STANFORD UNIVERSITY

Rare Earth Elements:
Strategies to Ensure Domestic Supply

Final Report for
the Bay Area Council and the Breakthrough Institute

Prepared By:

Kia Ghorashi, Lucinda Gibbs, Polly Hand, and Amber Luong

March 10, 2011
Stanford, CA

TABLE OF CONTENTS

EXECUTIVE SUMMARY

In late 2010, in the wake of growing concerns regarding domestic shortages of rare earth elements, the Department of Energy (DOE) released a comprehensive report analyzing the role of REEs and other critical materials in the clean energy economy. The DOE's study confirmed previously held beliefs about the rare earth market – namely, that China's production of 97 percent of the world's rare earth elements ostensibly poses supply risks to the United States.[1] Faced with increasing cuts on Chinese export quotas, the U.S. has reached a point where it must implement a series of actionable policies to ensure short-run supply of these critical materials.

Rare earth elements (REEs) – a group of 17 elements including Scandium, Yttrium, and the 15 Lanthanide elements located at the bottom of the periodic table – are critical inputs for the U.S. cleantech industry. These elements are required in the production of many important clean technologies, from wind turbines to electric vehicle motors, efficient lighting technologies to fuel cells. President Obama and other top U.S. policymakers have set high goals for the adoption of many of these clean technologies in the hopes of boosting our nation's economy and environmental sustainability.

To meet the targets for clean technology adoption over the next decade, however, our demand for REEs will increase significantly. China's current monopoly over global REE production and recent tightening of export quotas on REEs challenges the growth of the U.S. green economy.
In order to fulfil President Obama's goals, the United States must actively work to lessen its dependence on REEs for the technologies depicted in the following table:

[1] Lisa Margonelli, "Clean Energy's Dirty Little Secret," *The Atlantic Magazine*, May 2009,

Technology	Key REEs	Role in Technology	Future Concerns
Electric Vehicles	Lanthanum, neodymium, dysprosium	Batteries, magnets in electric motors	Significant REE use, but potential substitutes for REEs in electric motors under development. Lithium ion battery technology also under development.
Wind Turbines	Neodymium, praseodymium	Permanent magnets for next generation wind turbines (> 3 MW)	No known substitutes for neodymium magnets and large quantities are needed; Shortages likely in the future
Fuel Cells	Lanthanum, yttrium	Provides conductivity, used as stabilizing dopant[2]	No significant REE supply issues predicted, and technology advancements expected to reduce need for REEs in fuel cells.
Efficient Lighting	Yttrium, europium, terbium	Used in rare earth phosphor powders, which allow CFLs and LEDs to achieve high levels of efficiency	No known substitutes for yttrium. Significant demand growth expected for yttrium, europium, and terbium, leading to shortages.

REE POLICY OPTIONS

The U.S. must adopt a set of efficient policies to reduce the risk of short-term REE supply disruption and ensure that U.S. clean technology industries will be able to access a diversified supply of REE in the long-term. Despite this reality, the U.S has yet to adopt a specific and actionable policy with respect to the shortage of REEs. Preliminary legislation has been introduced in Congress to address the threat of critical material shortages, but the U.S. has yet to establish a clear policy direction to address these challenges. With the recent release of its *Critical Materials Strategy*, the DOE has taken an important step forward by quantifying the potential for supply disruptions of different REEs and laying out a broad slate of general program and policy directions for the consideration of policymakers.

The DOE proposed data collection, investments in research and development, recycling policy, financial assistance for domestic production, stockpiling, education and training, permitting, and diplomacy as potential policy options. Many of these proposed policies fail to address the short-term supply threat or the true barriers existing in the REE market today. While the DOE mentions the possibility of expediting domestic mine permitting and pursuing diplomatic action – two actionable policies with real potential for short run impact on domestic REE supply – the implications of each course of action have been insufficiently analyzed. This report evaluates both of these policy directions in depth and arrives at a specific set of recommendations for implementation, as summarized below.

[2] Note: A dopant is an impurity added to a substance in order to alter selected properties

Permitting for Domestic Production

The primary sources of delay for the mine permitting process are due to two factors: One, the bureaucratic procedures governing federal and state regulations; and two, the persistent litigation brought by groups opposed to mining activity. In the particular case of Australia, where permitting is completed in much shorter timeframes, well-defined rights for affected local populations and active dialogue between the mining industry and environmentalists could serve as examples of ways to reduce the instances of litigation and general opposition to projects that would otherwise meet the necessary standards. Given this analysis, there are two key recommendations that can ameliorate the permitting process, corresponding to near-term actions and longer-term strategic dialogue.

Improved coordination between Federal and State agencies

As recommended in last year's RESTART legislation (the Rare Earths Supply-Chain Technology and Resource Transformation Act), improved coordination between Federal and State agencies could involve an REE task force created to evaluate the nature of procedural delays and provide recommendations on streamlining the bureaucratic process. In particular, this task force should focus the source of past delays in issuing permits to determine whether the majority were due to legitimate environmental concerns, litigation, process delays, or some combination of those factors. Should litigation and process delays prove to be the cause in a significant number of cases, then further work could be done to ascertain the nature of the litigation and to identify whether specific parts of the approval process are common roadblocks. In the case of common sources of litigation, if resolutions were reached, these findings could serve as a guide for future engagement between opposition stakeholders and the mining industry, both with respect to the issues of concern as well as means of resolving conflicts in the future.

Improved industry engagement with concerned stakeholders

Although improved engagement between industry and concerned stakeholders may require a shift in the engagement strategy of the U.S. mining industry, there could be significant longer-term benefits from directly engaging concerned stakeholders as the Australian industry has done. From the perspective of local populations affected by mining practices, appropriate legislation could be introduced that outlines a clear procedure for addressing local concerns — an approach that seems to benefit both local communities and the mining industry in Australia. From an environmental perspective, the mining industry could demonstrate a commitment to improving performance through a number of international standards that have been established. Though the U.S. National Mining Association is a member of the International Council on Mining & Metals (ICMM), only a handful of individual companies are themselves members. The ICMM publishes an annual report on the performance of its individual company members with respect to a number of sustainability criteria, and a movement toward such transparency could make significant strides in restoring confidence in those mining companies who are making efforts to improve performance. In addition to the growing focus by NGOs on the mining sector, financial institutions are also increasingly focused on social and environmental risks, which can ultimately impact access to capital for mining companies.[3] Therefore embracing a transparent and widely-accepted set of standards may even enhance the U.S. mining industry's competitive positioning over time.

Strategic Cooperation

REE-consuming firms and their respective governments have adopted a variety of strategies in response to Chinese export restrictions, particularly over the past several months. Based on the positive experiences of key REE-importing nations (e.g. Japan) and future REE-producing nations (e.g. Australia) in forming strategic agreements to cooperate on REEs in at least some capacity, there is a range of potential actions that the U.S. might undertake within the sphere of strategic cooperation.

WTO Litigation

There is increasing momentum in Washington for the U.S. to join with other countries in filing a formal WTO complaint against China's export restrictions on REEs, but it may be advisable for the US to address shortages of REEs through other diplomatic initiatives, given the broader framework vis-à-vis China. Much of the current momentum is attributable to a recent WTO ruling that rejected China's defence of decreasing export quotas on strategic materials such as Coke and Bauxite for the same justifications used to impose export restrictions on REEs.[4] Regardless, the option of challenging Chinese trade policy in the WTO poses the most aggressive policy available to the U.S., as it threatens to further exacerbate Chinese-U.S. bilateral relations. Diplomatic relations between Beijing and Washington are currently characterized by tense negotiations over military and economic cooperation, such as currency appreciation and the recent delivery of military aid of over $6 billion to Taiwan.[5]

Pursue diplomatic agreements for bilateral cooperation

Engaging in bilateral negotiations with REE-supplier countries to reach agreements to

[3] David Brereton (2002), *The Role of Self-Regulation in Improving Corporate Social Performance: The Case of the Mining Industry*
[4] Juliane Von Reppert-Bismarck. "WTO opens China to rare earth challenge." Reuters. March 1, 2001.
[5] David Shambaugh. "Stabilizing Unstable U.S.-China Relations? Prospects for the Hu Jintao Visit." Brookings. January 2011. http://www.brookings.edu/papers/2011/01_us_china_shambaugh.aspx

cooperate on REEs can be an effective strategy for diversifying future REE supply, as well as for encouraging private sector action. One of Japan's most successful strategies in the wake of China's block on REEs to Japan in late 2010, for example, has been to incorporate cooperation on REE supply into bilateral diplomatic meetings at the highest levels (between heads of state, for example).[6] Japan engaged diplomatic counterparts in Australia, India, Vietnam, Mongolia, the E.U. and the U.S. to secure bilateral agreements to cooperate on REEs.[7] In many cases, the agreements that have stemmed from these meetings have also prompted parallel strategic alliances in the private sector, as discussed in more depth below.

Cooperate within existing multilateral organizations and free trade frameworks

For many other countries, including Australia, Vietnam, and Mongolia, as well as the European Union, cooperation on REEs represents more than a single-issue discussion. Often, agreements to cooperate on REEs are held out as a bargaining chip in general trade negotiations; India hopes that its cooperation with Japan on REEs, for example, will preclude further cooperation on nuclear power.[8] Additionally, Australia emphasized its REE resources in diplomatic meetings with Japan, successfully incentivizing Japan to re-open bilateral free trade talks that had long been stalled due to Japan's refusal to adopt a less protectionist stance on other trade issues.[9] As the U.S. government considers cooperating with other states to prevent a short run supply disruption, it will be important to consider the extent to which the U.S. can garner gains on REEs in exchange for concessions, including but not limited to relaxing U.S. trade protections on other goods.

[6] "Japan, Vietnam to jointly develop rare earths," Jiji Press, 22 Oct 2010, http://www.mcot.net/cfcustom/cache_page/118976.html
[7] Agence France-Presse. "Japan, Mongolia to launch talks on free trade, rare earths." 12 November 2010. http://www.bilaterals.org/spip.php?article18469
[8] Madelene Pearson, "India, Japan Agree to Consider Cooperation on Rare Earths," Bloomberg, 25 October 2010, http://www.businessweek.com/news/2010-10-25/india-japan-agree-to-consider-cooperation-on-rare-earths.html
[9] Rod McGuirk. "Japan, Australia to restart free trade talks." Associated Press. November 23 2010.

Facilitate private trade agreements between suppliers and consumers

Although calls for bilateral and multilateral cooperation are laudable, the negotiation of long-term cross-country contracts (whether in parallel to diplomatic negotiations or entirely in the private sphere) may represent the best policy for reducing REE supply disruptions in the short term. To facilitate the signing of contracts, cooperative efforts by governments and groups to diversify REE supply away from Chinese producers must be designed with the features of the REE market in mind. Due to the highly specific compositional nature of REE inputs for clean technologies, REEs are not traded on exchanges. Instead, REEs change hands from producers to users on contracts agreed to by the two parties.[10] As exemplified by the Japanese government's recent pursuit of diplomatic agreements for REE cooperation with various countries, which was followed directly (as soon as within a day) by the signing of contracts between Japanese REE-consuming firms and foreign REE mining ventures, government can play a key role in this process.[11] In a market characterized by specific contracts between REE suppliers and consumers, high level government diplomacy should focus on the development of strategic agreements that will facilitate private sector action.

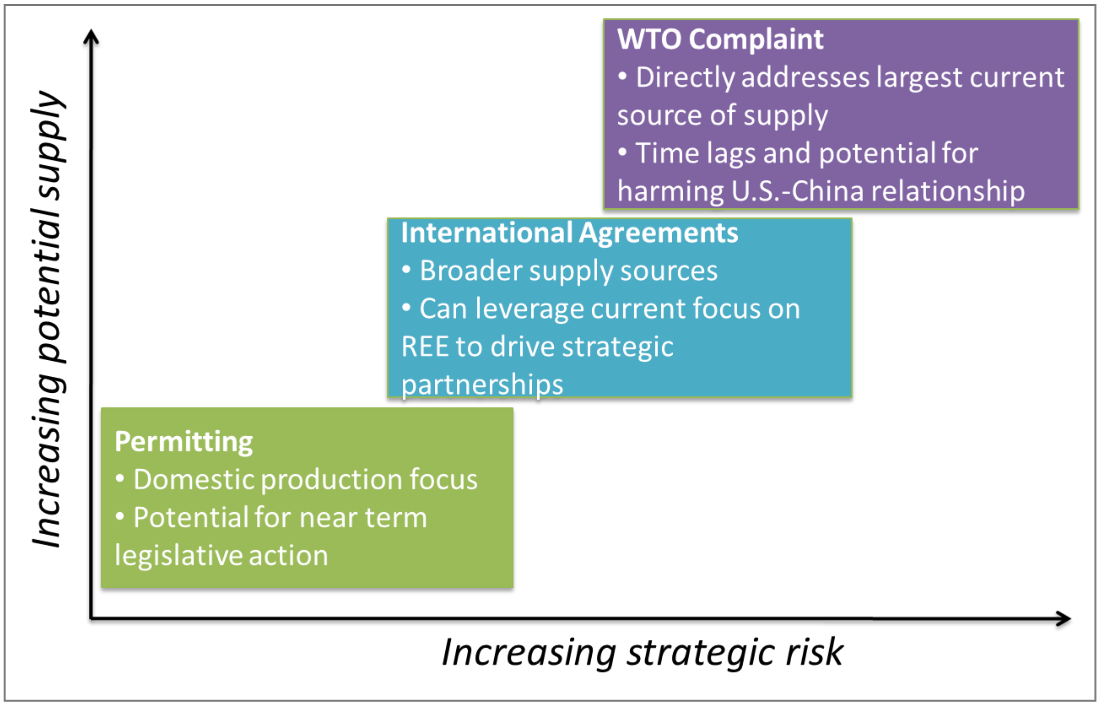
RECOMMENDATIONS

Given the range of policy recommendations that arise from our analysis, it is informative to compare these options in terms of their strategic risk and the size of the REE supply they have the potential to secure for the U.S. The figure below provides an assessment of these tradeoffs.

[10] These contracts vary from short-term or spot contracts (which allow the parties to interact frequently) to contracts with longer terms of six months to a year.

[11] Rod McGuirk, "Japan, Australia to restart free trade talks." Associated Press. Nov 23, 2010 and "Lynas signs rare earths dupply deal." AAP, with Reuters. November 24, 2010.

Policy Option Trade-offs



Based on the three strategies depicted above, the U.S. should pursue a two-fold policy of permitting and international agreements. The risks of pursuing WTO complaint against China are too high and require analysis of current bilateral relations. As stated earlier, bilateral relations between the U.S. and China are already tense due to limited cooperation over military and economic affairs. Taking China to the WTO may further exacerbate bilateral tensions and preclude cooperation on more pressing issues. The time lag accompanying a WTO dispute settlement process will also do little to solve the short-term supply shortages of REEs – it can take approximately two to three years to reach a WTO settlement.

Permitting and international agreements, on the other hand, represent more moderate policy approaches for the U.S. Both policies can be implemented domestically with little fear of jeopardizing our relationship with China. Meanwhile, the U.S. can continue bilateral negotiations with the Beijing in an effort to reverse Chinese export restrictions. Permitting and international agreements thus provide policy makers with actionable policies to achieve a desired solution to REE supply concerns.

ACKNOWLEDGMENTS

This project was prepared by a four-member team of graduate students in the Ford Dorsey Program in International Policy Studies (IPS) at Stanford University. It presents the results of a six-month practicum project, the capstone project of the IPS graduate curriculum. The authors would like to acknowledge support from a number of individuals who made this report possible.

We would first like to express our gratitude to our clients and advisor: Sean Randolph from the Bay Area Council, Jesse Jenkins and Devon Swezey from the Breakthrough Institute, and Professor Jim Sweeney from Stanford University. Their guidance through the course of the project helped us focus on the key issues in a broad-ranging and rapidly evolving topic area.

We greatly appreciate the valuable feedback and advice on all dimensions of the project from course instructor Joe Nation and his teaching assistants Michael Binder and Sarah Duffy. Their review of our documents and periodic strategy meetings helped us navigate a project that came with many analytical and logistical challenges.

We would also like to thank a number of individuals who graciously helped us parse through many technically challenging aspects of this topic, ranging from the scientific to the political: Ken Jacobson and James Paul from the Congressional Committee on Science and Technology, Dr. Tom Stern from the Hoover Institution, Dr. Karl Gschneider, Jr. from the Ames Laboratory, Dr. Ronald Stoltz from Sandia National Laboratories, and Diana Bauer from the Department of Energy.

We welcome any feedback or questions on this report at IPSrareearth@gmail.com.

INTRODUCTION

ISSUE AND MOTIVATION

The term rare earth elements (REEs) refers to a group of 17 elements, including Scandium, Yttrium, and the 15 Lanthanide elements located at the bottom of the periodic table, that are critical inputs to a range of important technologies. Although these elements are labeled rare, in many cases this label is more a reflection of commercial availability than natural scarcity. Naturally available quantities vary greatly among these elements: some are as readily available as industrial metals like nickel and copper, while others are rarer and found only in select countries. REEs are a crucial component in a variety of technologies, from consumer electronics to defense technologies, and have recently attracted significant attention for their role in the emerging cleantech sector.[12]

Despite their key role in a variety of U.S. industries, the U.S. does not currently have a stable domestic supply of REEs. Chinese producers are now responsible for roughly 97 percent of global production and refinement of REEs.[13] Beijing has espoused a host of export restrictions on the REE sector, often citing environmental justifications and domestic industry concerns. In 2007, for example, China instituted an export tax of 25 percent on the REEs europium, terbium, and dysprosium, and simultaneously suspended refunds of value added tax (VAT) (16 percent) on exports of REEs. More recently, Beijing initiated a series of steps towards increasing export restrictions on REEs. For example, in December 2010, China announced a further reduction of export quotas for the first half of 2011, representing a 35% cut over a one year period.[14]

Unsurprisingly, foreign downstream manufacturers of high-end technological goods are concerned about potential for supply disruption and cost increases due to the limited supply of REEs. In 2007, after China's export taxes and cancellation of VAT refunds were implemented, rare earth magnet producers were paying 31 percent more than Chinese businesses for REEs.[15] In fact, world prices were approximately 20 to 40 percent higher than Chinese prices for REEs in 2009.[16] According to the WTO secretariat, Chinese export restrictions have resulted in lower input prices for Chinese manufacturers and provided Chinese firms with a competitive

[12] Long, K., Van Gosen, B., Foley, N., and Cordier, D., *The Principal Rare Earth Elements Deposits of the United States—A Summary of Domestic Deposits and a Global Perspective.* U.S. Geological Survey Scientific Investigations Report 2010–5220, 2010.

[13] Lisa Margonelli, "Clean Energy's Dirty Little Secret," *The Atlantic Magazine*, May 2009, http://www.theatlantic.com/magazine/archive/2009/05/clean-energy-apos-s-dirty-little-secret/7377/.

[14] "China Cuts Export Quota On Rare Earth Metals," *Wall Street Journal,* December 29, 2010, http://online.wsj.com/article/SB10001424052970203513204576047041493111426.html

[15] Jane Korinek and Jeonghoi Kim, *OECD Trade Policy Working Paper 95: Export Restrictions on Strategic Raw Materials and Their Impact on Trace.* OECD, 2010.

[16] Suzanne Goldenberg, "Rare Earth Metals Mine is Key to U.S. Control Over Hi-Tech Future," *The Guardian*, December 26, 2010. http://www.guardian.co.uk/environment/2010/dec/26/rare-earth-metals-us

advantage ahead of foreign firms.[17] Such export restrictions not only benefit Chinese firms, but also bolster the Chinese economy as foreign firms look to relocate production in China.

At the same time, forecasts for a number of clean technologies are predicting substantial growth, and countries are competing for leadership in the emerging cleantech sector. According to President Barack Obama, "The nation that wins this competition will be the nation that leads the global economy…And I want America to be that nation."[18] In response to these concerns, the U.S. Department of Energy (DOE) recently released its *Critical Materials Strategy* to address the prospects of constrained future supplies of rare earth elements. In this report, the DOE outlines the current state of the global REE industry, assessing the prospect of future shortages in the REEs most critical to clean technologies and proposing policy options for addressing these issues.[19]

The primary objective of this report is to evaluate the challenges the U.S. cleantech industry will face and suggest potential policies to mitigate the near-term risks of constrained REE supply. In particular, our assessment of cleantech vulnerability will focus on four key technologies: electric vehicles (EVs), wind turbines, fuel cells, and efficient lighting technologies.[20,21] Building on the DOE's report, our policy analysis will focus on two specific policy directions: mine permitting and strategic cooperation.

