity Promotion Center and the Ruike National Engineering Center of Rare Earth Metallurgy and Function Materials. BRIRE now has nearly 500 employees, 50% of whom are technicians, along with 100 professorial senior engineers and 200 engineers, 40 of whom have doctorate and master's degrees. The center focuses on the comprehensive exploitation and utilization of rare earth resources and research on rare earth metallurgy, environmental protection, new rare earth functional materials, and rare earth applications.

The development of the State Key Laboratory of Rare Earth Materials Chemistry and Applications was approved by the State Commission of Planning and Development of China in 1991, with initial financing provided by the World Bank. The laboratory has been formally open to the public since 1995 and has 29 researchers on staff, including 3 Chinese Academy of Sciences (CAS) members, 13 professors and 3 senior engineers. The laboratory performs both fundamental and applied research, emphasizing the theory and technology of rare earth separation in high and ultrahigh purity, and the design synthesis and characterization of new functional materials containing rare earth elements. The laboratory's three major research areas are: (1) the development of rare earth separation chemistry, (2) solid state chemistry, and (3) coordination chemistry and physical chemistry. The laboratory has also participated in extensive successful academic exchanges and established collaborations with scientific institutes and universities both in China and abroad, enabling the laboratory to achieve international recognition in the field of rare earth materials. Organizations involved include the University of Texas Medical Branch at Galveston, Auburn

University, Cornell University, McGill University, University of Sheffield, Kyoto University, and the University of Hong Kong.

The State Key Laboratory of Rare Earth Resource Utilization was founded in 1987 with the approval of CAS. The laboratory was initially named the Open Laboratory of Rare Earth Chemistry and Physics, and then the title was changed in 2002 to CAS Key Laboratory of Rare Earth Chemistry and Physics, and then again to its current title, the CAS Key Laboratory of Rare Earth on Advanced Materials and Valuable Utilization of Resources. As of 2012 there were 32 faculty members in the laboratory, including two members of CAS. The National Science Fund selected four faculty members as Distinguished Young Scholars, and seven were recruited into the CAS Hundred Talents Program. Between 1999 and 2005, the laboratory received a Second Grade Award of Natural Science from the CAS and published 842 research papers, 51 of them in journals with an SCI impact factor larger than 3.0. Fifty-two patents have been granted to the institution as of 2012, among which six are international patents.

The environmental impact of rare earth mining operations is a major issue wherever mining occurs for those both inside and outside the rare earth industry. In China the traditional lack of regulatory control and poor mining practices are of particular concern, given the country's extremely high levels of rare earth output. According to the CSRE, “Every ton of rare earth produced generates approximately 8.5 kilograms (18.7 lbs) of fluorine and 13 kilograms (28.7 lbs) of dust; and using concentrated sulfuric acid high temperature calcination techniques to produce approximately one ton of calcined rare earth ore generates 9,600 to 12,000 cubic meters (339,021 to 423,776 cubic feet) of waste gas containing dust concentrate, hydrofluoric acid, sulfur dioxide, and sulfuric acid, approximately 75 cubic meters (2,649 cubic feet) of acidic wastewater, and about one ton of radioactive waste residue (containing water)”.

In recent years the Chinese government has realized the importance of maintaining control of rare earth resources, and as a result has placed a tight grip on the industry. They have undertaken various measures, including restricting export quotas on rare earths, implementing production quotas, closing down illegal rare earth operations, consolidating smaller operations into a few larger ones for better control, and practicing greater enforcement of new environmental regulations.

China is continuing to build a stronger vertical supply chain in the rare earth industry, encouraging the export of finished rare earth products by creating export limits for semi-finished products, and working to attract international companies to set up downstream industries in China. The cost difference between exported and domestic rare earths is sending a clear message to rare earth consumers outside China – according to Michael Silver, Chief Executive of American Elements, “there is roughly a 40 percent difference in the cost of rare earths if you're buying on an export basis, due to the cost of the quota and the export tax … A company that moves here gets an incredible benefit."