METHODOLOGY

Research on the cleantech sector was performed by reviewing existing literature and through personal interviews with industry stakeholders, including officials from the DOE, rare earth metallurgists and analysts, environmental scientists from Stanford, rare earth investors, and Congressional staffers responsible for REE legislation. Mine permitting policy research relied on publically available mining data from the U.S. Geological Survey (USGS) and regulatory fact sheets and resources from a number of federal agencies and state-specific agencies. In addition, international case studies were performed through a review of available literature and government documents. Strategic cooperation policy research was performed through an

[17] Peter Foster, "China tightens stranglehold on rare earth minerals," *Telegraph*, June 2, 2010, http://www.telegraph.co.uk/finance/china-business/7797015/China-tightens-stranglehold-on-rare-earth-minerals.html.

[18] "Remarks by the President Challenging Americans to Lead the Global Economy in Clean Energy," Office of the President, available online: http://www.whitehouse.gov/the-press-office/remarks-president-challenging-americans-lead-global-economy-clean-energy.

[19] The DOE report also focuses on several other critical materials such as lithium which are beyond the scope of this report

[20] In this context, competitiveness refers to the ability of the U.S. to meaningfully participate in the global market for clean technologies by gaining competitive advantage in the emerging cleantech sector.

[21] These technologies were chosen based on a review of recent REE/cleantech literature expressing concern over the impact of REE shortages on these specific industries.

analysis of the GATT's analytical index, China's Accession Protocol into the WTO, case studies of precedent measures in REE diplomacy, other countries' experiences with respect to strategic cooperation, and interviews with lawyers specializing in international trade.

REPORT STRUCTURE

Section II offers a detailed overview of the global REE market, including industry dynamics, the state of the U.S. market and current U.S. policy initiatives, a brief overview of China's REE industry, and an assessment of vulnerability in the cleantech sector. Section III offers a critical assessment of these policies, and the rationale behind our focus on permitting and diplomacy. Section IV outlines research and findings on the targeted policies of permitting and diplomacy. Section V concludes with a discussion of our recommendations for a new REE policy for the U.S.

BACKGROUND

THE GLOBAL REE MARKET

Rare Earth Element Properties and Uses

Within the group of 17 elements classified as REEs, each element has distinctive properties that support a variety of applications. Indeed, many REEs are not rare in terms of actual abundance in the earth's crust, and the current supply constraints are often said to be a matter of "contemporary economics not of scarcity".[22] Unlike other metals mined for industrial applications, REEs are rarely found in mineable concentrations in their source minerals, and multiple REEs are often found together, requiring further processing to isolate the individual metal oxides. The extraction and refining processes for REEs are key contributors to the high cost and potentially negative environmental consequences of mining these elements.

REEs can be broadly divided into two subgroups – light and heavy rare earths – based on the atomic number of the element (though a notable exception is yttrium, which shares many properties with the heavy REEs in spite of its lower atomic number). Generally speaking, the light REEs are more abundant than the heavy REEs, but the distribution of REEs in the source mineral ore is always site-specific. As a result, mining REEs is further complicated by the inability to apply a standardized extraction and refining process because "no two REE ores are truly alike".[23]

Table 1 below lists the REEs by category, including production totals for 2009 and sample applications of each element. Many unique properties of REEs are key to their value, such as the ability to create very strong magnets (and thus reduce the size of devices in which the magnets are used) as well as optical properties that allow them to emit light. However, it is important to note that the individual REEs have distinct properties and uses such that their demand is often linked to different markets. As a result, the distribution of individual REEs found in a deposit may not match the distribution of demand for industrial applications. For example, cerium is the most abundant REE (in production and natural abundance), yet for REE magnets the greatest demand is for neodymium and praseodymium.[24] Detailed technical information on the application of these REEs to specific technologies is provided later in this section and in the Appendix.

---

[22] Jack Lifton, "The Supply Issue For All Metals," *The Jack Lifton Report*, 2010.
[23] USGS 2010.
[24] Lynas Corporation, "Will there be sufficient rare earths to meet demand from clean energy technology?" Presented at the International Minor Metals Conference, London, April 2010, www.lynascorp.com/content/upload/files/Presentations/MMTA_APRIL_2010.pdf.

Table 1. REE Classification, Production, and Applications

Element Name	Atomic Number	2009 New Mine Production (metric tons)[a]	Selected Applications[b]
LIGHT REEs			
Scandium	21	Unknown	Lighting, lasers, consumer electronics, metal alloys
Lanthanum	57	32,860	Hybrid engines, metal alloys,
Cerium	58	62,992	Catalytic converters, petroleum refining, metal alloys
Praseodymium	59	6,150	Magnets
Neodymium	60	19,096	Hybrid engines, auto catalyst, laptop hard drives
Promethium	61	Unknown	X-ray source, lasers (though now this element thought to not be naturally occurring in earth's crust)
Samarium	62	1,364	Magnets
Europium	63	272	Red color for electronics screens, phosphors
Gadolinium	64	744	Magnets, phosphors
HEAVY REEs			
Terbium	65	450	Phosphors, permanent magnets
Dysprosium	66	2,000	Permanent magnets, hybrid engines
Holmium	67	Unknown	Glass coloring, lasers
Erbium	68	Unknown	Phosphors, colored glass
Thulium	69	Unknown	Medical x-ray units
Ytterbium	70	Unknown	Lasers, steel alloys
Lutetium	71	Unknown	Petroleum refining catalyst
Yttrium	39	8,900	Fluorescent lamps, metal alloy agent

[a]*Excludes production from previously mined mineral ore stockpiles. Source: Lifton (2010)*
[b]*Sources: Hurst (2009), U.S. Geological Survey, Circular 930-N*

REE Processing

The mining and extraction of rare earth elements is a complex process. REEs are primarily found in mineral deposits of bastnaesite and monazite. Due to concerns over the radioactive hazards associated with monazite – which contains thorium, a radioactive element – U.S. production is mainly limited to lower-thorium bastnaesite deposits.[25] A recent report by the Institute for the Analysis of Global Security (IAGS), a Washington, D.C. think tank, demonstrates the complexity of the extraction process for bastnaesite:

> "First, ore containing minerals...is taken out of the ground using normal mining procedures. The bastnaesite must then be removed from the ore, which generally contains a number of other minerals of little value. The bastnaesite is removed by crushing the ore into gravel size, then placing the crushed ore into a grinding mill. Once the ore is ground down through a mill into a fine sand or silt the different mineral grains become separated from each other. The sand or silt is then further processed to separate the bastnaesite from the other nonessential minerals. This is accomplished by running the mixture through a floatation process. During the floatation process an agent is added and air bubbles come up through the bottom of the tank. Bastnaesite sticks to those bubbles and floats to the top of the tank as a froth, where it is then scraped off. The bastnaesite contains the rare earth elements, which must be further separated into their respective pure forms in a separation plant, using acid and various solvent extraction separation steps. Each element has its own unique extraction steps and chemical processes and at times, these elements will require reprocessing to achieve the ideal purity."[26]

According to IAGS, from the initial ore extraction to the production of the REEs, the mining process takes approximately 10 days. REEs are separated based on atomic weight, with actual processing duration based on the specific element. Processing times may vary widely as a result. For example, separation begins with cerium, the most abundant rare earth, but terbium can take more than 30 days of processing.[27] This adds an additional challenge, as it is impossible to extract only high-value elements. For example, in the current market, there is significant demand for neodymium, which consequently fetches a high price in metal markets. Before separating out neodymium, time and resources are spent extracting less valuable elements such as cerium, which increases separation costs, reduces the payback from neodymium, and adds an oversupply of cerium to the market.[28] Thus, in order to extract more valuable elements, the price on some of the output is decreased, making any evaluation of the economic viability of a deposit extremely complex.

---

[25] Humphries 2010.
[26] Hurst 2009.
[27] "Factbox: From Mine to Wind Turbine: the Rare Earth Cycle," Reuters, accessed Nov. 9, 2010, http://www.reuters.com/article/idUSTRE6A759P20101109.
[28] Personal interview with Congressional Staffers of the Science and Technology Committee.

Moreover, REEs are found in varying quantities in each deposit, so extraction methods must be customized to the individual mine, requiring significant industry knowledge and skill.[29] According to the USGS, due to the complexity of the ores; the infrastructure and financing needs; and, lower unit values, REE mining falls into the most difficult class of mining.[30] The separation plant must also be tailored for the specific local geology. For these reasons, ramping up REE production is a specialized, costly process.

Production, Consumption, and Price Trends

Table 2 lists the 2009 REE production figures by country, clearly showing that China dominates the production of REEs globally. Additionally, REE reserves are more widely distributed than current production, indicating that a number of countries could potentially contribute to future global supply once they access their own rare earth mines.

Table 2. World Total REE Production and Reserves for 2009 (metric tons)

	Estimated Mine Production	Reserves
U.S.	---	13,000,000
Australia	---	5,400,000
Brazil	650	48,000
China	120,000	36,000,000
Commonwealth of Independent States	N/A	19,000,000
India	2,700	3,100,000
Malaysia	380	30,000
Other	N/A	22,000,000
World Total (rounded)	**124,000**	**99,000,000**

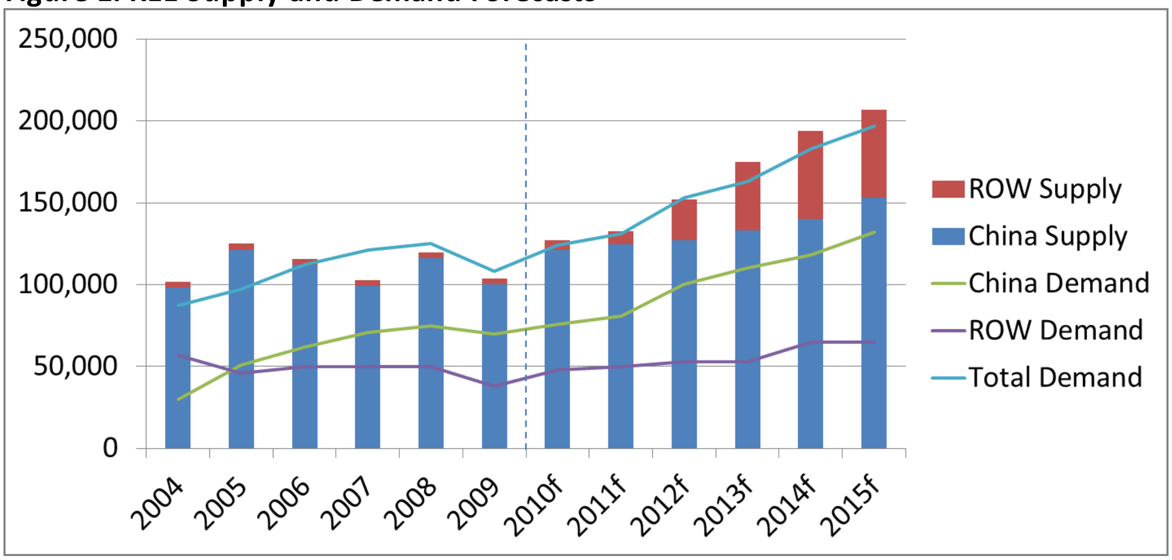
Source: U.S. Geological Survey, Mineral Commodity Summaries, January 2010

Global demand for REEs (in aggregate) is estimated at 134,000 metric tons per year, with projected increases to 180,000 metric tons per year by 2012 and could reach more than 200,000 metric tons per year by 2014.[31] According to Lynas Corporation, much of this growth will be driven by increasing demand for magnets and battery alloys through 2014, at rates of 12 percent and 15 percent growth per annum, respectively.[32] From China alone, significant amounts of growth are expected due to rapid deployment of clean technologies that use REEs. For example, China is planning to quintuple its installed capacity of wind energy over the next

[29] J. Seaman,"Rare Earths and Clean Energy: Analyzing China's Upper Hand." Paris: Institut Francais des Relations Internationales, 2010.
[30] USGS 2010.
[31] Humphries 2010.
[32] Lynas Corporation 2010.

decade, increasing to 100 GW by 2020.[33] While China's output is also expected to rise over this time period, it is not expected to be sufficient to meet the growing global demand for REE; in particular, supply shortages are anticipated to be an issue for the rare earth industry over the next five to ten years.[34] By 2015, many experts believe there will be an annual shortage of approximately 40,000 metric tons.[35] Figure 1 shows forecasts of REE supply and demand in aggregate.

Figure 1. REE Supply and Demand Forecasts

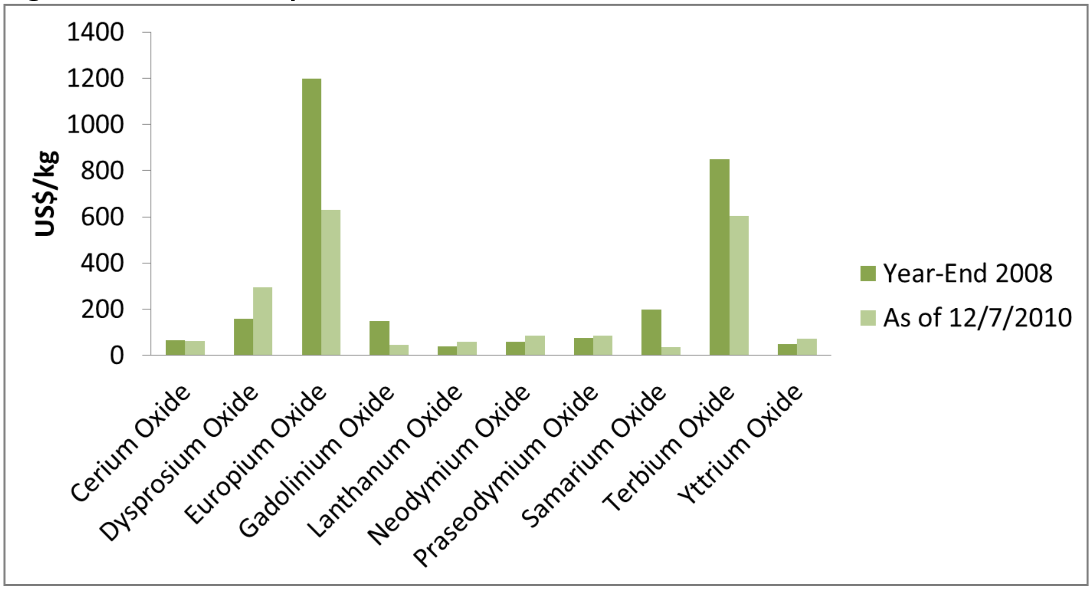


Source: "Developing a World Class Rare Earths Deposit in South Africa," Frontier Rare Earths, February 2011.

Figure 2 compares REE price data for year-end 2008 and recent price data for selected REE oxides (where current prices were available). Looking at a cross-section of individual REE prices, they appear to reflect the relative scarcity of the various elements. However, in recent years pricing fluctuations also appear to reflect higher demand for certain elements – for example, prices for more scarce elements (with little demand) such as terbium decreased over the last two years, while prices for neodymium, a key component of REE magnets, have increased by nearly 50 percent.

[33] Hurst 2009.
[34] Lynas Corporation 2010.
[35] Hurst 2009.

Figure 2. Recent REE price data



Sources: U.S. Geological Survey, 2008 Minerals Yearbook; www.metal-pages.com. All prices listed are the midpoint of the bid-ask spread indicated on the site.

Future Supply Prospects

Given the recent awareness of the importance of REEs to key sectors and the geopolitical concerns surrounding the control of these resources, "the most intense period ever of direct exploration for REE is currently underway."[36] Over the last 2 years, as many as 150 projects have been launched with the purpose of REE exploration worldwide.[37] There is a long, but uncertain, lead time to developing new commercially viable REE projects, so it will take time before the results of this increased activity come to fruition. However, based on a review of worldwide reserves and resources, and the degree to which these deposits have been explored and assessed, the U.S. Geological Survey believes that there could be short and medium term supply sources sufficient to meet anticipated global demand across the U.S., Australia, and Canada.[38] These reserves and resources are broken into several categories outlined in Table 3:[39]

---

[36] USGS 2010.
[37] USGS 2010.
[38] USGS 2010.
[39] *Resources* is the standard term for estimates of existing deposits, whether or not it is economically feasible to extract them. *Reserves*, on the other hand, is the term used to classify the subset of resources which is deemed economically feasible to recover given current prices and technology. Reliable data for China, North Korea, and Russia were not available. (USGS 2010).

Table 3. Global REE Reserves and Resources

Classification	Description	Locations
Proven and probable reserves	Estimated to exist and be economically feasible to recover	Mountain Pass, CA
Measured-in-pit resources	Deposit exploration is sufficient for mining plan estimation, and a mine already designed or exists; not yet determined to be economically viable	Australia, Canada, South Africa
Measured, indicated, inferred resources	Deposits have been explored, but no economic feasibility studies or mine designs have been completed	Wyoming; Australia, Canada, Greenland, Malawi
Unclassified resources	Includes known deposits unlikely to be recovered due to location and/or lack of economic viability as well as deposits that have been minimally explored	Various in U.S.; Australia, Brazil, Burundi, Canada, Kenya, Kyrgyzstan, South Africa, Turkey, Vietnam

Source: USGS (2010)

Total rare earth oxides (TREO) (the form in which REEs naturally occur in the mineral ore) in the first three categories are estimated to be about 14 million metric tons, which the U.S. Geological Survey deems the only potential sources of additional supply in the short and medium term.[40] However, it should be noted that only one of these categories – proven and probable reserves – includes deposits that have been determined to be economically feasible to recover.

From a longer-term perspective, there are a number of factors that may support the economics of developing new sources of REE supply and gaining a geographically diverse market of suppliers: China's growing domestic demand, further export limits, limits to new mines in China, increasing prices for REEs, and demand growth in emerging economies such as India and countries in Southeast Asia.[41]

---

[40] USGS 2010.
[41] U.S. Geological Survey, *2008 Minerals Yearbook*, 2008.

THE U.S. REE MARKET

The decline and disappearance of the U.S. REE industry

Currently, China dominates virtually all levels of the global REE supply chain. This has not always been the case, however. From 1952 onwards, the U.S. possessed a significant REE mining apparatus and produced a notable proportion of the global REE supply.[42] In fact, the U.S. was a world leader in the production of light REE consumed domestically until 1998, when the Mountain Pass REE mine in California was forced to close (described in greater detail below). At the time, only heavy REEs were imported from monazite concentrates abroad.[43]

The U.S. REE industry went into decline in the 1990s, and finally disappeared with the closing of Mountain Pass mine in 2002, as a result of the confluence of three factors. First, the imposition of tighter environmental regulations on mining involving radioactive materials began to drive many sources of REE (particularly from monazite, but also from other deposits) out of the market, beginning in the 1980s.[44] As previously discussed, the purification of REEs is a complex process and tends to result in a variety of undesirable and highly regulated side products, particularly thorium and uranium.

Second, as Chinese production increased, Chinese producers began to undercut the Mountain Pass mine on price. Not only did the Chinese face lower regulatory costs, they also benefited from China's low labor costs and large, high quality resources.[45]

Third, the Mountain Pass mining facility began to have safety issues with its "tailings," which refers to the slushy waste product of the first step of separating REEs from the rocks they are found in. When the Mountain Pass mine was operating at full capacity, it produced 850 gallons of waste saltwater containing radioactive elements hourly, every day of the year. The tailings were transported down an eleven-mile pipeline to evaporation ponds.[46] In 1998, however, the pipeline burst, leading to tailing leaks. Four years later, the company's permit for storing the tailings lapsed and mining ceased at the Mountain Pass REE deposit.[47] Calling the mine's poor environmental record "legendary," an industry veteran recently said the spill will cost an estimated $185 million to clean up, a requirement if the Mountain Pass mine facility is to re-open.[48]

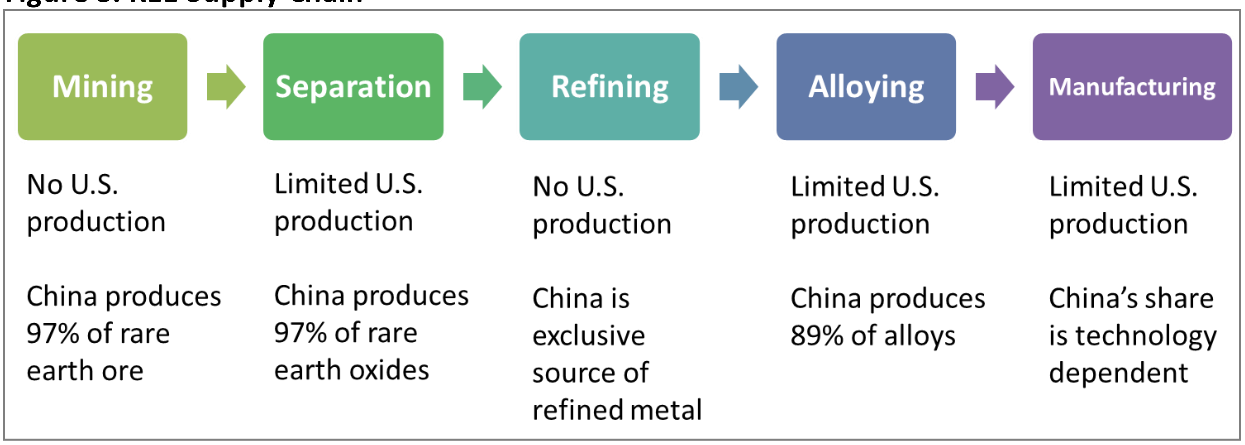
---

[42] "Rare earths mine to come back on line to fuel green cars," *Mining Engineering*, Vol. 61, No. 10, (2009), http://findarticles.com/p/articles/mi_hb5976/is_200910/ai_n42043615/.
[43] USGS 2010.
[44] Ibid.
[45] Hurst 2010 in USGS 2010.
[46] Katherine Bourzac, "Can the U.S. Rare Earth Industry Rebound?" *Technology Review*, October 29, 2010, http://www.technologyreview.com/energy/26655/.
[47] Mining Engineering 2009.
[48] Andrew Restuccia, "Troubled Mine Holds Hope for U.S. Rare Earth Industry," *The New Mexico Independent*,

The Current U.S. Market

The U.S., which previously performed all stages of the REE supply chain, currently lacks the capacity and technical expertise for each phase of REE processing: mining, separating, refining, alloying, and manufacturing. As demonstrated in Figure 3, even if the U.S. ramps up mining efforts, further processing would most likely take place in China.

Figure 3. REE Supply Chain



Source: Adapted from GAO (2010) analysis of industry data[49]

These supply chain dynamics can be explained by a number of factors. First, it is not merely an issue of expertise, but economics. Since the mid-1990s, when significant amounts of cheaply priced Chinese REE were introduced to the global market, REE prices have dropped dramatically.[50] At the same time, the costs of compliance with increasingly stringent environmental legislation have risen, as many REEs contain radioactive by-products such as thorium and radium.

Second, the time required to launch mining and production operations can also be highly prolonged. Even if a company secures the capital to start production, it can take seven to fifteen years to bring an REE project online, "largely due to the time it takes to comply with multiple state and federal regulations."[51] Mine permitting in itself is a time-consuming process, and due to the radioactive nature and complex geology of many REE deposits, the permitting process is even more stringent and subject to more legal challenges than normal metal mines. It is interesting to note that the Pogo mine, in Alaska, was developed under an expedited

---

October 25, 2010, http://newmexicoindependent.com/65686/troubled-mine-holds-hope-for-u-s-rare-earth-industry.

[49] U.S. Government Accountability Office, "Rare Earth Materials in the Defense Supply Chain," United States Government Accountability Office response to the National Defense Authorization Act for Fiscal Year 2010 (Pub. L. No. 111-84), 2010.

[50] USGS 2010.

[51] Ibid.

permitting schedule, yet still took seven years.[52] The mine permitting process is discussed in depth in Section IV.

Third, improving U.S. supply chain capacity will also be a timely endeavor. It could take two to five years to develop a pilot processing plant. Many industry experts also believe that competing with China will require new processing technology that may not be available at commercial scale for up to four years.[53]

Nevertheless, in response to fears of continuing U.S. reliance on China for all REE supplies, Molycorp Minerals, owner of the Mountain Pass mine, plans to reopen its open pit mine and begin mining in 2012.[54] By installing safer and more environmentally sound technologies, Molycorp hopes to drive operating costs below their former levels and below even the level of Chinese mines.[55] Rising prices of REEs in recent months, driven in part by the market's expectation of future shortages, are also affecting Molycorp's interest in re-opening Mountain Pass.

In addition to restarting mining operations, Molycorp has designed a new, cheaper separation process, and broke ground on a new REE separation facility at Mountain Pass in early January 2011. The new facility will recycle the waste water produced from the process, as well as many of the chemicals necessary to separate out the REEs in an attempt to become a "near-zero emissions" facility.[56] Molycorp is also installing a new natural gas pipeline that will enable it to generate its own electricity on-site, reducing the use of diesel at the mine and obviating the necessity of buying high-priced electricity from the grid.[57] In order to turn Mountain Pass into an environmentally sustainable producer, however, Molycorp will face an up-front project cost of $531 million and annual costs of $2.4 million on environmental monitoring and compliance.[58,59] Although Molycorp and Mountain Pass have the advantage of offering the shortest potential ramp-up time for sources of domestic production, it is unclear whether they will ultimately be capable of producing the REEs that U.S. clean technology industries most demand at lower cost than Chinese competitors.

These developments suggest that the U.S. may be able to break into a least one part of the REE supply chain in the fairly near term. However, the future U.S. impact on supply and demand for

---

[52] USGS 2010.
[53] GAO 2010.
[54] Ibid.
[55] Keith Bradsher, "Challenging China in Rare Earth Mining," The New York Times, 21 April 2010, http://www.nytimes.com/2010/04/22/business/energy-environment/22rare.html?pagewanted=all
[56] Restuccia 2010.
[57] "Technology reviving mine – Molycorp winds up in position of power," The Sun (San Bernadino and the Inland Empire), 22 January 2011, http://robocaster.com/sbsun/podcast-episode-home/localcolleges-ci_17169506/technology-reviving-mine-molycorp-winds-up-in-position-of-power.aspx
[58] Margonelli 2009.
[59] Bradsher 2010.

individual REEs remains unknown. Light REEs such as neodymium and cerium are preferentially concentrated in the Mountain Pass ore.[60] However, most REE deposits currently considered for development are enriched in light REEs and would likely flood the market for cerium if put into production. By contrast, heavy REEs are in short supply with limited reserves.[61] According to some industry sources, there is likely to be an annual shortfall in the supply of key heavy rare earths, including Terbium (80 to 270 metric tons), Dysprosium (220 to 630 metric tons), and Europium (up to 45 metric tons), by 2014.[62] In other words, it may be challenging for the U.S. to satisfy all domestic demand through domestic sources.

Current U.S. Policy[63]

In the last year, the U.S. federal government has become increasingly attuned to the significance of rare earth elements and the country's limited domestic supply. Recent Chinese export policies, such as Beijing's decision to further reduce export quotas, has sparked concern in Washington that the U.S. may be vulnerable to foreign control of a critical raw material. Consequently, federal policymakers, both in Congress and the Executive branch, have devised and implemented a series of preliminary policies to address the U.S.' domestic supply of REEs.

Legislation

In late 2009, when policymakers were becoming aware that rare earth elements were an integral component of important clean technologies, Congress turned to the DOE to spearhead REE policy. At the time, however, no government agency was adequately prepared to address the domestic shortage of rare earth elements. Neither the DOE nor the Department of Defense (DoD) had adequate staff, funding, and expertise to examine the domestic production of REEs. Both government agencies responded by establishing in-house task forces to analyze a series of rare earth-related questions, such as how significant rare earth materials are for national defense applications and whether the U.S. currently possesses the technological capabilities necessary to refine mined REEs.

Problems of inadequate preparation were not simply limited to the DoD and DOE, however. The Office of Science and Technology Policy, for example, was supposed to oversee the National Critical Materials Council – an organization intended to closely monitor the supply of

---

[60] S.B. Castor, "The Mountain Pass rare-earth carbonatite and associated ultrapotassic rocks", *The Canadian Mineralogist*, Vol. 46, No. 4.
[61] USGS 2010.
[62] Jamie Tuer, "Roskill Rare Earth Conference Summary," Memorandum sent to Hudson Resources Inc. stockholders, November 25, 2009, http://www.hudsonresources.ca/files/2009_Roskill_Rare_Earth_Conference_Summary.pdf.
[63] The majority of content in this section is drawn from interviews with the DOE and Committee on Science and Technology.

critical raw material. Due to a series of budget cuts and staff relocations in the 1990s, the Council was effectively disbanded, as its responsibilities were relocated and lost within the National Science Technology Council.

Meanwhile, on Capitol Hill, members and staff on the Committee on Science and Technology were actively writing legislation seeking to address the shortage of rare earths. In September 2010, the House passed bill H.R. 6160, the Rare Earths and Critical Materials Revitalization Act of 2010. Specifically, H.R. 6160 proposed increased funding for R&D and loan guarantees to spur private investment in domestic rare earths mines and refinement facilities. In fact, H.R. 6160's loan guarantees to private companies are perhaps the most important facet of U.S. federal policy related to REEs.

Customarily, private mining companies, like Molycorp, apply for DOE loan guarantee programs to raise capital for mining operations. However, Molycorp has repeatedly been denied loan guarantees, primarily because the DOE asks private companies to demonstrate that their proposed investments will reduce GHG emissions, in accordance with the Stimulus Bill. H.R. 6160 seeks to facilitate loan guarantees by stipulating that investments directed towards REEs should qualify, regardless of GHG emissions reductions.

Despite H.R 6160's promising loan guarantees, the bill did not pass before the 112th Congress took office in January. According to Congressional staffers on the Science and Technology Committee, a majority Republican Congress will likely ease the provisions of H.R. 6160 (now called H.R. 618 for the 112th Congress) and remove its loan guarantees and R&D stipends to reduce overall government spending. Many Republican Congressman will likely point to Molycorp's $350 million IPO as an indication that the market, not government spending, is capable of resuscitating the U.S.'s domestic REE industry.

In addition, in March 2010 Representative Mike Coffman introduced the Rare Earth Supply Technology and Resources Transformation (RESTART) Act, or H.R. 4866.[64] The RESTART Act calls for a working group made up of officials from the Department of Commerce, the DOE, the DoD, the Department of the Interior, and the State Department to reestablish a competitive REE supply chain. In addition, it calls for a strategic stockpile, and instructs the U.S. Trade Representative (USTR) to "(1) initiate and report to Congress on a comprehensive review of international trade practices in the rare earth materials market; or (2) initiate an action before the World Trade Organization (WTO) as a result of the review."[65] While RESTART is no longer alive, in late December 2010, Representative Coffman announced plans to introduce a similar rare earth bill in the 2011 session. According to Coffman's press release, the bill would include a provision to "establish a Rare Earth Policy Task Force across relevant Executive Branch agencies

[64] H.R. 4866 Bill Summary and Status, Library of Congress Thomas Database Online. Available at: http://thomas.loc.gov/cgi-bin/bdquery/z?d111:HR04866:@@@D&summ2=m&

[65] Ibid

to expedite the development of alternative sources of supply."[66] In addition, Coffman has stated that the bill will decrease the amount of time spent on environmental impact studies, while asserting that environmental regulations should not be relaxed.[67]

In June 2010, a separate bill, also known as RESTART, was introduced to the Senate by Senator Lisa Murkowski (S. 3521). The bill's stated purpose was to establish "the Rare Earth Policy Task Force to monitor and assist federal agencies in expediting the review and approval of permits to accelerate the completion of projects that will increase investment in, exploration for, and development of domestic rare earths."[68] More specifically, the bill directs the task force to explore options to expedite the permitting process pursuant to the Federal Land Policy and Management Act of 1976 (FLPMA); the Act of June 4, 1897 (the "Organic Act of 1897"); and the National Forest Management Act of 1976.

The DOE Critical Materials Strategy

In late 2010, in the wake of growing concerns regarding domestic shortages of rare earth elements, the DOE released a comprehensive report analyzing the role of REEs and other critical materials in the clean energy economy. The *Critical Materials Strategy* assesses both the short (0-5 years) and medium (5-15 years) term outlook for rare earth elements based on their usage in a number of cleantech applications.

The report concludes the following:[69]

- **Clean technologies will consume an increasing share of global critical materials.** Clean technologies currently are responsible for 20 percent of global critical materials demand, but the need for additional supplies of REEs will grow in proportion to the growth of global demand for cleantech applications.
- **REE supply shortages are most likely a short run risk.** Many clean technologies (including wind turbines, EVs, photovoltaic cells, and florescent lighting) use materials at risk of short term supply shortages, but these risks will decrease in the medium to long term.
- **Dysprosium, neodymium, terbium, europium, and yttrium are the most critical REEs in the short term.** "Criticality" is measured based on an index that combines risk of supply disruption and importance to the clean energy economy.

[66] "Coffman to Introduce Rare Earth Bill in Press http://coffman.house.gov/index.php?option=com_content&task=view&id=394&Itemid=10

[67] Williams, Emile (January 12, 2011). "Coffman Bill Would Spur Domestic Mining of Rare Earth Metals." Columbine Courier. Available online: http://www.columbinecourier.com/content/coffman-bill-would-spur-domestic-mining-rare-earth-metals

[68] S.3521 Bill Summary and Status, Library of Congress Thomas Database Online. Available at: http://thomas.loc.gov/cgi-bin/bdquery/z?d111:SN03521:@@@D&summ2=m&

[69] DOE *Critical Materials Strategy.* Washington D.C.: U.S. Department of Energy.

- **Policy and investment can reduce risk of supply disruption.** This is particularly true in the medium to long term.
- **Data are limited, and thus, comprehensive analysis is challenging.**

In light of these conclusions, the DOE provided a list of potential policy interventions, many of which are outside of their jurisdiction but represent possible options for reducing supply risk. Table 4 outlines each of the policy interventions, notes which government entity has jurisdiction over this type of policy, and offers our assessment of the likely timeframe for impact.

Table 4. DOE Policy Recommendations

Policy Recommendation	Jurisdiction	Summary	Timeframe*
Research and Development (R&D)	DOE	Areas of priority: magnets motors and generators; batteries, photovoltaics and lighting; environmentally sound mining; materials processing; recycling	Medium to long term
Data Collection	DOE; DoD; USGS; EIA; other gov. agencies	The DOE will work with government agencies and other stakeholders to fill in data gaps that currently limit accurate, in depth analysis. Areas include: annual production and consumption of individual REEs; prices at which REEs trade; materials intensity of different energy technologies; potential substitutes for critical materials in these technologies	Short, medium and long term
Financial Assistance for Domestic Production and Processing	DOE	The DOE references two sources of financial assistance: loan guarantees and price supports. However, the DOE cannot provide loan guarantees in this sector, and it is unclear how price supports would be implemented.	Short and medium term
Stockpiles	DoD; DOE	The U.S. could stockpile critical materials (such as REEs) in order to "diminish the leverage of monopoly suppliers in crisis situations," and promote domestic mine investment. Not recommended.	Short term
Recycling Policy	DOE; other gov. agencies	The DOE recommends considering policies which encourage higher rates of recovery of critical materials, as well as additional R&D dedicated to recycling (as discussed above).	Medium to long term
Education and Workforce Training	DOE; DoD; NSF; other gov. agencies	Investment in education and training will support a growing manufacturing base and encourage innovation in materials sciences through nternships, fellowships and scholarships	Medium to long term
Permitting for Domestic Production	EPA; federal, state and local agencies	In order to expedite the permitting process, the DOE recommends more coordination between state and federal agencies and industry education on best practices.	Short, medium and long term
Diplomacy	DOE; State Department	Cooperation with other countries either facing similar challenges or with access to critical materials will be key in meeting global and domestic challenges. The DOE pledges to "engage other countries through dialogues and collaborative institutions."	Short, medium and long term

Source: DOE Critical Materials Strategy.
**Timeframe data is based upon our own research and analysis.*

REES IN CHINA

China's rare earth industry is supported by over fifty years of dedicated research, in terms of production, refinement, and integration into valuable technologies. Institutions such as the state-run Rare Earth Materials Chemistry and Applications Lab and the Rare Earth Resource Utilization Lab encourage continued innovation and development in the REE market. The Baotou Research Institute of Rare Earths, established in 1963, is the largest rare earth research institute in the world.[70] In comparison, according to Yaron Varona, Executive Director of IAGS's Technology and Rare Earth Elements Center, "If the [U.S.] mines that are being planned were all to come online tomorrow that would be fantastic, but there would be nobody to run them."[71] The U.S has only one primary research center for REEs – the Ames Laboratory – which allocates only a portion of its R&D funding to rare earths.

Nonetheless, China's rare earth industry has been plagued with a number of challenges impacting current and future prospects. Increased global demand for rare earths has fueled growing illegal trade, with 18,000 metric tons of REEs smuggled out of the country in 2008. Official customs statistics report almost 37,000 metric tons of REE exports in the same year.[72] In other words, one third of all REEs flowing out of China are smuggled. Environmental degradation has also caused China to consider adopting additional environmental regulations. For example, the permissible content of the pollutant ammonia nitrogen, known to be toxic to aquatic animals, may be lowered to 15 mg per liter of production waste water from the current 25 mg.[73]

China has also implemented measures towards industry consolidation. Citing environmental efforts, such as the suggestion to eliminate producers whose annual production capacity is less than 8,000 metric tons of mixed rare earth products, serves dual purposes for the Chinese government. Eliminating small producers and consolidating the industry will improve environmental oversight, but will also allow China to gain further control over the REE industry. For example, many of China's smaller mining operations have been a significant source of REEs for Japan; eliminating these producers will tighten exports and aid China in policing quotas.[74]

REES IN THE CLEANTECH CONTEXT

A number of clean technologies depend on REEs, and depending on the availability of substitutes or prospects for recycling, REE shortages could prove critical for the development of these industries. This evaluation specifically focuses on four technologies that have been

[70] Humphries 2010.
[71] Restuccia 2010.
[72] Hurst 2009.
[73] "China May Further Tighten Environmental Standards for Rare Earth Production," Xinhua News Agency, November 7, 2010, http://news.xinhuanet.com/english2010/china/2010-11/07/c_13594978.htm.
[74] Personal interview with Congressional Staffers on the Science and Technology Committee.

chosen both for their dependence on REEs and their significance for the cleantech sector. An overview of these technologies is outlined in Table 5, and the sections that follow provide further background.

Table 5. Summary of REE Applications in Selected Technologies

Technology	Key REEs	Role in Technology	Future Concerns
Electric Vehicles	Lanthanum, neodymium, dysprosium	Batteries, magnets in electric motors	Significant REE use, but potential substitutes for REEs in electric motors under development. Lithium ion battery technology also under development.
Wind Turbines	Neodymium, praseodymium	Permanent magnets for next generation wind turbines (> 3 MW)	No known substitutes for neodymium magnets and large quantities are needed; Shortages likely in the future
Fuel Cells	Lanthanum, yttrium	Provides conductivity, used as stabilizing dopant[75]	No significant REE supply issues predicted, and technology advancements expected to reduce need for REEs in fuel cells.
Efficient Lighting	Yttrium, europium, terbium	Used in rare earth phosphor powders, which allow CFLs and LEDs to achieve high levels of efficiency	No known substitutes for yttrium. Significant demand growth expected for yttrium, europium, and terbium, leading to shortages.

Electric Vehicles (Batteries and Motors)

One of the most salient applications of REEs is in electric vehicles (EVs). Although REEs are used in standard fuel engine vehicles, there are significantly more REEs in EVs, as both the electric motor and battery of electric vehicles use substantial amounts of REEs.

Nickel-metal hydride (NiMH) batteries are primarily used in conventional hybrid vehicles. One of the key components of the NiMH battery is the REE lanthanum. Toyota's electric Prius, for example, uses 10 to 15 kg (22 to 33 lbs) of lanthanum.[76] Rare earth analysts project that 5,500 to 7,200 tons of lanthanum – which is approximately one third of the world's production – will be needed for Toyota's scheduled one million Prius units in model year 2011.[77] According to 2010Q3 prices for lanthanum per kilogram, Toyota alone could potentially spend \$210 M to \$290 M on lanthanum acquisition for NiMH batteries.[78]

---

[75] Note: A dopant is an impurity added to a substance in order to alter selected properties
[76] "As hybrid cars gobble rare metals, shortage looms," Reuters, last modified August 21, 2009, http://www.reuters.com/article/idUSTRE57U02B20090831.
[77] Ibid.
[78] Calculation based on 2008 Lanthanum prices by USGS 2008 Mineral Yearbook.

The other significant use of rare earth elements in EVs – neodymium – is in the electric motors. Neodymium iron boron magnets, small gold-plated cylinders only 6.4 by 2.3 mm in size, are used in EV motors because of their small size and powerful magnetic force.
According to industry reports, the Toyota Prius motor contains approximately 2.2 lbs of neodymium, while global supply of neodymium over the past five years has been approximately 17,000 metric tons.[79,80] Given its goal of producing one million Priuses by 2011, Toyota will need roughly 900 metric tons of globally produced neodymium and will spend $55 million in raw materials acquisition.