China is also putting significant effort into closing down illegal operations and consolidating small operations into larger ones, measures intended to help the Chinese government ultimately gain complete control over the industry. The MIIT would establish an expert board for rare earth extraction and oversee the industry as a whole. The board would make impromptu onsite visits to mines and inspect operations to ensure that national directives are being implemented and executed appropriately. According to the draft plan, “Rare-Earth Industry Development Plan of 2009–2015,” the previous 120 mining companies will be merged into fewer than 20, and 73 processing firms will merge into approximately 20 by 2015. In the first week of July 2010, authorities in China announced a number of changes affecting the rare earth sector, one of which was their plan to consolidate the disparate rare earth companies into 3-5 conglomerates. Also, according to the announcement, “rare earth prices would be set and published by the central government on a monthly basis, through a unified pricing structure covering the main provinces responsible for rare earth production.”

A top official from the country’s MIIT group spoke on the subject of rare earth industry consolidation during a meeting of the Fifth Session of the 11th National People’s Congress in China. He reaffirmed that China will establish three or four single large enterprises as a result of government-driven consolidation efforts, referencing the fact that the first enterprise, Baotou Steel Rare-Earth Hi-Tech Co., had completed efforts to absorb 14 related companies. It is also of note that the Chinese government has provided sizeable loans to four major companies to further boost consolidation efforts by allowing them to purchase smaller operations. A major concern for the rest of the world, however, is that the oligopoly created from this process may be able to limit exports without the need for government export quotas, thereby putting them out of the WTO’s regulatory reach.

China’s environmental regulations for its rare earth mining and processing industries would not even be considered minimal by Western standards. Only as recently as October 2011 did the Ministry of Environmental Protection (MEP) finally put into effect the new "Emission Standards of Pollutants from Rare Earths Industry" restrictions. The MEP standards regulate six atmospheric and fourteen water pollutants, and are divided into two categories: those for existing enterprises and those for new enterprises. However, issues such as selfchecking by rare earth companies, unannounced penalty rules, and a lack of any standards for pollutant discharge techniques threaten to derail the process even as it begins. In the words of one Chinese news source, "the measure barely poses a threat to those companies that have no plan to expand production or go public."

There are additional concerns with the new standards. It is estimated that the additional yearly cost associated with water pollutant treatment would add roughly US$145-220 to every metric ton of rare earths. China is able to run its rare earth industry at approximately one-third the cost of other countries, partially due to its loose environmental regulations, and the higher cost could lead to a decrease in rare earths production. It could potentially hurt China's industry-leading status if other global sources were to come online and compete on price. According to industry expert Dudley Kingsnorth, "I think it will be at least 10 years before China will match our standards."

The future of the rare earth industry requires careful analysis and monitoring, particularly in light of the volatile environment encountered during 2011. Countries throughout the world are concerned about potential threats to continued access to rare earths and their intermediate products, due to their importance within future technologies. According to the USGS, there are sufficient exploitable reserves of rare earths around the world to meet estimated needs for a long time to come. The challenges lie in the difficulty of discovering rich deposits and processing them in a way that is economically viable while also minimizing the resulting damage to the environment. China, as almost a solo producer for a number of years, will continue to dominate the rare earth industry in the near future. In 2004, China produced approximately 90–100,000 metric tons of REOs; in 2010 Kingsnorth predicted that this production level would increase to 160–170,000 metric tons by 2014 (Table 4). Since global demand was estimated to be over 170-190,000 metric tons by 2014 (Table 3), approximately 20,000 metric tons in global production would need to be provided by ROW producers. Kingsnorth also estimated in 2010 that three rare earth elements would be in short supply by 2015: neodymium, terbium and dysprosium. In 2009 demand for rare earth oxides fell to 85,000 metric tons following the global financial crisis, impacting the forecast in Table 3. As seen in Figure 2, more recent projections from Kingsnorth in 2012 show global demand forecast to now be only 150,000 metric tons by 2015. This still represents a shortfall of approximately 20,000 metric tons, again required from ROW producers, although the projection now shows ROW production growing to approximately 70,000 metric tons. Additionally, China expects that it will become a net importer of rare earths within the

Table 3: Global Rare Earths Demand in 2008 and 2014 (forecast)

Application	**Consumption REO (metric tons per annum: tpa) ±15 percent** 2008	2014f	**Market Share 2014 (percent)**
Catalysts	25,000	30–33,000	17
Glass	12,000	12–13,000	7
Polishing	15,000	19–21,000	11
Metal Alloys	22,250	42–48,000	25
Magnets	26,250	38–42,000	22
Phosphors & pigments	9,000	11–13,000	7
Ceramics	7,000	8–10,000	5
Other	7,500	9–12,000	6
Totals	124,000	170–190,000	100

Table 4: Chinese Production of Rare Earth Chemical Concentrates 2004–2014 (tpa REO ±10%)

Year	**Bayan Obo Bastnaesite**	**Sichuan Bastnaesite**	**Ion Adsorption Clays**	**Monazite**	**Total**	**NDRC Quotas**
2004	42–48,000	20–24,000	28–32,000		90–100,000	n/a
2006	45–55,000	22–26,000	40–50,000	8–12,000	125–140,000	n/a
2008	60–70,000	10–15,000	45–55,000	8–12,000	125–140,000	127,280
2010	55–65,000	10–15,000	35–45,000	4–8,000	110–130,000	122,000
2014e	80–100,000	20–40,000	40–50,000	8–12,000	160–170,000	140–160,000

Note: Illegal or uncontrolled mining and processing is not included. This has amounted to 10–20,000 tpa REO over the last 3–5 years.

next five years and is not going to increase production, according to a 2011 CSRE report.

In December 2010 (with a follow-up in 2011), the DoE conducted an analysis of the role of rare earths and other strategic materials in clean energy, combining the importance of a material to the clean energy economy with supply risk to create a measure of criticality. Of the materials analyzed, five rare earth metals (dysprosium, neodymium, terbium, europium and yttrium) are assessed as most critical in the short term (2011-2015). The same five rare earth materials remain critical in the medium term (5-15 years). Cerium and lanthanum are near critical in the short term, but their status drops to not critical over the medium term.

Various countries worldwide are looking to secure alternative sources of rare earths, particularly those with industries that rely on rare earth materials. Japan is a prime example, with sensitive Sino-Japanese relations and a strong high tech manufacturing industry, where a steady supply of rare earth materials is key. The following is a discussion of potential rare earth suppliers both within the U.S. and globally.

There are a number of rare earth mines outside of China that show promise as sources of additional global supply. With the exception of Nolans Bore, Dubbo, Steenkampskraal, Mt Weld and Mountain Pass, most potential REE projects are in the initial stage of the production process, as shown in the chart of processes that potential suppliers are following (Figure 9). It will often take years and hundreds of millions of dollars, as well as favorable economic conditions both in the global economy and in the rare earth industry, before even initial production is possible.

The DoE has compiled estimates of the production of rare earth elements from new mines projected to be online by 2015. Australia's Mount Weld mine came online in 2011, and California's Mountain Pass mine is projected to be in full Phase 1 production in the fourth quarter of 2012. There are several promising deposits worldwide that could be candidates for development in the medium term. It is worth noting, however, that these alternative sources may struggle to compete with China, due to three factors: the cost and time involved in developing rare earth production facilities, the fact that a significant portion of Chinese rare earths are mined as a by-product of other profitable materials, and that China's ion adsorption clay deposits are cheaper and easier to process.