Wind Turbines

Wind turbine manufacturers are moving to turbine designs that utilize REE permanent magnets (PM), as new-generation wind turbines are increasingly scaling to three megawatts (MW) or higher instead of gearboxes. Using rare earth-based PM (primarily composed of neodymium) enables turbines to be lighter, smaller, and require less maintenance.[81] The advantages of a PM wind turbine over earlier, non-PM designs can be seen in the Appendix.

Although direct drive turbines' use of permanent magnets provides improved reliability and reduced costs of electricity generation, these models require significant amounts of rare earth inputs. According to one industry source, each three MW PM turbine uses about one ton of neodymium, an important REE that forms the strongest known type of PM structure ($Nd_2Fe_{14}B$) when combined with Iron and Boron.[82] Taking into account the variance between different turbine designs, it is reasonable to estimate that a direct drive turbine contains between 565 to 1,000 kg of NdFeB material per MW of rated capacity.[83]

However, various other REEs are required to produce materials for PM turbines. Based on typical temperature resistance requirements for NdFeB magnets, production of every 1,000 kg of NdFeB magnet materials requires about 350 kg of neodymium oxide and 38 kg of dysprosium oxide. Overall, neodymium makes up only about 69 percent of the REE consumption within the magnet application (although the distribution varies from manufacturer to manufacturer). Praseodymium makes up about 23 percent of REE consumption for magnets; dysprosium is 5 percent, gadolinium is 2 percent, and terbium is less than 1 percent.[84]

79 "As hybrid cars gobble rare metals, shortage looms," Reuters, last modified August 21, 2009, http://www.reuters.com/article/idUSTRE57U02B20090831.
80 USGS 2008 Minerals Yearbook.
81 Lynas Corporation 2010.
82 Lynas Corporation 2010.
83 Oliver M. Bayani, "Direct-driven wind turbines: the way of the future?" Ecoseed, October 29, 2010, http://www.ecoseed.org/en/wind-energy/other-wind-technologies/article/58-other-wind-technologies/8322-direct-driven-turbines--the-way-of-the-future-.
84 Ibid.

Thus, every MW of wind power generated using these next generation turbines requires about half a ton of REEs.[85] Growth forecasts indicate that the proportion of wind turbines utilizing rare earth permanent magnets will rise as wind capacity is added. In fact, some sources argue that the industry's switch from geared electromagnetic induction wind turbines to direct drive PM turbines will require an additional 3,000 to 5,000 metric tons of neodymium by 2014.[86]

Fuel Cells

Fuel cells, which are essentially chemical batteries that convert fuel into electrical energy, also use rare earth elements as a key input. There are a number of different fuel cell types, including polymer electrolyte membrane, alkaline, phosphoric acid, molten carbonate, and solid oxide (SOFC). The National Energy Technology Laboratory (NETL) lists SOFCs as the only fuel cell with a significant quantity of REEs.[87,88] However, SOFCs are considered one of the most promising fuel cell technologies due to their use in combined heat and power (CHP) applications and combined cycle electric power plants.[89]

According to NETL, at today's prices, REEs make up $12/kilowatt (kW) of the initial cost of an SOFC. In comparison, in 2008 REEs contributed approximately $1/kW. Despite this significant cost increase, this only represents 1 percent of SOFC power plant costs, and is unlikely to significantly impact the economics of SOFC. For example, platinum group elements (PGE) are a significant component in fuel cells, are 10,000 times less abundant than REEs, and 500-1000 times more expensive.[90] In addition, assuming four gigawatts (GW) a year of new capacity, four GW a year of stack replacements, and 90 percent recycling, fuel cells make up less than 5 percent of annual production demand.[91] Therefore, NETL concludes that "REE demand for SOFC applications is not likely to substantially impact overall supply-demand balances for REEs...and plausible fluctuations in REE prices are not likely to fundamentally alter the economic viability of SOFC in power generation applications."[92]

---

[85] Martin LaMonica, "Pay dirt: Why rare earth metals matter to tech (FAQ)," CNET, November 10, 2010, http://news.cnet.com/8301-11128_3-20021139-54.html#ixzz14GJ5wj00.

[86] Tuer 2009. For a more detailed analysis of Chinese and US growth projections in wind energy, see the Appendix.

[87] Additional research is necessary to confirm this.

[88] NETL 2004.

[89] DOE (2010). "Tubular Solid Oxide Fuel Cell Technology." Washington, D.C.: U.S. Department of Energy Website. Available online: http://www.fossil.energy.gov/programs/powersystems/fuelcells/fuelcells_solidoxide.html

[90] NETL 2010.

[91] Ibid.

[92] Ibid.

Efficient Lighting Technologies

Two key lighting technologies often cited for their use of REEs are Compact Fluorescent Lamps (CFLs) and Light-Emitting Diodes (LEDs). CFLs are primarily used for residential applications, replacing incumbent incandescent lighting technology. Meanwhile, LED lighting has broad applications in the residential and commercial sectors, aviation, and outdoor lighting. The efficiency gains in CFLs and LEDs, specifically phosphor-based LEDs, are primarily due to the use of rare earth phosphors. A phosphor is a term for any material that can emit visible light, via the addition of impurity ions, and phosphors used in lighting are often in powder form. Phosphors did not always utilize REEs, but in the 1970s rare earth ions were introduced into phosphors (originally Europium and Terbium), resulting in significant improvements in efficiency and revolutionizing the lighting market.[93] These technological strides benefitted both CFL and LED technology, and it is said that, "in many applications, the performance of rare earth phosphors is almost ideal and consequently the use of rare earth phosphors has pushed the performance of devices based on them to their physical limits".[94]

A rare earth phosphor can include multiple REEs in varying combinations depending on the specifications of the lighting design (e.g. color) and manufacturer, and for some applications, blends of multiple phosphors are combined. While it is therefore difficult to generalize a set quantity of any given REE in a CFL or LED, Table 6 below lists proportions that apply to the overall production of rare earth phosphors.

Table 6. REE Usage in Phosphors

Rare Earth Element	Usage (percentage)
Cerium	11%
Europium	4.9%
Gadolinium	1.8%
Lanthanum	8.5%
Terbium	4.6%
Yttrium	69.2%
	100.0%

Source: Adapted from Lynas Corporation (2010)

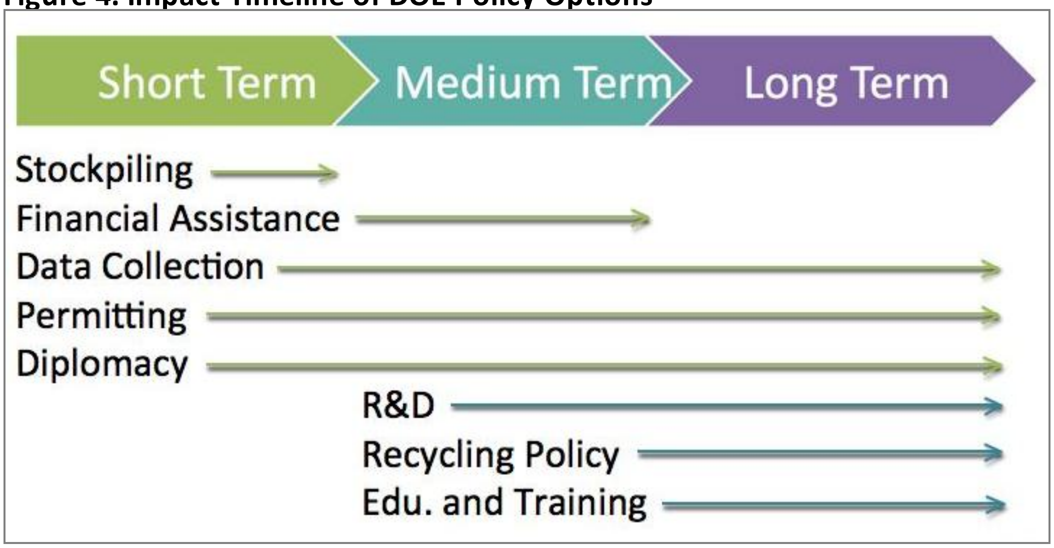
---

[93] Cees Ronda and Alok Srivastava, "Luminescence Science and Display Materials", *The Electrochemical Society Interface*, Spring 2006, www.electrochem.org/dl/interface/spr/spr06/spr06_p55-57.pdf.
[94] C.R. Ronda, T. Justel, and H. Nikol, "Rare earth phosphors: fundamentals and applications," *Journal of Alloys and Compounds*, Vol. 275-277 (1998), doi:10.1016/S0925-8388(98)00416-2.

Response to the DOE's Critical Materials Strategy

The DOE's Critical Materials Strategy proposes a set of eight broad program and policy directions to address risks, constraints and opportunities in the REE supply chain, as summarized in Table 4 in the preceding section. Although the DOE explicitly concludes that supply disruption is primarily a short-term concern, however, not all of their recommendations represent programs or policies that could help address the expected near-term supply disruption of REEs. Our analysis of the likely timeline for impact of each of the DOE's proposed policies is expressed in Figure 4 below.

Figure 4. Impact Timeline of DOE Policy Options



Source: DOE (2010) and our own analysis

Exemplifying the DOE's lack of short term focus, the Critical Minerals Strategy recommends increased funding for three policies unlikely to have significant impact for at least five years: research and development (R&D), recycling policy and education and training. While R&D investment, particularly with a focus on cleaner REE processing techniques, recycling processes, and substitutes, does represent a critical strategy for building a competitive domestic REE industry, the impact of the funding allocations to R&D will likely only be felt in the long-term. REE recycling policies will ultimately be important as well, but are not likely to represent a preferred policy until rising REE prices make improving recycling technology and developing accompanying infrastructure economical. Increased investment in education and workforce training also represents a helpful recommendation, but one that will only pan out if opportunities exist in the domestic market that will reward investment in education or training.

Other DOE recommendations can be implemented in the short run, but do not directly or efficiently address the critical issue of diversifying U.S. supply. For example, the DOE proposes that major U.S. agencies (particularly the EIA and USGS) engage in data collection in order to fill the significant data gaps that currently exist, especially with respect to annual production and consumption of individual REEs, prices, "materials intensity of different energy technologies," and substitutes. This is a valid suggestion that will aid the U.S. in long-term policymaking, but will again take time to execute and will not have any immediate impact on the prevention of short-term supply disruptions. Along the same lines, the DOE recommends that financial assistance for domestic production and processing be considered. Indeed, loan guarantees may offer a good alternative for companies struggling to raise money in the capital markets, but it is important to consider why REE companies might be failing to gain traditional financing, and whether the reasons stem from uncertainty related to the long lead-time for mine permitting. Price supports also deserve critical assessment; like the option of building REE stockpiles however, they would likely cause even more distortion of the global REE market in the short term.

To summarize, many of the DOE's recommended policies will most likely yield results in the medium to long term (as summarized in Table 4), while other recommendations appear economically inefficient or inept to address barriers that exist in the current REE market. Given the high probability of a supply disruption of REEs in the short run, policy options with expected returns in the short run deserve particular focus in any analysis. Of the DOE's recommendations, two policies merit further analysis because of their short-run consequences and ability to address the most significant barriers in the REE market: permitting for domestic production and diplomacy.

The DOE report only discusses these two policy options in brief and fails to address the strategic considerations that would affect their implementation. With respect to expediting REE mine permitting, the DOE simply recommends more coordination between state and federal agencies and industry education on best practices. And while the DOE emphasizes that diplomacy and cooperation with other countries (either those facing similar challenges or those with access to critical materials) will be key in meeting global and domestic challenges, it does not offer any detailed analysis of how different actions within the realm of diplomacy might actually be implemented. The DOE's vague analysis can largely be attributed to its limited bureaucratic jurisdiction over both policy areas.

Given the broad strokes overview offered by the DOE, this report will develop an in-depth analysis of these two policy options. In the following sections, the implications of each policy is analyzed and supported with the aid of analysis of precedent cases and comparison with other countries' strategies. Finally, we develop conclusions regarding the advantages, disadvantages and recommended strategies for policy implementation to mitigate risks of short run supply disruptions of REEs.

Evaluating Two Key DOE Recommendations

PERMITTING FOR DOMESTIC PRODUCTION

By focusing on permitting for domestic production, we specifically focus on strategies for expediting the permitting process. The DOE report recommends “improved coordination between state and federal agencies as well as among federal agencies during all stages of permitting” and “government engagement with the private sector on best practices.”[95] However, permitting is outside the jurisdiction of the DOE, and the *Critical Materials Strategy* does not provide any specific recommendations for how the permitting process should be systematically improved.

To evaluate this policy option in more depth we explored:

- Time lines for the permitting process in the U.S.
- Legislation relevant to permitting
- Current U.S. domestic permitting processes
- Case studies of China and Australia

Existing Time Line for U.S. Permitting Process

One of the key challenges to building REE supply chain infrastructure in the U.S. is the long lead-time necessary to permit an REE mine. A long permitting process not only hinders the ability to build a domestic supply in the short run, but also adds significant costs that make REE mining uncompetitive relative to countries with shorter lead times. While some of the U.S permitting process incorporates legitimate environmental and safety standards, there evidence that U.S. permitting time is significantly more prolonged than countries with similar regulations. Even if a company secures the capital to start production, it can take seven to fifteen years to bring an REE project online, “largely due to the time it takes to comply with multiple state and federal regulations.”[96] Mine permitting in itself is a time-consuming process, and while there is less available data on permitting REE mines, Table 7 provides examples of timelines from a variety of metal mines in the U.S. that have opened since 2000.

---

[95] DOE 2010
[96] Ibid.

Table 7. Time Required to Obtain Permits in a Sample of U.S. Metal Mines

Mine	Commodity	Permitting Began	Permitting Completed	Total Years	Litigation Reported
Alta Mesa, TX	Uranium	1999	2004	5	No
Ashdown, NV	Molybdenum, Gold	2004	2006	2	No
Carlota, AZ	Copper	1992	2007	15	Yes
Eagle, MI	Nickel, Copper, Cobalt, PGE[97]	2004	2010	6	Yes
East Boulder, MT	PGE	1995	1998	3	No
Kensington, AK	Gold	1988	2005	17	Yes
Phoenix, NV	Gold	1999	2004	5	No
Pogo, AK	Gold	1997	2004	7	No
Rock Creek, AK	Gold	2003	2006	3	Yes
Safford, AZ	Copper	1998	2006	8	Yes

Source: Adapted from USGS 2010

In particular, litigation by government agencies and non-governmental organizations can add long permitting and development delays to the process. Due to the radioactive nature and complex geology of many REE deposits, the permitting process is even more stringent and subject to more legal challenges than the samples above. It is interesting to note that the Pogo mine, in Alaska, was developed under an expedited permitting schedule, yet still took seven years.[98]

To put the U.S. time line in context, Table 8 shows the ranking of countries according to permitting delays, from a report published by minerals industry advisors Behre Dolbear:

Table 8. Countries with the Longest Delays in Permitting

Rank	Longest Delays	Shortest
1	U.S.	Australia
2	Papua New Guinea	Mexico
3	D.R.C.	Tanzania
4	India	Chile
5	Indonesia	Colombia
6	Kazakhstan	Ghana
7	Russia	Mongolia

Source: Behre Dolbear (2010). 2010 Ranking of Countries for Mining Investment

[97] Platinum Group Metals (PGE)
[98] USGS 2010.

The U.S. is ranked number one for permitting delays, which the report attributes to "increased regulations and pending negative revisions to the federal mining law, wetlands regulations, mountaintop mining, and carbon dioxide legislation. A few mining friendly states (Nevada, Utah, Kentucky, West Virginia, Arizona) are somewhat of an exception to this rule but are negatively impacted by federal rules that they are bound to enforce."[99] Also notable is Australia's ranking of number one – a case we will explore in more depth below.

Permitting-Relevant Legislation

While RESTART is no longer alive, in late December 2010, Representative Mike Coffman (R, Colorado), a member of the House Armed Services Committee, announced plans to introduce a rare earth bill in the 2011 session. According to Coffman's press release, the bill would include a provision to "establish a Rare Earth Policy Task Force across relevant Executive Branch agencies to expedite the development of alternative sources of supply."[100] In addition, Coffman has stated that the bill will decrease the amount of time spent on environmental impact studies, while asserting that environmental regulations should not be relaxed.[101] These provisions could have a measurable impact on permitting times for two key reasons.

First, the environmental review is a critical component of the permitting process, as there are a number of environmental impacts associated with REE mining and production:

- **General mining impacts** – The first stages of REE production, which involve extracting the ore containing minerals from the ground, are completed using standard mining techniques. While these mining processes have a number of associated environmental impacts, they are not specific to REEs.

- **Discharge of pollutants used in refining process** – Once the minerals are extracted from the ore, the REEs must be separated from the source mineral, often using strongly acidic or alkaline chemical solvents that can be discharged into the local environment via untreated wastewater. The actual solvents and processes used will vary for each REE, but highly toxic substances such as oxalic acid and ammonium bicarbonate are used in this process, both of which have been found in the Yellow River in China.[102]

[99] Behre Dolbear 2010
[100] "Coffman to Introduce Rare Earth Bill in Press
http://coffman.house.gov/index.php?option=com_content&task=view&id=394&Itemid=10
[101] Williams, Emile (January 12, 2011). "Coffman Bill Would Spur Domestic Mining of Rare Earth Metals." Columbine Courier. Available online: http://www.columbinecourier.com/content/coffman-bill-would-spur-domestic-mining-rare-earth-metals
[102] Hurst 2009

- **Radioactive tailings** – Since REEs often are found alongside thorium, a radioactive element, the mining process often produces tailings (the waste material that remains after the REEs have been extracted from the source mineral) that include radioactive material. Proper disposal of radioactive tailings is critical to preventing contamination risks and health risks to mine workers. The amount of tailings produced is not trivial – as many as 2000 tons of tailings can result from the production of one ton of REE.[103]

If the environmental review process can be expedited without compromising existing environmental standards, this change could reduce overall permitting times. However, further details have not been offered on how this action might be achieved.

Second, the proposed task force would be well-placed to review improvements to the current permitting process in the context of its mandate to expedite the development of alternative supply sources.

The Domestic Permitting Process

According to the USGS, permitting will typically require "an approved plan of operations, a positive environmental impact study, and some kind of final permission by a government agency."[104] Table 9 lists a number of statutes and regulations that may impact the mine permitting process:[105]

[103] Hurst 2009
[104] USGS 2010
[105] EPA (1995). *EPA Office of Compliance Sector Notebook Project: Profile of the Metal Mining Industry*. Washington, D.C.: U.S. Environmental Protection Agency.

Table 9. U.S. Mining Regulations

Regulation or Statute	Summary	Agency
Resource Conservation and Recovery Act (RCRA) of 1976	Facilities that treat, store or dispose of hazardous waste generation must apply for a permit from either the EPA or state agency. In October 1980, RCRA was amended to exclude "solid waste from the extraction, beneficiation[106], and processing of ores or minerals" from being regulated as hazardous materials.[107] However, mining operations can be held responsible for their hazardous waste via the Comprehensive Response Compensation and Liability Act (CERCLA).	EPA; State agencies given authority by EPA
Federal Water Pollution Control Act or the "Clean Water Act" (CWA)	The CWA regulates indirect and direct discharges. Facilities that plan to discharge into U.S. waters must obtain a permit, with discharge limits specific to industry and technology. Facilities must also follow federal and local water quality criteria and standards. The CWA also regulates storm water discharges and pretreatment standards.	EPA
Safe Drinking Water Act (SDWA)	EPA must establish regulations to ensure quality drinking water supply. If an operation includes an injection mine, they must obtain an Underground Injection Control permit. Primarily state enforced.	EPA; State agencies
Clean Air Act (CAA)	The CAA mandates that the EPA must establish, implement, maintain, and enforce ambient air quality standards to limit criteria pollutants.[108] "Major sources" regulated under the CAA must obtain a permit from a state program.	EPA; State agencies
General Mining Law of 1872	Allows individuals and corporations to prospect on public lands and stake a claim on any deposits. The Bureau of Land Management (BLM) oversees the regulation of mining claims under the Federal Land Policy and Management Act of 1976. The Forest Service (FS) also regulates mining activities on Forest Service land.	BLM; FS
National Environmental Policy Act (NEPA)	Federal agencies are required to prepare Environmental Impact Statement (EIS) assessing the adverse environmental effects of a project, and provide reasonable alternatives. BLM or FS approval may require an EIS, and provides the basis for a permitting decision.	EPA; BLM; FS
Endangered Species Act (ESA)	The ESA exists to protect threatened or endangered species and their ecosystems. A BLM review of mining operations must consult with the U.S. Fish and Wildlife Service (USFWS), and an EIS must be prepares if USFWS decides the operation impacts Federal or State-listed threatened and endangered species.	BLM; USFWS

Source: EPA Profile of the Metal Mining Industry (1995)

---

[106] Beneficiation operations include "crushing, grinding, washing, dissolution, crystallization, filtration, sorting, sizing, drying, sintering, pelletizing, briquetting, calcining, roasting in preparation for leaching (to produce a final or intermediate product that does not undergo further beneficiation or processing), gravity concentration, magnetic separation, electrostatic separation, flotation, ion exchange, solvent extraction, electrowinning, precipitation, amalgamation, and heap, dump, vat, tank, and in situ leaching." (EPA website)

[107] EPA (2010). *Bevill Amendment Questions*. U.S. Environmental Protection Agency. Available online: http://www.epa.gov/oecaerth/assistance/sectors/minerals/processing/bevillquestions.html

[108] Criteria pollutants include carbon monoxide, lead, nitrogen dioxide, particulate matter, ozone, and sulfur dioxide.