Given the combination of high global demand for rare earths and export restrictions imposed by the Chinese government, it is logical that some U.S. government and industry leaders advocate establishing a government-run economic stockpile and/or private-sector stockpiles that would contain supplies of rare earths as needed for commercial and military applications. As of 2012, the importance of investigating a U.S. stockpile of rare earths has now been officially recognized with recently introduced legislation. In H.R. 1540, the National Defense Authorization Act for Fiscal Year 2012, signed into law by President Obama in December 2011, Section 853 directs that the "Administrator of the Defense Logistics Agency Strategic Materials shall submit to the Secretary of Defense an assessment of the feasibility and advisability of establishing an inventory of rare earth materials."

Japan is steadily building a large strategic REE stockpile, and China's Xu Guangxian has alleged that Japanese industry has already stockpiled sufficient rare earth inventories for the next 20 years.

Figure 9: Rare Earth Mine Development Progress as of June 2011

Note: As of February 2012, Mountain Pass, CA began Phase 1 production startup.

JOGMEC officially announced on its website that the country's national stockpile has "42 days of standard consumption in Japan (70% of stockpile target)," while private industry has "18 days of standard consumption in Japan (30% of stockpile target)."

China has been building a strategic stockpile of rare earths with a focus on concentrates, in addition to the stockpile already being gathered by China's top rare earth producer, Baotou Steel Rare-Earth High-Tech Co. National guidelines issued by China's State Council in May 2011 acknowledged rare earths as a key part of national strategic reserves. According to the guidelines, China will set up a strategic stockpile for rare earth metals in addition to its existing rare earth oxide stockpile, giving the country guaranteed supplies and the ability to manipulate domestic and international supply conditions and market pricing as necessary.

Due to a cheap, plentiful supply of rare earths from China over the past decade, there has been little incentive to develop rare earth substitutes or effectively recycle rare earth materials. With rapidly rising rare earth prices and growing concerns about supply insecurity, the DoE has proposed to identify appropriate substitutes and improve recycling, reuse and more efficient use of critical rare earth materials.

Rare earth substitutes are generally either unknown or provide inferior performance due to the specific functions of rare earths. When there are substitutes for rare earths available, they are even more expensive materials, such as platinum-group elements that can be used to replace cheaper light rare earths in petroleum cracking and automotive catalysts. Additionally, there has been no success during the past 20 years of research to find alternatives for NdFeB magnet material with a similar energy product. Similarly, the most expensive rare earth element, europium, currently has no substitute and is used in millions of computer monitors worldwide. Some rare earth substitutions may be possible where specific magnetic and metallurgical properties are required. However, the more specific the properties required, the less likely the possibility of substitution becomes. As a result, rare earths are still required in certain applications, including magnets, optical glass components, X-ray pigments, phosphors, polishing applications, catalysts and magnets.

Systems and components are also being redesigned to either use rare earths less or remove them completely. There are several examples of active research projects and products where the use of rare earths is either minimized or nonexistent, with the aim of functionality similar to existing technologies. Specifically, the development of REE-free battery technology has been primarily focused on batteries used in hybrid and electric vehicles, due to the amount of rare earths used in each battery and the growing level of production of these vehicles.

The amount of metal that can be recovered via recycling is quite limited for very rare REEs. Nevertheless, these elements are important for eco-friendly vehicle production and demand for them is increasing rapidly, so the primary importance of recovery by recycling is to reduce the amount of material currently imported from China. China produces rare earth metals from denuded ore, while not traditionally being overly concerned about environmental measures. As a result, advanced countries have been able to obtain such metals cheaply from China. Australia and the U.S. also have large deposits of rare earth metals, but they prefer not to produce metals in their countries, since refining causes major environmental problems. Thus, metals refined in advanced countries will continue to be very expensive. Although the concentration of rare earth metals from recycling is not high, the recycling process does not have serious environmental problems. Thus, rare earth metal production via recycling has merit in view of its environmental cost, independent of other considerations such as politics or strategy.