As demonstrated in Table 9, there is a high level of coordination necessary between a number of government agencies – the EPA, BLM, USFWS, FS, USGS to name a few – that increases the bureaucratic requisites needed to launch a REE mining operation. In addition to Federal statutes and regulations, mining operations are subject to a number of state-specific laws. According to the EPA:

> "States that require bonding and/or permitting include Alaska, Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, South Dakota, Utah, Washington, and Wyoming. To regulate mining activity in the State of Colorado, for example, the State requires mining operations to obtain: 1) a performance bond, 2) a reclamation bond, and 3) a permit. The performance bond outlines what the mining operation intends to do on the land, and is simply a promise from the mining operation that it will reclaim the land. This bond gives Colorado the authority to pursue reclamation costs from mining operations that fail to properly reclaim the land. The reclamation bond, also known as a financial warranty, equals the cost the State would incur if it were to hire someone to reclaim the site should the mining operation fail to do so. Although performance bonds are updated periodically, the bonds have not always been adequate to cover closure costs."[109]

Therefore, expediting the permitting process will not only require Federal coordination, but may rely heavily on state-specific mandates. Alaska, for instance, recently passed a House Resolution expressing support for expediting the permitting and production process for Ucore Uranium Inc.'s Bokan Mountain project in southeast Alaska.[110] It is unclear how this support will translate into streamlining the permitting process, however.

The Experience of China's and Australia's Mining Sectors

Mining regulations and procedures differ widely across countries, often as a function of the governance structure, property rights, and the overall strength of and ability to implement environmental regulations. To the extent that the U.S. permitting process is thought to be a potential barrier to near-term development of increased domestic REE production, it is worth considering the experiences of other countries with significant mining sectors to assess whether there are key differences at the root of any perceived efficiencies in the mining permit process. In other words, is the U.S. simply at a relative disadvantage because of other countries' less rigid environmental standards? Or, is it possible to maintain high environmental standards yet find other means of expediting the process?

---

[109] EPA 2010

[110] Rare Metal Blog (April 22, 2010). "State of Alaska Announces Support for Expedited Permitting and Production of Ucore's Bokan Heavy Rare Earth Project."

China

Lax environmental regulations are often cited as a source of China's competitive advantage in REE mining and production. However, China's REE mining industry is currently undergoing a major restructuring, in large part to improve oversight of an industry that has grown to such size and geographic distribution that illegal mining, smuggling, and poor environmental management remain serious issues. The Chinese Ministry for Industry and Information Technology (MIIT) recently put forth draft strategic plans for the REE industry (known as the 2009-2015 Plans for Developing the Rare Earth Industry). As part of these plans, no new REE mining permits will be issued through 2011, and many smaller and illegal mines are being merged to consolidate the industry.[111]

There are a number of domestic environmental regulations in place in China, but the regulations that specifically pertain to mining activities are "highly fragmented".[112] In addition, future revisions are planned to augment existing environmental standards that pertain to the REE industry. The main challenge China faces is not the creation of, but the implementation and enforcement of these regulations. The administrative structure in China is often cited as a reason for the poor record of compliance with existing regulations. In addition to the laws themselves being fragmented, the responsibilities for the mining industry and environmental protection are similarly split among many levels of the government structure, often resulting in duplication of duties among agencies.

In the area of environmental protection, jurisdiction is split between the Ministry of Land and Resources (MLR)[113], the Environment and Resources Protection Commission (ERPC), the State Environmental Protection Agency (SEPA), and the provincial, municipal, and county level versions of each. The problem of enforcement arises from the fact that governments at the local level "are assigned disproportionate authority and responsibility for environmental regulation, management, and protection," and local governments are often narrowly focused on economic growth, with little regard for the potential environmental consequences of the associated activities.[114]

In summary, the environmental issues surrounding the mining industry in China seem not to be the result of a lack of environmental regulations, but rather the product of an unwieldy administrative structure, heavily weighted at the local level, that results in poor enforcement of these regulations. China appears to be taking steps to address these issues, and while poor enforcement will likely continue, Chinese REE producers will see higher costs related to regulation in the long term. More importantly, REE mining operations have devastated the

---

111 DOE 2010

112 Karapinar, Baris. "Export restrictions on natural resources: policy options and opportunities for Africa." World Trade Institute.

113 Note that the MLR also has responsibility for issuing mining permits

114 Asian Development Bank (2007). *Country Environmental Analysis for the People's Republic of China*

environment in many of China's mining regions.[115] While the REE industry enjoys lower costs in the short run, mining operators are not taking into account externalities that drastically increase social costs. Therefore, this is not a model the U.S. should adopt, and will likely cease to propel the Chinese REE mining industry in the long run.

Australia

Australia has a relatively short turnaround time for the mine permitting process, making it an especially interesting case to review against the current U.S. framework. Like the U.S., Australia has a federal system of government, with powers shared between the Commonwealth government and those of the individual States and Territories. Each of the six states (and the Northern Territory) has a Department of Mines, Minerals, and Energy and its own specific laws that guide the permitting process and mining activity in general—but in substance and in practice these laws are quite similar across the country.[116] Laws pertaining to environmental regulations and indigenous land rights are set at the federal level, though the administration of environmental regulations in the mining industry are typically handled at the state level.

Locations of significant deposits often coincide with areas where native title applies (meaning local indigenous communities have rights to the land), and the Native Title Act is credited for truly empowering indigenous groups in Australia to be closely involved in the mining license process when their lands are at stake.[117] In fact, a document published by the Department of Resources, Energy, and Tourism outlines the steps in the approval process for mineral exploration. It specifically notes that in the Native Title Act 1993 process, "the use of standard Heritage Agreements with Native Title Representative Bodies is widespread in [Western Australia] and minimizes objections to license applications".[118] This clear process for handling a common conflict that arises in the permitting process may contribute to the relatively short timeframe in which permits can be issued – some sources say they can be granted in as little as six months.[119] In addition to strong indigenous rights, companies representing 90% of Australia's mineral production have undertaken a number of voluntary measures to demonstrate a commitment to improving the environmental record of the industry, including the adoption of standards whose oversight includes representation from the environmental community and indigenous populations.[120]

---

[115] Hurst 2009
[116] Department of Resources, Energy and Tourism (DRET) (2010), *Minerals and Petroleum Exploration and Development Guide for Investors*, Australian Government.
[117] David Brereton (2002), *The Role of Self-Regulation in Improving Corporate Social Performance: The Case of the Mining Industry*
[118] DRET 2010
[119] Kym Livesley, "Australia: Mining: The Regulation of Exploration & Extraction: Getting the Deal Through", Mondaq, http://www.mondaq.com/australia/article.asp?articleid=108106
[120] Brereton 2002

Several important insights can be drawn from the Australia case study. Most significantly, Australia has structured an efficient, expedited permitting process while maintaining similar environmental standards in the U.S. Two key features of the mining regulations and environmental standards in Australia merit increased attention. First, the strong federal level legislation protecting native title directly addresses an otherwise significant source of conflict likely to face the mining industry that would otherwise prolong the permitting process. And second, the direct engagement of the environmental community by the mining industry creates a forum for continued dialog with interest groups that might otherwise pursue litigation to exercise control over the mining industry's activities.

There are certainly differences between Australia and the U.S. that may account for some of these differences. For example, much of the land area in Australia is very sparsely populated, with less than one person per square kilometer.[121] With such low population density, there will naturally be fewer impacted communities, which enables targeted legislation to address these conflicts. However, it is clear that litigation can significantly delay the permitting process, and both the government and mining industry in Australia have taken concrete steps to reduce potential sources of such litigation.

STRATEGIC COOPERATION AS A REE STRATEGY

The DOE's *Critical Materials Strategy* offers a broad set of diplomatic recommendations to mitigate REE supply risks. Increasing cooperation and diplomatic overtures are cited as tools for exchanging useful information, helping improve transparency in markets for critical materials, optimizing resources for research and accelerating research and development.[122] However, suggestions for operationalizing these goals are less specific, and consist primarily of the following:

[121] Australian Bureau of Statistics, http://www.abs.gov.au
[122] US DOE 2010, p. 108.

> "Working closely with the State Department and other agencies, DOE will **engage other countries through dialogues and collaborative institutions**…Building on ongoing discussions with partners such as the European Union and Japan, DOE will engage significant producers and consumers of critical materials. DOE will **participate in multilateral fora**, such as the International Energy Agency, to advance our goals with respect to critical materials as well. On issues of trade promotion and compliance, DOE will **support the U.S. Trade Representative** in its efforts to uphold the rules-based global trading system and ensure open and fair global markets for producers and consumers of critical materials… Building on its existing energy diplomacy, DOE intends to **work with China** and other countries on these issues in the years ahead."[123]

Many of these suggestions are ambiguously defined because of the DOE's limited jurisdiction over issues of foreign policy. It is also somewhat unclear what party within the U.S. government would be required to undertake these actions, or how successful each strategy might be. In order to clarify the extent to which these or other diplomatic solutions may be advisable for the U.S., it is critical to do the following: First, compare other countries' policies of strategic cooperation, accounting for the variation stemming from countries' respective roles in the REE supply chain. And, second, to examine past precedents that may provide policy makers with insight on how to implement effective diplomatic strategies, such as litigation through the WTO.

REE strategies within the diplomatic arena: a cross-country comparison

The possibility of supply disruptions of REEs has increasingly come to the attention of business and political leaders, and many governments have begun implementing strategies in response. The DOE's diplomacy-related aspects of this discussion, as well as a summary of recent developments in the diplomatic arena, are presented in Table 10.

[123] DOE 2010, pp. 108-109, emphasis added.

Table 10. REE Policies of Selected Countries

	Goal	Business Policy	Cooperation/Diplomacy	Materials of Interest
Australia	Maintain investment in the mining industry while fairly taxing the depletion of national resources	• Low tax on the value of extracted resources • High tax on mine profits • Tax rebates for mineral exploration • Fast turnaround for land permit applications	• Sign delivery contracts with EU REE consumers (firms) • Incorporate REEs into free trade talks with Japan (government)	Ta, No, V, Li and REEs
China	Maintain a stable supply of raw materials for domestic use through industry consolidation, mitigating overproduction and reducing illegal trade	• Taxes and quotas on REE exports • Prohibition of foreign companies in REE mining • Industry consolidation • Unified pricing mechanisms* • Production quotas • Moratorium on new mining permits until mid-2011	• Deny WTO violation and continue to pursue industrial policy in support cleantech industry (government)	Sb, Sn, W, Fe, Hg, Al, Zn, V, Mo, REEs
European Union	Limit the impact of potential material supply shortages on the European economy	• Mineral trade policy for open international markets* • Information gathering* • Land permit streamlining* • Increased recycling regulations*	• Reach internal consensus on stance to take vis-à-vis China (government) • Cooperate with U.S. and Japan • Secure delivery contracts with REE producers outside Europe (firms)	Sb, Be, Co, Ga, Ge, In, Mg, Nb, REEs, Ta, W, Fluorspar and Graphite
Japan	Secure a stable supply of raw materials for Japanese industries	• Funding for international mineral exploration • Loan guarantees for high-risk mineral projects • Stockpiling • Information gathering	•Develop trade agreements with REE-supplier countries (i.e. Vietnam, etc.) • Establish contracts with mining companies	Ni, Mn, Co, W, Mo, REEs, V**
South Korea	Ensure a reliable supply of materials critical to Korean mainstay industries	• Financial support for Korean firms at overseas mines • Free Trade Agreements and MOUs with resource-rich nations • Stockpiling	• Reduce domestic demand •Invest in overseas projects •Secure supply access through contracts	As, Ti, Co, In, Mo, Mn, Ta, Ga, V, W, Li and REEs

*Source: U.S. DOE (2010) and various others (see below); *proposed policy*

In light of the significant variation between other countries' strategies, a cross-national comparison is helpful in determining what aspects of these policies may be useful for the U.S. The following section will describe the policies that both governments and industries are pursuing within the realm of strategic cooperation. Following an analysis of each country's REE strategies, the section will conclude with a discussion of how other countries' policies may provide the U.S. useful insight on how to achieve a diplomatic solution to REE supply shortages.

European Union

Since 2008, the European Commission (EC) has been developing and refining a new "integrated strategy" for a list of 14 critical raw materials, including REEs.[124] The goal of the strategy is to ensure stable supply of REEs to Europe, since the EC is highly concerned that any supply disruption could "hamper the development of a green market economy."[125] Europe has set high standards for green technology adoption (both with regards to vehicles and renewable energy production) that would be impossible to meet if a significant bottleneck formed in the production of technologies that include REE components. Additionally, REEs are indispensable as inputs to the high-end industries for which the EU has a competitive advantage; ensuring continued availability of these inputs is understood to be critical to the future of these industries.

The EU has nevertheless been criticized by various parties for its slow process of reaching an agreement on appropriate methods of rare earth cooperation. Commenting on the new strategy, European Member of Parliament Reinhard Bütikofer accused the Commission of "failing to develop a convincing strategy for fair cooperation with countries that are rich in raw materials. A strategy for cooperation with China…is also lacking. While the rhetoric on raw materials diplomacy is less confrontational, the Commission has not set out a coherent political vision."[126] These criticisms aside, one of the three main pillars of the EC's strategy has been to pursue so-called "raw materials diplomacy." This raw materials diplomacy is intended to:

[124] Enterprise and Industry Directorate General, "Critical Raw Materials for the EU," European Commission, 30 July 2010, http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/report-b_en.pdf
[125] IFRI. http://ifri.org/index.php?page=detail-contribution&id=6024&id_provenance=79&provenance_context_id=
[126] European Greens, "EU raw minerals strategy – Commission proposal undermined by lack of focus and poorly-define measures," EurActiv, 2 February 2011, http://pr.euractiv.com/press-release/eu-raw-materials-strategy-commission-proposal-undermined-lack-focus-and-poorly-defined

- **Maintain current EU policy choices** in the negotiation of bilateral and regional trade agreements;

- Consider the merits of **pursuing dispute settlement initiatives at WTO level** so as to include in such initiatives more raw materials important for the EU industry. Such actions may give rise to important case law so long as existing GATT rules lack clarity and are limited in scope;

- Engage without reservation in **consultations with third countries** whose policies are causing distortions on international raw materials markets in order to discourage certain policy measures and to request adherence with market forces;

- Foster an effective **exchange-of-views** on certain policies made within the institutional framework of EU economic cooperation agreements (e.g. with China on the latter country's NFM recycling plan to year 2015);

- Continue to raise **awareness on the economic impact of export restrictions** on developing and developed countries in various multilateral fora, such as WTO or the OECD;

- Consider shaping a new EU-wide policy on **foreign investment agreements** in such a manner as to better protect EU investments in raw materials abroad and ensure a level playing-field with other foreign investors who benefit from the backing of State funds;

- Continue to increase **coherence of EU policy** with respect to raw materials supply, for example in the assessment of injurious dumping and subsidies.[127]

These policy directions are significantly more specific than those offered by the DOE, but it is nevertheless important to review recent developments to understand how each of these policies is being implemented.

There has been some cooperation between the EU, Japan and the U.S. with respect to developing REE recycling technologies. The European Commission has reported, for instance, that it intends to follow Japan's lead in paving the way for a new law to recycle REEs in the future.[128] EU and U.S. officials met in late December 2010 to discuss cooperation on rare earths, following a roundtable between Japan and the U.S. on the same topic in November. In light of

[127] Enterprise and Industry Directorate General, "Critical Raw Materials for the EU," European Commission, 30 July 2010, http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/report-b_en.pdf

[128] Roman Baudzus, "EU is Paving the Way for New Law to Recycle Rare Earth Materials," GoldMoney, 31 January 2011, http://www.goldmoney.com/gold-research/eu-is-paving-the-way-for-new-law-to-recycle-rare-earth-minerals.html

these meetings, the Japanese Minister of Industry has suggested that countries like Japan, the U.S. and the EU build a "triangular cooperation" network, since "all of the [rare earth-] consuming countries' problems need to be solved through cooperation." He said that the focus should be on better understanding the supply chain, strengthening efforts to diversify supply sources, increasing recycling, and developing both substitute materials and new technologies that reduce the amount of rare earths used, and cooperating to encourage China to "establish quotas sufficient to prevent adverse effects on the world industrial supply chain."[129]

Additionally, sources suggest that there is a growing opportunity for cooperation between the U.S. Congress and members of the European Parliament (MPs). For example, Congressman Bart Gordon, chairman of the Committee on Science & Technology of the House of Representatives, has proposed holding parallel hearings in Brussels and Washington, which could lead to information sharing on mineral supplies and a united EU-US approach to the issue at the World Trade Organization. He argues that American and European researchers could also collaborate more closely to find substitute minerals, improve recycling and ensure natural resources are used efficiently. Finally, there have been suggestions that collaboration on rare earths could be a template for further cooperation in areas such as intellectual property, cyber security, clean water, energy security and carbon capture and storage (CCS).[130]

The EU has also not ruled out applying retaliatory trade measures in tandem with its strategic allies. As China tightens export restrictions and implements tougher environmental standards for mining (which is also expected to raise export prices), some members of the European Parliament and business community have accused China of harboring a protectionist agenda and proposing that the EU respond by blocking Beijing from other markets.[131] However, several commissioners in the 27-strong European Union executive cabinet (including trade commissioner Karel De Gucht) as well as some member states (like Great Britain) are opposed to retaliation. A first draft of a strategic document on the issue included the threat of retaliation, but was dropped from the revised version by late January 2011.

As the European Commission delayed plans to release its critical materials strategy, some European consumers of REEs began securing supply guarantees through non-governmental routes. In early November, a prominent European rare earths consumer signed a new long-term supply agreement with Australian rare-earths producer Lynas, ensuring access to 11,000 tons of REE per year from Lynas Advanced Materials Plant in Malaysia.[132]

---

[129] "EU, US, Japan should cooperate on rare earth supply," EurActiv, 4 February 2011, http://www.euractiv.com/en/sustainability/eu-us-japan-cooperate-rare-earth-supply-news-501917

[130] "EU-US to collaborate on 'rare earths'", EurActiv, 14 July 2010, http://www.euractiv.com/en/sustainability/eu-us-collaborate-rare-earths-news-496286

[131] "Europe wrong-footed on China rare earths response," EUbusiness Ltd., 28 Jan 2011, http://www.eubusiness.com/news-eu/china-economy.8bu

[132] Esmarie Swanepoel, "Lynas inks rare earths supply deal with European consumer," Mining Weekly, 9 November 2010, http://www.miningweekly.com/article/lynas-inks-rare-earths-supply-deal-with-european-customer-2010-

Interestingly, European industry groups (like the European Association of Automotive Suppliers, which represents about 3,000 suppliers) and individual companies that consume REE, namely auto-parts makers like Continental AG and Bosch, have pressured the European Commission to pursue alternative options for the supply of REEs. Analysts predict that about 2.2 percent of an estimated 14.5 million cars made in the European Union in 2013 will be electric cars, and the figure may rise to 6 percent of 17 million cars, or 1 million vehicles, by 2020.[133] This volume of production would require significant REE inputs. The head of the German auto federation VDA, Matthias Wissmann, has argued that "supply difficulties or sharp price increases for these metals affect the competitive position of our companies," and "that is why we need a strong commitment by political leaders in charge of the question to be assured of the raw material's availability."[134] Industry groups are lobbying the European Commission to not only initiate trade talks with China, but also explore ways to secure delivery contracts from other export nations such as Australia.[135]

In sum, then, the European Union has belatedly issued a raw materials strategy that consists of various strategies dependent upon cooperation and diplomacy. As diplomatic efforts have been slow to develop, private sector actors have stepped forward to lobby the European Commission and multilateral organizations (like the G-20) to take a harder stance on the issue. At the same time, European companies that consume REE inputs have sought to secure cross-border delivery contracts with REE producers outside Europe, rather than wait for a belated diplomatic solution.

Japan

Japan lacks domestic rare earth resources, but has become the largest producer of Neodymium-Iron-Boron and Samarium-Cobalt magnets outside of China, and has a strong foothold in the production of other rare earth applications further upstream. After China, which consumes about 65% of global REE inputs, Japan has the greatest demand for REEs of any country in the world.[136] Given its high demand for REEs today, which will be compounded by

---

11-09

[133] Ola Kinnander and Cornelius Rahn, "Continental AG, Bosch Push EU to Secure Access to Rare Earths," Bloomberg, 31 October 2010, http://www.bloomberg.com/news/2010-10-31/continental-ag-bosch-push-eu-to-secure-access-to-rare-earths.html

[134] Dalai Fazio, "Monopoly markets, how the rare earth element threat is a microcosm," Diplomacy and Power Politics, 25 October 2010, http://www.diplomacyandpower.com/?cat=94

[135] Ola Kinnander and Cornelius Rahn, "Continental AG, Bosch Push EU to Secure Access to Rare Earths," Bloomberg, 31 October 2010, http://www.bloomberg.com/news/2010-10-31/continental-ag-bosch-push-eu-to-secure-access-to-rare-earths.html

[136] Mure Dickie, et al., "Japan cries foul over rare earths," Financial Times, 24 October 2010, http://www.ft.com/cms/s/0/6ad460d4-df93-11df-bed9-00144feabdc0.html#axzz1DsjnOeBW

Japan's plans to forge ahead in new cleantech markets (i.e. electric cars),[137] the Japanese government and Japanese firms have each been aggressively seeking partnerships with global REE mining organizations in the form of off-take agreements, joint ventures and acquisitions. Each of these initiatives aims to provide Japan and companies like Toyota Motor Corp, Mitsui, Mitsubishi and others with access to key supplies if China should continue to slash exports.[138] Even so, government sources in Tokyo describe a "panic mentality" among some large industrial groups, given that securing a REE supply is so critical to both military and "green" technologies.[139]

Japanese firms and government officials alike have been spearheading international cooperation on REEs through developing agreements with nations and mining companies that promise a supply of REEs outside of China. Toyota Motor Corporation established a rare earth task force to monitor its supply chain and, through its trading company Toyota Tsusho, invested in a rare earth mining joint venture in Vietnam in 2008 to export rare earths to Japan.[140]

In November 2010, after shipments from China to Japan had stalled amid a spat over disputed islands in the East China Sea, Australia promised to be a future long-term supplier of rare earths to Japan. Australian Foreign Minister Kevin Rudd reportedly used a meeting with Japanese Foreign Minister Seiji Maehara to offer Japan a reliable supply of Australian REEs as part of a "fresh start" on stalled negotiations for a free trade deal and a less protectionist Japanese trade policy.[141] In response, Lynas, an Australian minerals explorer and developer, and Japanese trading house Sojitz Corp (Japan's largest importer of REEs) agreed to off-take, distribution and financing arrangements as part of a strategic alliance agreement signed between the two companies; this "strategic alliance" secured 9,000 metric tons of rare earths a year over the next 10 years for Sojitz.[142] In exchange, Sojitz will be Lynas' exclusive distributor into Japan, with about 70 per cent of the Australian company's 22,000 metric ton capacity now allocated. Lynas Corporation Ltd will also secure up to $250 million in funding with the help of Sojitz to expand production and ensure additional supplies of rare earth products for the Japanese market.[143]

[137] Leo Lewis, "Greenland challenge to Chinese over rare earth metals," The Times, 5 October 2009, http://business.timesonline.co.uk/tol/business/industry_sectors/natural_resources/article6860901.ece
[138] IFRI 2010.
[139] Leo Lewis, "Greenland challenge to Chinese over rare earth metals," The Times, 5 October 2009, http://business.timesonline.co.uk/tol/business/industry_sectors/natural_resources/article6860901.ece
[140] AP, "Nations Wary of Dependence on China's Rare Earths." *Associated Press*, 4 October 2010.
[141] Rod McGuirk. "Japan, Australia to restart free trade talks." Associated Press. 23 Nov 2010. http://www.bilaterals.org/spip.php?article18546
[142] James Fontanella-Khan and Michiyo Nakamoto, "Toyota Tshusho in deal for India rare earths," Financial Times, 8 December 2010, http://www.ft.com/cms/s/0/fde2d544-02f8-11e0-bb1e-00144feabdc0.html#ixzz1DafQB4qJ
[143] "Lynas signs rare earths supply deal," AAP, with Reuters, 24 November 2010, http://www.raremetalblog.com/2010/11/lynas-signs-rare-earths-supply-deal.html

In December 2010, Toyota Tsusho reached an agreement with Indian Rare Earths, a state-owned group, to build a plant in the eastern state of Orissa that will secure Japan about 3,000 to 4,000 metric tons a year of REEs by 2012. This most recent deal follows an agreement signed in October between New Delhi and Tokyo to co-operate on the development and reuse of rare earth materials within India. Japan's Prime Minister Naoto Kan and his Indian counterpart, Manmohan Singh, decided to explore the possibility of bilateral cooperation in development, re-cycling, substitutes and re-use of rare earths.[144] Policymakers in New Delhi reportedly believe that the souring trade relations between Japan and China represent an opportunity for India to develop and boost its production of rare earths. India had stopped producing rare earths in 2004 due to lack of market competitiveness, but improved in-house technology (and synergies with existing mining operations) and has enabled India to be more competitive. India and Japan are also trying to agree a civilian nuclear deal that will allow the use of Japanese technology and investment in developing India's nuclear power sector.[145]

Japan's efforts have not stopped there. In an attempt to further diversify Japan's supply of REEs, Japanese Prime Minister Naoto Kan and his Vietnamese counterpart, Nguyen Tan Dung, have agreed that Vietnam will help supply Japan with REE. Northern parts of Vietnam are believed to have untapped reserves of certain rare earth elements, such as cerium and dysprosium. For the envisaged joint rare earth venture, Japan plans to provide its exploration and smelting technologies to Vietnam.[146] Likewise, Japanese trading house Sumitomo Corporation established a joint venture in Kazakhstan with the goal of producing 3,000 tons of rare earths per year.[147] Japanese Prime Minister Naoto Kan and Mongolia's President Tsakhia Elbegdorj are also launching trade talks early this year to discuss "ways to cooperate in development of mineral resources in Mongolia, including rare earth minerals" crucial for Japan's manufacturing of high-tech products.[148]

Japan's approach to REE diplomacy to date has been fairly aggressive, an unsurprising fact given Japan's large consumptions of REEs. In a bid to diversify its REE supply, the Japanese government has reached out to various governments to reach cooperative agreements with respect to REE mining and trade. As the Japanese government has begun stockpiling REEs and stepping up its diplomatic efforts, Japanese companies have meanwhile been aggressively pursuing contracts with REE suppliers at an unmatched pace.

---

144 Madelene Pearson, "India, Japan Agree to Consider Cooperation on Rare Earths," Bloomberg, 25 October 2010, http://www.businessweek.com/news/2010-10-25/india-japan-agree-to-consider-cooperation-on-rare-earths.html

145 Krittivas Mukherjee, "India aims for 2011 rare earth exports: official," Reuters, 27 October 2010, http://www.reuters.com/article/2010/10/27/us-india-rareearths-interview-idUSTRE69Q1V320101027

146 "Japan, Vietnam to jointly develop rare earths," Jiji Press, 22 Oct 2010, http://www.mcot.net/cfcustom/cache_page/118976.html

147 "Japan Looks Past China for Metals," *Asahi Shimbun*, October 1 2010.

148 Agence France-Presse. "Japan, Mongolia to launch talks on free trade, rare earths." 12 November 2010. http://www.bilaterals.org/spip.php?article18469

South Korea

Although REE demand in South Korea represents a lower proportion of global demand than that of China, Japan, the EU or the U.S., the Korean clean tech sector is sufficiently reliant on REEs to provoke a domestic fear of supply disruption. South Korea's official strategy for reducing its dependency on Chinese supplies of rare earths has been to cut overall imports of REEs almost two-thirds since 2005. Imports have fallen as products that use the minerals, including cathode ray tube televisions, have grown outmoded and because companies switched to substitutes such as steel and aluminum. South Korea, which is reliant on imports for almost all its energy and mineral needs (like Japan), plans to increase rare-earth stockpiles 19- fold to 1,200 tons in 2016. Additionally, South Korea is actively seeking to cooperate with countries besides China, especially Japan and the U.S., to explore the possibility of jointly developing mines."[149]

South Korean companies are also cooperating with other international firms to secure REE supply for the country's clean tech industry. In a dramatic increase from last year's $2.2 billion, South Korean companies have earmarked $7 billion for overseas resources development projects this year. According to a report by the South Korean Ministry of Knowledge Economy, the massive increase in development funding is intended to help insulate South Korea from sudden international price hikes. State-run corporations including Korea Resources Corp. and Korea Electric Power Corp. plan to spend around $2.58 billion to acquire rare earth metals and other foreign resources. The spending is a result of price fluctuations in the last three years that have begun to negatively affect business operations. Meanwhile, Green Technology Solutions, Inc (GTSO) announced that it will invest in the development of mining claims and operations in the country of Mongolia, in a bid to help corporate and government interests in Korea access REE. GTSO has entered into a joint venture agreement with Rare Earth Exporters of Mongolia (REE) in order to procure rare-earth mining claims and operations in Mongolia. To avoid shipping through China, the joint venture plans to transport Mongolian mining products via railway to the port Vladivostok, Russia. Destinations for these mining products are set to include the U.S., Japan and South Korea.[150]

To summarize, South Korea's approach represents a variation on the diplomatic strategies of both the EU and Japan with respect to REEs. Like the EU, which is turning its eyes to resource development opportunities in Africa, South Korea is investing in overseas resources development projects in a bid to increase long-run REE supply opportunities outside of China. At the same time, South Korean firms are securing contracts for supply of REEs in the short run. This method of securing corporate-level negotiations and agreements, which is often pursued

---

[149] Bomi Lim, "South Korea to Cut Rare Earth Dependency on China as Imports Drop," Bloomberg, 21 October 2010, http://www.bloomberg.com/news/2010-10-22/south-korea-to-cut-dependency-on-china-rare-earth-supplies-as-imports-drop.html

[150] "GTSO Eyes Billions in S. Korean Rare Earth Earmarks," Business Wire, 9 February 2011, http://finance.yahoo.com/news/GTSO-Eyes-Billions-in-S-bw-2933960259.html?x=0&.v=1

in parallel and with the assistance of governmental agreements, seems to represent a very promising path forward for countries whose important industries depend on REE inputs.

As this case-dependent analysis has illustrated, countries with a stake in the global REE supply chain are embarking upon a policy of strategic cooperation to hedge against the risk of supply disruptions. In the next section, one particular cooperative approach—that of bringing a complaint against China to the WTO—will be discussed in more detail.

REE Strategies through International Organizations: The WTO

Part of the U.S. diplomatic strategy towards China's export restrictions of rare earth elements could involve WTO litigation. Until now, the U.S. has not filed a formal WTO dispute settlement claim against China for its export policies on REEs. Nonetheless, if the U.S. does in fact decide to progress through the WTO, several articles in the GATT and WTO must be closely examined to understand the outcome of a possible dispute settlement process.

The first relevant GATT article related to Chinese export restrictions on strategic materials is Article XI. Accordingly, GATT Article XI, paragraph 2(b) states that export prohibitions or restrictions may be temporarily applied "to prevent or relieve critical shortages of foodstuffs or other products essential to the exporting."[151] Rare earth elements obviously do not fall into the category of "critical shortages of foodstuffs," but could be conceived as "other products." The GATT Analytical Index relegates a considerable of flexibility to the term "other products," citing that the importance of such products must be judged in relation to the particular country.[152]

One of the most prominent cases involving export restrictions and the application of GATT Article XI involved Canada's export of unprocessed herring and salmon. Canada claimed that its quotas prohibiting the export of herring and salmon were permitted under Article XI: 2(b), as the restriction of fish exports was essential for maintaining quality standards. Nevertheless, as the GATT panel continued its investigation, it found that Canada also prohibited the export of certain unprocessed salmon and herring even if they were failing to meet quality standards—thus rendering the application of Article XI:2(b) unnecessary.[153]

Based on past precedent, it is unlikely that the WTO would rule in favor of China's restriction of rare earth elements based on GATT Article XI:2(b), primarily because Chinese rare earth elements would not be considered in shortage to its economy. Rather, China has an abundance of rare earth elements that currently exceed its domestic demands.

[151] GATT Analytical Index. Article XI. p. 326
[152] Ibid. p. 327
[153] Ibid, 327.

The second, and likely more important, GATT Article that could affect a WTO dispute settlement against China is Article XX, specifically, Article XX:(g). GATT Article XX(g) states that a restriction on international trade may be permitted if it relates to the "conservation of exhaustible resources if such measures are made effective in conjunction with restrictions on domestic production or consumption."[154] Article XX:(b) of the GATT also makes reference to environmental regulations, stating that export restrictions may "be necessary to protect, human, animal or plant life or health" and that the responding party must demonstrate a legitimate threat to these factors.[155]

Referencing the aforementioned case of Canadian salmon, the same GATT panel also analyzed Canada's decisions to impose export restrictions in accordance with Article XX:(g). The GATT panel agreed with Canadian complaints that salmon and herring stocks are, indeed, "exhaustible natural resources" and that harvest limitations are "restrictions on domestic production." The GATT panel's primary responsibility was in determining whether export restrictions on unprocessed salmon and herring were related to the conservation of these natural resources.

The panel arrived at several conclusions. First, it was determined that an export restriction did not have to be *necessary* for the conservation of an exhaustible natural resource, but had to be *primarily aimed* at its conservation. Secondly, the GATT panel considered Canada's argument that export restrictions were not conservation measures per se, but facilitated conservation in their provision of the statistical foundation for harvesting restrictions.[156] Ultimately, however, the panel found that Canada was limiting the purchase of unprocessed salmon and herring only to foreign consumers, not domestic consumers. The GATT thus ruled against Canada's export restrictions, claiming they could not be deemed primarily aimed at the conservation of salmon and herring stocks.

Article XX(g)—particularly, its reference to the conservative of exhaustible natural resources—has immediate implications for a WTO dispute settlement against China's export policies of rare earths. The Chinese government would likely claim that the imposition of export restrictions on rare earths would threaten the natural abundance of rare earth elements; consequently, it is imposing restrictions to limit global consumption. Yet, Chinese domestic consumption of rare earth elements continues to increase[157], undermining China's possible invocation of Article XX(g).

---

[154] GATT Analytical Index. Article XX. p. 583.
[155] Ibid, p. 583
[156] Ibid, p. 586
[157] "Economy Vulnerable to Rare Earth Shortages, Report Says," *New York Times,* 12 December 2010 http://www.nytimes.com/2010/12/15/business/global/15rare.html?pagewanted=2&sq=China Rare Earth&st=nyt&scp=1

Another case relevant to a possible WTO dispute settlement involving rare earth elements was recently filed recently against China. In April 2009, the U.S., EU, and Mexico legally charged China in the WTO because of its export policies towards several strategic materials—specifically, bauxite, coke, fluorspar, magnesium, manganese, silicon carbide, silicon metal, and zinc. According to the WTO dispute settlement process, China has imposed export duties and reducing quotas on the aforementioned materials, precluding fair export policies. Specifically, China imposed temporary export duties of 10% to 40% on bauxite, coke, fluorspar, magnesium, manganese, silicon carbide, silicon metal, and zinc.

Due to the similarities between the most recent WTO settlement filed against China and its rare earth export policies, the following paragraphs will examine China's justification for restricting exports of bauxite, coke, fluorspar, magnesium, manganese, silicon carbide, silicon metal, and zinc to project how China would likely defend itself in a WTO rare earth dispute.

Throughout the dispute process, China has presented two basic arguments defending its decisions to impose export restraints on the aforementioned minerals. These arguments center around the GATT Articles previously analyzed. First, China argues that it maintains the right to impose export restrictions in order to promote economic growth, as long as the restraints assist China in achieving its goal of "promot[ing] the production of more sophisticated processed products."[158] The second argument proposed by China relates to environmental considerations. Specifically, the Chinese government argues that export restrictions on the listed minerals are needed to protect the environment.[159]

In response, the opposing parties have argued that China's defense of its export policies is flawed for the following reasons. According to the contending parties, China's attempt to invoke Articles XX(b) and (g) of the GATT are unwarranted, given the fact that domestic production of bauxite, magnesium, etc. has continued unabated. That is, the environmental impact of producing a raw material is the same whether that material is used domestically or exported for foreign production.

The plaintiffs also criticized Chinese export restrictions as being inconsistent with China's obligations under its WTO Accession Protocol. Upon entry into the WTO in 2001, China made specific obligations regarding export policies, specifically export taxes. In paragraph 11.3 of its Accession Protocol, China broadly committed to the elimination of all taxes and charges applied to exports, as listed below:

[158] China's Written Submission. Paragraph 366.
[159] Ibid, 366.

> "China shall eliminate all taxes and charges applied to exports unless specifically provided for in Annex 6 of this Protocol or applied in conformity with the provisions of Article VIII of the GATT 1994."[160]

There are several exceptions to export taxes and duties as listed in Annex 6 of the Accession Protocol. If an item is listed in Annex 6, then China has the ability to legally levy an export duty on the listed product. However, most of the aforementioned materials were not originally embedded in the text of Annex 6.

Most recently, in February 2011, the WTO issued a preliminary report to the relevant parties in the April 2009 WTO dispute settlement case regarding China's export restrictions on strategic materials. The WTO concluded that China has no legal right to impose export restrictions on the nine raw materials, despite its defense that increased exports will threaten the environment.[161] The final report will not be released until April 2011 at which point China will be provided an opportunity to appeal the ruling. Some trade analysts speculate that this victory will spur the U.S. to challenge China's REE policies in the WTO, largely because China's defense of its rare earth export restrictions are very similar to its defense in the current WTO case.

Several other interesting parallels can be extended to a possible WTO dispute settlement regarding China's policies on rare earth elements. First, China's WTO Accession Protocol explicitly states that China shall eliminate all taxes and charges applied to exports unless specifically provided for in Annex 6 of this Protocol or applied in conformity with the provisions of Article VIII of the GATT 1994.[162]

Secondly, Annex 6 of the Accession Protocol does *not* list rare earth elements as a material that China is legally able to impose export taxes.[163] Therefore, China would have to justify its decisions to levy export taxes on rare earth elements in line with Articles XI, 2(b) or Articles XX(b) and (g). Similarly, Annex 6 does not condone quantitative restrictions, such as quotas. China's decision in October 2010 to cease rare earth exports to Japan would likely be viewed as a violation according to both the Accession Protocol, much less the founding principles of the GATT. If such measures were implemented again, China would have to prove that export restrictions satisfied environmental exceptions under GATT Article XX.

[160] USTR. "China—Measures Related to the Exportation of Various Raw Materials." p. 17
[161] "Trade Judges See Flaw in China Policies: Preliminary WTO Report Finds No Case for Some of Beijing's Export Restrictions," *Wall Street* Journal, 18 February 2011.
[162] GATT Article VIII (b)it must not 'represent an indirect protection to domestic products
[163] WTO. China's Accession Protocol. November 10, 2001. p. 93

Much of China's ability to defend export taxes on rare earth elements will be contingent on its domestic policies that address environmental protection. That is, China will need to present credible environmental policies that could buttress its defense of exercising Article XX(g) and the "conservation of exhaustible resources." Some of China's previous policy initiatives could undermine its case for a legitimate invocation of Article XX(g), however. For instance, in the 2001 *National Mineral Resources Plan*, China states that the configuration of mineral exports should be "adjusted to increase their profitability and increase their advantageous position in international markets."[164]

More recently, however, China's trade policies appear to be increasingly attuned to environmental considerations. Article 15 (2) of China's "Foreign Trade Law of the PRC" makes direct reference to environmental preservation, stating "the import or export needs to be restricted or prohibited in order to protect the human health or security, the animals and plants life or health or the environment."[165] The Chinese government has also launched a crackdown on the illegal mining of rare earth elements, which has included numerous police raids in Guangdong Province. The Ministry of Land and Resources seized control of 11 rare earth mining districts, removing administrative oversight from provincial officials.[166] Granted, part of the Ministry of Land and Resources' crackdown on rare earth mines could be linked to the illegal trafficking of rare earth elements on the black market. Many of China's recent initiatives on best mining practices, nonetheless, could be part of a broader strategy in preparation of a future WTO dispute settlement. The cases above shed light on what a WTO China rare earth dispute settlement process may entail. Regardless, China's export policies on rare earth elements and the legal battles it fights in the WTO will ostensibly be linked to a broader Chinese-U.S. strategic relationship.

U.S.-China Diplomatic Relations: Where does WTO litigation fit in?

Improving the US-China bilateral relationship is a key strategic imperative for the Obama administration. From military cooperation to currency valuation, the U.S. and China have sought to cooperate on a wide array of issues beyond the trade of strategic materials. China's announcement in December 2010 to enact a 35 percent cut in quotas poses a legitimate dilemma for the U.S.-China bilateral relationship. The Chinese Commerce Ministry announced that it had awarded quotas totaling 14,446 tons to 31 Chinese-owned and foreign-owned companies, denying that it would increase export quotas in 2011.[167] The following paragraphs

[164] *National Mineral Resources Plan*, Section 2 4(3) (JE-17).
[165] Foreign Trade Law of the People's Republic of China. 2007. http://wms2.mofcom.gov.cn/aarticle/policyreleasingcenter/200905/20090506257820.html).
[166] "Beijing Tights Its Control of Vital Minerals," *New York Times,* 20 January 2011. http://www.nytimes.com/2011/01/21/business/global/21rare.html
[167] "China to Tighten Limits on Rare Earth Exports in Early 2011," *New York Times,* 29 December 2010. http://www.nytimes.com/2010/12/29/business/global/29rare.html?pagewanted=2&sq=China Rare

will examine how such export policies fit into the broader strategic relationship between the U.S. and China.

In November 2009, President Obama traveled to China in the hopes of rekindling a strong bilateral partnership between the Beijing and Washington. Both parties agreed to foster greater cooperation on key issues such as climate change, nuclear non-proliferation, and economic stability. Yet, a year and half later, relations between the two countries have become increasingly strained. Economic recovery in the U.S. has been tepid for the last year, and China has stubbornly refused to appreciate the Renminbi.

Although not directly linked, many American politicians perceive China's recalcitrance on economic cooperation not only as a reason for slow economy recovery, but also as a sign of China's rise to power. Meanwhile, many Chinese policymakers view the U.S. as a declining great power, seeking to desperately prevent China from closing the economic and military gap separating the two. Before examining how rare earth elements affect U.S.-Chinese strategic relations, it is first important to identify why distrust between the two great powers has increased so significantly since 2009.

In terms of geostrategic and military relations, China and the U.S. have recently butted heads over a series of issues. With regard to North Korea, China has stymied the U.S.'s ability to impose crippling economic sanctions through the United Nations. Fearful of instability north of its borders—and, a potentially unified Korean peninsula allied to the U.S.—leadership in Beijing has been content to preserve that status quo and maintain close ties with Kim Jung-Il's regime. In fact, after North Korea sunk the South Korean vessel *Chenoan*, China did not publicly condemn North Korea for the attack, much to the dissatisfaction of the U.S..

China has also been increasing budgetary expenditures on military technologies. Not only is it in the process of building its first naval aircraft carrier, but it infamously tested a new stealth-bomber during Hu Jintao's visit to Washington DC in January 2011. The escalating geostrategic tensions between the U.S. and China are not solely because of Beijing's decisions, however. In 2010, President Obama authorized $6.4 billion in defensive arms and equipment to Taiwan, which China demands must be stopped because Taiwan is considered part of China.[168] In addition to Taiwanese arms sales, the U.S. military recently received authorization from President Obama for a "Buy American" provision for the purchase of solar panels. Recent arguments that China unfairly subsidizes its solar industry lead Washington to the decision to require that the DoD solely buy American solar panels.[169]

Earth&st=nyt&scp=7

[168] David Shambaugh. "Stabilizing Unstable U.S.-China Relations? Prospects for the Hu Jintao Visit." Brookings. January 2011. http://www.brookings.edu/papers/2011/01_us_china_shambaugh.aspx

[169] "Pentagon Must 'Buy American,' Barring Chinese Solar Panels, *The New York Times.* 10 January 2011 http://www.nytimes.com/2011/01/10/business/global/10solar.html?pagewanted=2

Another key provision in the defense appropriations bill relates to China and rare earth elements. The bill requires that the DoD immediately launch a study of the U.S. military's need for rare earth elements in the future, and whether the U.S. should begin amassing a strategic supply of REEs for critical military technologies. The DoD's announcement to launch such a study was shortly proceeded by China's unofficial announcement to begin creating its own rare earth elements stockpile. Unofficial reports from Chinese government agencies state that storage facilities have recently been built in the Chinese province of Inner Mongolia and can hold more than 39,000 metric tons of rare earth elements.[170] Under the supervision of the Ministry of Land and Resources, ten storage facilities are being constructed by Baotou Steel Rare-Earth—the world's largest producer of rare earths.

The implications of China's decision to stock pile rare earth elements may exacerbate geostrategic tensions with the U.S.. As both the Chinese and U.S. military continue to closely monitor each other's strategic posturing, China's decision to store REEs could spark a similar response in the U.S.. Increased pressure from the Department of Defense to acquire large quantities of REEs will only complicate the diplomatic gesturing the U.S. makes towards China's export policies on REEs.

Aside from geo-strategic and military affairs, Chinese-U.S. bilateral relations have also become increasingly strained because of economic factors. Most notably, China's reluctance to appreciate the Renminbi has lead to heated disputes Washington and Beijing. The fragmented nature of China's domestic political system--specifically, fights between central bankers who want to appreciate the currency and party bosses who want to protect the massive industrial machine that relies on cheap exports--has undermined President Hu's ability to make serious concessions on revaluing the Renminbi.[171]

Despite strained tensions, the U.S.-China bilateral relationship is becoming increasingly intertwined. The growth of U.S. exports to China was 32 percent last year, nearly double the export growth to any other country.[172] In 2009, estimated trade in goods between China and the U.S. reached $366 billion.[173] Regardless, both parties are experiencing economic hardship. In China, concerns over inflation, income disparity, and over-seas protectionism are leading Chinese leadership to espouse unfair trade policies. Meanwhile, in the U.S., high unemployment levels and weak economic recovery are amplifying pessimistic expectations of a positive U.S.-China relationship, even though the interdependence existing between both

---

[170] "China Builds Strategic Reserve of Rare-Earth Metals," *Wall Street Journal,* 07 February 2011.

[171] "Hu Jintao's Limits Come Into Focus as China Rises," *The New York Times,* 17 January 2011, http://www.nytimes.com/2011/01/17/world/asia/17china.html?scp=15&sq=China+Rare+Earth&st=nyt

[172] Homi Kharas. "Around the Halls: China President Hu Jintao's Visit to Washington." Brookings. 14 January 2011. http://www.brookings.edu/opinions/2011/0114_halls_jintao.aspx

[173] Evan Feigenbaum. "Why US-China Relations Will Get Tougher." Council on Foreign Relations. 7 February 2011. http://www.cfr.org/china/why-us-china-relations-get-tougher/p24022

parties highlights the significance of improving economic relations. Yet, in January 2011, limited progress was achieved on economic issues during Hu Jintao's visit to the U.S.. Debates over currency issues were almost intentionally neglected, as the Obama administration managed to extract only $45 billion in new Chinese contracts to buy American goods and services—a relatively small sum given the size of both the Chinese and U.S. economies. President Obama's decision not to directly engage Hu Jintao on the valuation of the Renminbi and other sensitive economic issues is not a sign of exasperation. Rather, it is part of a broader strategy of the U.S. to address less-sensitive economic issues and see if rising inflation will cause China to appreciate their currency.[174]

The diffusion of economic tensions with China will rest on several factors. First, the U.S.' economy needs to recover so that U.S. can assume its role as a global leader, and shy away form blaming China for its economic woes. Secondly, the U.S. and China must identify mutual avenues of cooperation. The development of clean energy technologies is a prime example. Each nation's capabilities are relatively good complements to one another.[175] Invariably, disagreement will ensue, as evinced by the U.S.'s decision to challenge China's clean-energy subsidies in the WTO. When such disagreement arises, the U.S. must not pressure China bilaterally, but multilaterally in conjunction with other major powers. Japan and India are equally loathe to the rise of China's power in Asia, and would likely work collaboratively with Washington on critical issues. The likelihood of achieving a desired resolution to China's export restrictions will increase as the amount of multilateral pressure expands.

Ultimately, any diplomatic strategy Washington implements to reverse China's export restrictions on rare earth elements will rest on the aforementioned political and economic tensions. That is, the U.S. Trade Representative cannot simply contact his Chinese counterpart and commence negotiations on how the U.S. can have uninterrupted access to Chinese rare earth elements. Rather, the sensitive nature of REE trade will have to take into account various political, economic, and military realities defining the U.S.-China relationship.

Given the current state of Chinese-U.S. relations, it seems unlikely that the Obama administration will press China on its export restrictions of rare earth elements through the WTO. Simply stated, there appear to be too many more important strategic initiatives that the U.S. needs to achieve before further straining relations with Beijing with WTO litigation. From cooperation on North Korea and Iran to currency appreciation, there are more pressing policy problems than rare earth elements that the U.S. must first address. Additionally, resorting to WTO litigation can be a timely process. Often, cases take nearly three years to resolve, thus preventing the U.S. from attaining a short-term solution to its limited supply of rare earth elements.

---

[174] "Hu Jintao's Limits Come into Focus as China Rises," *The New York Times*, 17 January 2011. http://www.nytimes.com/2011/01/17/world/asia/17china.html?scp=15&sq=China+Rare+Earth&st=nyt

[175] Ken Lieberthal. "Recalibrating U.S.-China Relations." Brookings Institution. 17 January 2011. http://www.brookings.edu/opinions/2011/0117_us_china_relations_lieberthal.aspx

Conclusions

PERMITTING FOR DOMESTIC PRODUCTION

Both the DOE report and proposed legislation discuss the potential to expedite REE mine permitting, but there is little to no guidance on how this might be implemented. Unsurprisingly, there is general support in the mining industry for a faster, easier permitting process, but disagreement over implementation. Donald Ranta, CEO of Rare Element Resources Ltd. stated that "the way [the government] could help us the most is with a fast-track on permitting."[176] However, Molycorp (who has already been permitted) has publicly opposed any short cuts for environmental reviews for other mining corporations, saying it would undermine the existing industry. The U.S. National Mining Association does not appear to have a specific stance on REE mining, but it has put forth a number of publications that focus on the blocking of coal mine permits by the EPA.[177]

Based on our review of the relevant regulations and procedures in place in the U.S., the primary sources of delay seem to be the intertwined bureaucratic layers at the federal and state level that govern the mining permit process and the persistent litigation brought by groups opposed to the mining activity. Lowering environmental standards is neither desirable in the U.S. nor is it an objective of the Chinese government, whose Environment Minister and Prime Minister recently made strong statements regarding the need to mitigate environmental problems that have accompanied the country's staggering growth.[178] And in the particular case of Australia, where permitting is completed in much shorter timeframes, well-defined rights for affected local populations and active dialogue between the mining industry and environmentalists could serve as examples of ways to reduce the instances of litigation and general opposition to projects that would otherwise meet the necessary standards. Given this analysis, there are two key recommendations that can help address concerns over permitting time, corresponding to near-term actions and longer-term strategic dialogue.

[176] Snyder, Jim (January 14, 2011). "Rare-Earths Producer Molycorp, Rivals Lobby Congress." Bloomberg. Available online: http://www.bloomberg.com/news/2011-01-14/rare-earths-producer-molycorp-rivals-seek-u-s-aid-as-china-chops-exports.html
[177] See http://www.nma.org
[178] Andrew Jacobs, "China Issues Warning on Climate and Growth," New York Times, 28 February 2011, http://www.nytimes.com/2011/03/01/world/asia/01beijing.html

Improved coordination between Federal and State agencies

As recommended in the RESTART legislation, this approach could involve an REE task force created to evaluate the nature of procedural delays and provide recommendations on streamlining the agency process. The goal would be to retain the integrity of the environmental review procedures while seeking to reduce potential conflicts and delays due to the bureaucratic structure itself.

In particular, this task force should focus on reviewing the source of past delays in issuing permits to determine whether the majority were due to legitimate environmental concerns, litigation, process delays, or some combination of those factors. Should litigation and process delays prove to be the cause in a significant number of cases, then further work could be done to ascertain the nature of the litigation and to identify whether specific parts of the approval process are common roadblocks. In the case of common sources of litigation, if resolutions were reached, these findings could serve as a guide for future engagement between opposition stakeholders and the mining industry, both with respect to the issues of concern as well as means of resolving conflicts in the future. With respect to process delays, it may be the case that consolidation of specific points in the approval process within a certain agency could streamline the permitting process. Since these measures would be relatively discrete in nature, they provide a potential path for more immediate action to improve permitting times.

Improved industry engagement with concerned stakeholders

Although it may require a shift in the engagement strategy of the U.S. mining industry, there could be significant longer-term benefits from directly engaging concerned stakeholders as the Australian industry has done. As the role of NGOs While the nature of specific concerns and litigation raised in the U.S. may differ, a collaborative process to address potential conflicts may yield similar benefits with regard to permitting time, based on the findings of the REE task force we recommend. Broadly speaking, this type of engagement could yield a number of potential outcomes. From the perspective of local populations affected by mining practices, appropriate legislation could be introduced that outlines a clear procedure for addressing local concerns, which is an approach that seems to benefit both local communities and the mining industry in Australia. From a broader environmental perspective, there are a number of international standards that have been established for the mining industry by organizations such as the World Bank, and by demonstrating a commitment to transparency and working toward these standards, U.S. mining companies may find more support from the environmental community in the long-run, provided that representatives from prominent groups have a voice in the process.

For instance, though the U.S. National Mining Association is a member of the International Council on Mining & Metals (ICMM), only a handful of individual companies are themselves members. The ICMM publishes an annual report on the performance of its individual company members with respect to a number of sustainability criteria, and a movement toward such transparency could make significant strides in restoring confidence in those mining companies who are making efforts to improve performance. In addition to the growing focus by NGOs on the mining sector, financial institutions are also increasingly focused on social and environmental risks, which can ultimately impact access to capital for mining companies.[179] Therefore embracing a transparent and widely-accepted set of standards may even enhance the U.S. mining industry's competitive positioning over time.

STRATEGIC COOPERATION AS AN REE STRATEGY

As China has tightened export controls, REE-consuming firms and their respective governments have adopted a variety of strategies in response. Although stockpiling (according to specific products consumption), securing REE supply early (at the mine development stage, through contracts), and attempting to develop a domestic "mine to magnet" supply-chain have each been adopted by some countries, all interested parties are engaging in what is being termed a new discipline: "raw material security diplomacy."[180] This section has analyzed various countries' diplomatic strategies with respect to REEs, as well as examined in depth one particular route that countries might cooperate on to challenge China's manipulation of the REE market: raising a case through the WTO. However, it is also important to question whether there are any aspects of diplomatic strategies that the U.S. might newly seek to implement, and examine what the implications of implementation might actually be.

Intergovernmental cooperation and diplomatic agreements

If the country cases analyzed above provide any clue, it is likely that many parties within the U.S. government would be required to take action to implement the various diplomatic strategies that are available. As the Department of Energy expressed in the policy recommendations portion of its Critical Minerals Strategy, the DOE can play a role in international cooperation on recycling policy, research and development, and information sharing with other governments. However, if the U.S. did choose to seriously pursue a case against China at the WTO, despite the set of strategic implications discussed above, the office of the U.S. Trade Representative would play a pivotal role.[181] One of Japan's strategies, since China temporarily halted REE shipments in late 2010, has been to incorporate cooperation on REE supply into bilateral trade talks negotiated at the highest levels (between heads of state, for example).[182] If the U.S. wishes to emulate this strategy to diversify its REE supply, rather

---

[179] Brereton 2002

[180] Christian Hocquard. IFRI Energy Breakfast Roundtable, May 20th 2010, Brussels.

[181] U.S. Trade Representative. "U.S. Launches Section 301 Investigation into China's Policies Affecting Trade and Investment in Green Technologies," October 2010, http://www.ustr.gov/node/6223

[182] "Japan, Vietnam to jointly develop rare earths," Jiji Press, 22 Oct 2010,

than emphasizing domestic production, it will be important for the offices of the President or the Secretary of State to engage in negotiations. When it comes to cooperating with the EU over REE issues, it is likely that U.S. Congressional Committees will be able to play an important role.[183]

For many of the countries profiled above, cooperation on rare earths represents more than a single-issue discussion. Often, agreements to cooperate on REEs are held out as a bargaining chip in general trade negotiations or as a component of development policy. The European Commission's recent strategy paper, for example, says that the EU will also financially support future mining activities of rare earth minerals in African countries. In exchange, the EU wants to secure a prior claim to the metals mined in these countries.[184] As part of its agreement with Japan to help supply REE from an Orissa mining operation, the Indian government hopes to receive assistance in developing its nuclear energy program. The prospect of securing REE supply from Australian mines was a significant carrot facing Japan when they resolved to return to the table to discuss a trade agreement with Australia. In each of these cases, as well as the various other examples discussed in the case analyses, agreement to cooperate on REEs has represented a bargaining chip within a larger and more complex diplomatic relationship. As the U.S. government considers cooperating with other states to prevent a short run supply disruption, it will be important to consider the extent to which the U.S. can garner gains on REEs in exchange for concessions on other issues.

Stakeholder cooperation within multilateral and free trade organizations

Even as parties within the U.S. government carry out bilateral trade talks or cooperate with other individual countries on REE issues, American REE-consuming industries may have an important opportunity to influence outcomes through coordinated action. One example of this type of action occurred in November 2010, when a broad coalition of 37 business groups from North America, Europe and Asia sent a letter to the heads of state of the Group of 20 major economies, asking them to make a commitment at their meeting that trade in crucial rare earths will not be interrupted because of industrial policies or political disputes. They asked that the G-20 leaders and their governments commit themselves to "refrain from export taxes, quotas or other market-distorting measures on rare earth elements that restrict global supply and unnecessarily contribute to price volatility, including through respect for the rules of the World Trade Organization and commitments resulting from its members' accession protocols." The diverse nature of the groups signing the letter is obvious from a glimpse of a list of some

---

http://www.mcot.net/cfcustom/cache_page/118976.html

[183] "EU-US to collaborate on 'rare earths'", EurActiv, 14 July 2010, http://www.euractiv.com/en/sustainability/eu-us-collaborate-rare-earths-news-496286

[184] Roman Baudzus, "EU is Paving the Way for New Law to Recycle Rare Earth Materials," GoldMoney, 31 January 2011, http://www.goldmoney.com/gold-research/eu-is-paving-the-way-for-new-law-to-recycle-rare-earth-minerals.html

signers: the Alliance of Automobile Manufacturers, the American Petroleum Institute, the Business Roundtable, the Consumer Electronics Association, the National Association of Manufacturers, the U.S. Magnetic Materials Association, the Brazil-U.S. Business Council, Business Europe, the Canadian Chamber of Commerce, the Federation of Korean Industries and the Japan Electronics and Information Technology Industries Association.[185] Applying pressure on policymakers gathered at multilateral fora such as the G-20 may offer REE consuming-industries a promising opportunity to influence policy outcomes. In order for this coordinated lobbying to be effective, however, it will be important for representatives of states at these multilateral fora to heed the concerns and respond to the demands of industry groups important to their economies.

Private trade agreements between suppliers and consumers

Although calls for bilateral and multilateral cooperation to share information and diversify global REE production are laudable, the negotiation of long-term cross-country contracts (whether in parallel to diplomatic negotiations or entirely in the private sphere) may represent the best policy for reducing REE supply disruptions in the short term. Cooperative efforts by governments and groups to diversify REE supply away from Chinese producers must be designed with the features of the REE market in mind. Due to the highly specific compositional nature of REE inputs for clean technologies REE are not traded on exchanges. Instead, REEs change hands from producers to users on contracts agreed to by the two parties.[186]

As China has tightened its export restrictions on REEs, REE-consuming firms have been developing contracts with suppliers as quickly as possible. According to Mark Smith, CEO of American REE-producing firm Molycorp, “customers are calling every day wanting to try to tie up more and more of our production, and that is certainly to be expected because supply and demand are out of sync right now.”[187] Molycorp is reportedly in discussions with Canadian-based Neo Material Technologies to send rare earths to China; in exchange, Neo would help Molycorp to make rare-earth alloys and metals in Thailand.[188] Meanwhile, Japanese firms have secured delivery contracts with an Australian mine, a state-owned mining operation in India, and other operations.

While these contractual agreements are sometimes purely business transactions (free from government involvement), they often follow behind official trade agreements (i.e. the agreement Australia made to help Japan diversify its supply). As exemplified by the Japanese

[185] Keith Bradsher, “Rare Earth Stand is Asked of G-20,” New York Times, 5 November 2010, http://www.nytimes.com/2010/11/05/business/global/05rarechina.html
[186] These contracts vary from short-term or spot contracts to contracts with longer terms of six months to a year.
[187] “Molycorp’s Smith Interview on Rare Earths Oct. 28,” Bloomberg, 28 October 2010, http://www.bloomberg.com/video/64052146/
[188] http://www.tradereform.org/2011/01/americas-valuable-minerals-could-be-headed-for-china/

government's pursuit of diplomatic agreements for REEs via cooperation with various countries, which was followed by the signing of contracts between Japanese REE-consuming firms and foreign REE mining ventures, government can play a key role in this process.[189][190] In a market characterized by specific contracts between REE suppliers and consumers, high level government diplomacy should focus on the development of strategic agreements that will facilitate private sector action.

Pursuing WTO Litigation

There are essentially two available options the U.S. can pursue through the WTO vis-à-vis China's rare earth export restrictions: One, the U.S. can elect to file a formal dispute settlement claim and bring the case before a WTO panel. Or, two, the U.S. can refrain from WTO litigation and instead exert bilateral pressure on China to ease its export restrictions.

There are several negative costs associated with filing a WTO complaint against Chinese REE policies. First, filing a WTO complaint does little to remedy the limited supply of rare earths in the short run. WTO cases can take up to three years to fully process, as demonstrated by the case above which was filed two years ago and has still not been adjourned. Secondly, U.S.-Chinese relations have become increasingly tense over the last year. It may be very likely that issues of economic and military cooperation with Beijing currently trump the need to press China in the WTO and further exacerbate bilateral relationships. Relative to the other policy listed in this report, WTO litigation is by far the most aggressive option and could elicit a negative response from Beijing, such as increased restrictions on other valuable Chinese exports. Coupled with the long time constraint associated with a WTO complaint, the risks of engaging China in the WTO may outweigh the limited short-term benefits.

On the other hand, inaction through the WTO may also prove very costly. Not only does it appear likely that the U.S. could win a WTO case against China based recent rulings, but the U.S. may find that exerting bilateral pressure on China to remove REE export restrictions will not work without the legitimacy of an established international institution. At the same time, inaction via the WTO will not undermine the current U.S.-China bilateral relationship. If the U.S. identifies that its short-term demand for rare earth elements cannot be satisfied by alternative options, then it may behoove the Obama administration to take China to the WTO. In the meanwhile, however, the Obama administration should assess how rare earth elements fit in the broader strategic framework towards China, taking into account all the potential costs and benefits associated with a prolonged legal battle in the WTO.

[189] McGuirk, Rod. "Japan, Australia to restart free trade talks." Associated Press. 23 Nov 2010. http://www.bilaterals.org/spip.php?article18546

[190] "Lynas signs rare earths supply deal," AAP, with Reuters, 24 November 2010, http://www.raremetalblog.com/2010/11/lynas-signs-rare-earths-supply-deal.html

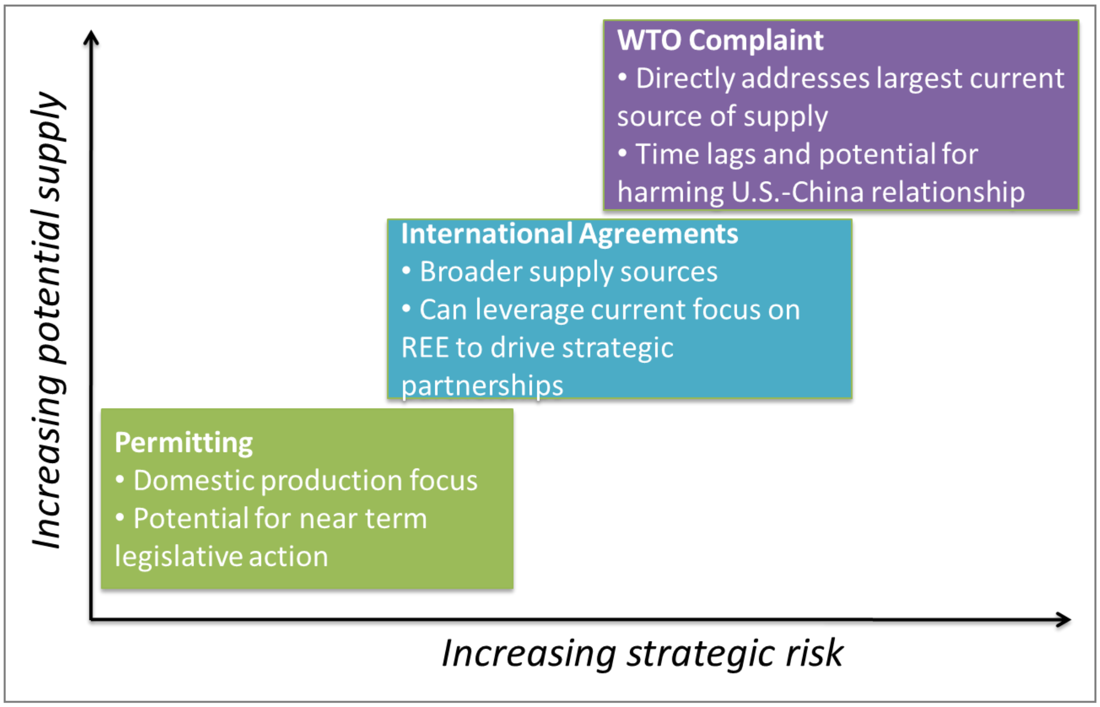
RECOMMENDATIONS

We can combine the policy options we have explored in-depth into a single framework to better characterize the trade-offs associated with each option. The two metrics by which we rank each of the policies are:

- Size of the potential supply targeted by the policy option
- Strategic risk associated with the policy option

The relationship between size of target supply and strategic risk for each option is depicted in Figure 5.

Figure 5. Policy Option Trade-offs

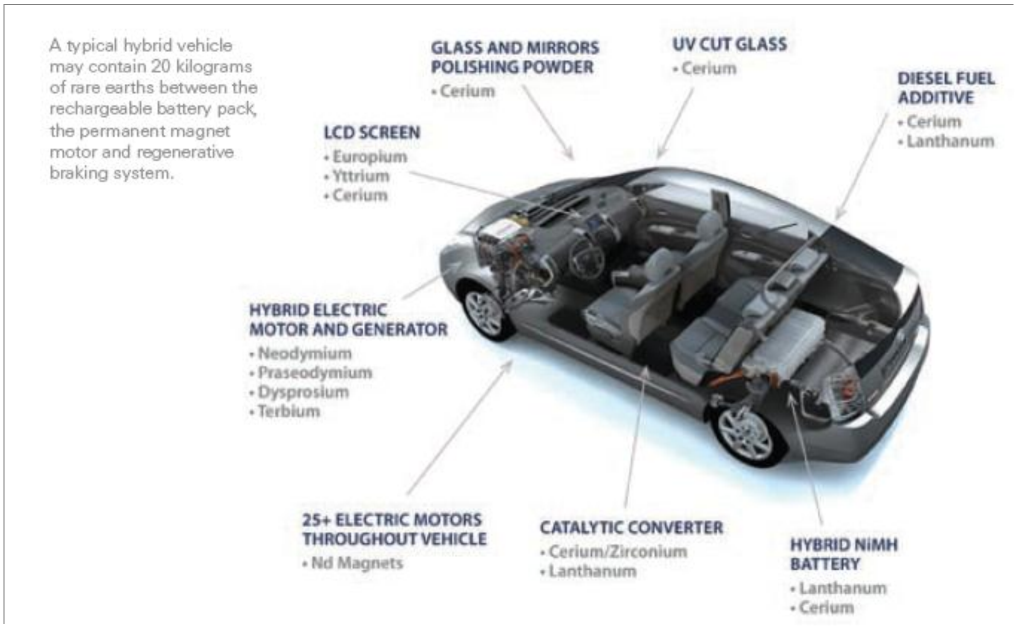


Based on the three strategies depicted above, we ultimately recommend that the U.S. pursue a two-fold policy of permitting and international agreements. Simply put, the risks of pursuing WTO complaint against China are too high to warrant action. As stated earlier, bilateral relations between the U.S. and China are already tense due to limited cooperation over military and economic affairs. Taking China to the WTO may further exacerbate bilateral tensions and preclude cooperation on more pressing issues. The time lag accompanying a WTO dispute settlement process will also do little to solve the short-term supply shortages of REEs.

Permitting and international agreements, on the other hand, represent more moderate policy approaches for the U.S. Both policies can be implemented domestically with little fear of jeopardizing our relationship with China. Meanwhile, the U.S. can continue bilateral negotiations with the Beijing in an effort to reverse Chinese export restrictions. Permitting and international agreements thus provide policy makers with actionable policies to achieve a desired solution to REE supply concerns.

Appendix: Applications of REE in Clean Technologies

ELECTRIC VEHICLES



Source: Arafura Annual Operations Report 2009

Market Overview

The manufacturing of electric vehicle battery packs for use by original equipment manufacturers (OEM) consists of four stages: component production and the acquisition of raw materials; cell production; module production; and, assembly of modules into the battery pack.[191] Battery production is characterized by five main attributes: power, energy, longevity, cost, and safety.[192] There are trade offs between these attributes based on the different chemistries and models of batteries. The two predominant types of electric vehicle batteries are lithium-ion and nickel-metal hydride (NiMH) batteries. Recent reports have shed negative light on battery technologies for electric vehicles, citing that battery chemistries for PHEV applications are "not ready for commercial production due to performance limitations."[193]

---

[191] Boston Consulting Group, *Batteries for Electric Cars: Challenges, Opportunities, and the Outlook to 2020*, accessed October 3, 2010, www.bcg.com/documents/file36615.pdf.
[192] Jonn Axsen, Kenneth S. Kurani, and Andrew F. Burke, "Are Batteries Ready for Plug-in Hybrid Buyers?" *Transport Policy*, Vol 17 (2010): 173-182, doi:10.1016/j.tranpol.2010.01.004.
[193] M. Franklin et al., "Modelling Lithium-Ion Battery Electrode Properties," Presented at the 24th Annual Workshop on Mathematical Problems in Industry, Worcester Polytechnic Institute, June 2008, www.math.wpi.edu/MPI2008/TIAX/TIAXFinal.pdf.

Nonetheless, both types of batteries are used in hybrid, plug-in hybrids, and electric vehicles. NiMH and lithium-ion batteries are not, however, interchangeable in different vehicles. That is, NiMH batteries are customarily used only in conventional hybrids, while lithium-ion batteries are used predominantly in electric vehicles.

NiMH Batteries

A key component in NiMH batteries is the rare earth element, Lanthanum. Lanthanum is one of the most abundantly mined and produced rare earth element, where annual production for the last five years as been approximately 33,000 metric tons. Nonetheless, rare earth analysts project that 5,500 to 7,200 tons of lanthanum—which is approximately one third of the world's production—will be needed for Toyota's scheduled one million Prius units in model year 2011.[194] Thus, according to 2010 Q3 prices for Lanthanum per kilogram, Toyota alone could potentially spend $210 M to $290 M on Lanthanum acquisition for NiMH batteries.[195] Despite the potential shortage of REE, some automobile companies have maintained their projected production figures, seeking to find REE substitutes. Toyota, for instance, recently announced the production of an induction motor for EVs which unlike the current model, does not require any rare earths.[196] Similarly, in order to ensure access to lanthanum, American companies, like Energy Conversion Devices Inc., built battery manufacturing facilities in China to ensure constant supply of REEs and supply automobile manufacturers, such as China.[197]

---

[194] Ibid.

[195] Calculation based on 2008 Lanthanum prices by USGS 2008 Mineral Yearbook.

[196] "Toyota reading motors that don't use rare earths," Bloomberg, last modified January 14, 2010. http://www.bloomberg.com/news/2011-01-14/toyota-readying-electric-motors-that-don-t-use-rare-earths.html

[197] Jack Lifton, "Toyota far Passes GM when It Comes to EV," Seeking Alpha, July 9, 2009, http://seekingalpha.com/instablog/65370-jack-lifton/12427-the-tellurium-supply-conjecture-and-the-future-of-first-solar.

Despite NiMH batteries' high power output and capacity, they do not store energy efficiently. Moreover, oversized NiMH batteries are limited in their ability to quickly transfer energy in and out of the battery; resultantly, NiMH hybrid batteries hold more energy than is needed and are thus more expensive than they need to be.[198] The costs of manufacturing and production for NiMH EV batteries are not significantly high, particularly because of the low materials costs resulting from nickel-based chemistry. In fact, NiMH production costs are cheaper relative to those of lithium-ion batteries. Nickel-metal batteries are thus ideal for hybrid vehicles due to their low production costs, high reliability, and moderate-demand charge sustaining operation.[199] In order to advance NiMH battery production, Toyota Motor Corp. and Matsushita Electric Industrial Co. intend to spend around $360billion yen to build a production plan in Taiwa, Miyaga Prefecture. The plant is estimated to produce 300,000 NiMH batteries per year.[200]

Electric Motors

Moderately priced Neodymium iron boron magnets provide auto manufacturers with a small magnet capable of significantly reducing the weight of electric motors. Lynas Corporation estimates that electric motors containing neodymium magnets weigh half as much as standard ferrite motors.[201] It should also be noted that neodymium is not solely used in the electric motor, however, as demonstrated in the graph above. In fact, EV's regenerative breaking system can use up to 2 lbs of neodymium magnets.

In 2009, production of neodymium magnets was approximately 85,000 metric tons. As neodymium magnets continue to be used in electric vehicles, analysts forecast that the global neodymium iron boron industry will maintain growth rates of 15 percent in the next five years, where China's neodymium industry will maintain a growth rate of 20 percent.[202]

Future Trends and Substitutes

Lithium-ion batteries have emerged as a viable power source for electric vehicles. Unlike NiMH batteries, Lithium-ion batteries do not require the use of rare earth elements. Rather, they use lithium, an element that is significantly cheaper than lanthanum. Nevertheless, Lithium-ion

[198] "Honda's Low-Cost Hybrid Strategy: Lithium Ion Batteries," HybridCars, last modified March 18, 2010, http://www.hybridcars.com/news/honda-low-cost-hybrid-strategy-lithium-ion-batteries-27544.html.
[199] "Toyota's First Production Lithium-Ion Drive Battery," Toyota Motor Sales U.S.A., last modified April 13, 2010, http://www.toyota.com/esq/articles/2010/Toyotas_First_Production_Lithium_Ion_Drive_Battery.html
[200] Nikkei Press Release. http://www.hybridautoreview.net/toyota-to-raise-stake-in-panasonic-battery-venture.html.
[201] Lynas Corporation 2010.
[202] Forbes. http://www.forbes.com/feeds/businesswire/2010/11/15/businesswire148657201.html

batteries are thirty percent more expensive than NiMH hybrid batteries because they are capable of storing twice the energy of NiMH batteries. Consequently, major automobile companies, like Toyota and Honda, have increased investment in Lithium-ion battery technologies. Lithium batteries still provide car manufacturers an opportunity to reduce battery costs because of their small size; they are not oversized like NiMH batteries.

Currently, pure electric and PHEV vehicles primarily use Lithium-ion batteries, indicating a steady shift away from NiMH battery technologies. According to Toyota, high energy density and compactness are making Lithium-ion batteries the most preferred battery in the near future. One of the technical reasons why Lithium-ion batteries are becoming increasingly preferred to NiMh batteries is because pure electric and PHEV require higher energy density to meet the higher demands of charge-depleting operation which NiMH batteries cannot effectively satisfy.[203]

Substitutes also exist for the EV's electric motor, such as ferrite oxide magnets. Rather than use neodymium for permanent magnets, magnet manufactures can use another rare earth element—dysprosium. Nevertheless, dysprosium is not only more expensive than neodymium, but it also can only replace up to 6 percent of the neodymium (Avalon). A more viable substitute, however, are ferrite magnets. Japanese manufacturer Hitachi has developed an electric motor that uses a ferrite magnet based on ferric oxide material. Furthermore, a Sunnyvale-based company, NovaTorque, uses low-ferrite magnets that are 15 to 17 times cheaper than neodymium magnets.[204] Unlike the rare earth elements neodymium and dysprosium, ferrite magnets are significantly cheaper, providing battery manufacturers and OEMs more affordable motor inputs.

WIND TURBINES

Market Overview

Wind generates only two percent of electricity in the U.S. today, but the wind industry is growing rapidly in the U.S. and around the world; over the past decade, the annual growth rate of installed wind capacity has been 28 percent.[205] Although many economic and policy-related factors are driving this growth, improvements in wind turbine technology are playing key roles in increasing the cost-competitiveness of wind energy with conventional energy sources.

---

[203] Kurani, Kenneth. "Are Batteries Ready for Plug-in Hybrid Buyers?" UC Davis. February 2010.

[204] EE times. http://www.eetimes.com/electronics-news/4209736/Opinion-The-rare-earth-challenge. Green Tech Media: http://www.greentechmedia.com/articles/read/an-electric-motor-that-cures-the-rare-earth-blues/

[205] Global Wind Energy Council, *Global Wind 2009 Report*, accessed November 23, 2010, http://www.gwec.net/fileadmin/documents/Publications/Global_Wind_2007_report/GWEC_Global_Wind_2009_Report_LOWRES_15th.%20Apr.pdf.

Typically, wind turbines have converted the wind currents into energy by relying on a gearbox turning a slow-moving turbine rotor into faster-rotating gears, which then convert mechanical energy into electricity in a generator.[206] Due to constant stress from wind turbulence, however, gearboxes have high maintenance requirements. A small defect in any one component among the multiple wheels and bearings in the gearbox can bring the turbine to a halt. The reality that gearboxes are both "clunky and expensive" further detracts from the attractiveness of their inclusion in a wind turbine design.[207]

As new-generation wind turbines are increasingly scaling to three MW or higher, manufacturers are moving to turbine designs that utilize PMs instead of gearboxes These so-called "direct-drive generators" connect the rotor shaft directly to the generator, rather than utilizing a gearbox as a middleman. The slower rotational speed of the rotor shaft gets offset by the presence of magnets that spin around at a larger diameter – and hence higher speed – to produce more current in the generator coil.[208]

Comparing a new Siemens Energy Direct Drive (PM) wind turbine, which began selling in April 2010, with a similar gearbox model offers a useful illustration of the advantages of PM over earlier, non-PM designs (see table below).

Comparison between PM and Conventional Wind Turbine Models

Technical specifications	Conventional geared model[209] (SWT-2.3-101)	Permanent magnet model[210] (SWT-3.0-101)
Rated power	2.3 MW	3.0 MW
Rotor diameter	101 m	101 m
Nacelle weight	82 tons	73 tons
Cut-in wind speed	3-4m/s	3 m/s
Components	blade, rotor hub, nacelle, tower, controller, and gearbox (with 12 moving parts, 24 bearings, and 2 hydraulic systems)	blade, rotor hub, nacelle, tower, controller, and permanent magnet generator (with 2 bearings)

Source: Siemens Energy (2009 and 2010) and Bayani (2010)

---

[206] Jacobsen and DeLucchi. "Wind, solar, water power for the world."
[207] Jeremy Hsu, "General Electric Gives Gearless Wind Turbines a Big Boost," *Popular Science*, September 23, 2009, http://www.popsci.com/scitech/article/2009-09/wind-power-giant-gives-gearless-turbines-boost.
[208] Ibid.
[209] Siemens Energy, *The new standard for moderate wind conditions: Siemens Wind Turbine SWT-2.3-101*, accessed November 21, 2010, http://www.usa.siemens.com/en/windpower/framework/_resources/pdf/Siemens-SWT-2.3-101_Print.pdf.
[210] Siemens Energy, *Bright outlook for improved profitability: Direct drive wind turbine SWT-3.0-101*, accessed November 21, 2010, http://www.energy.siemens.com/hq/pool/hq/power-generation/wind-power/E50001-W310-A161-X-4A00_SWT-3.0-101_US.pdf.

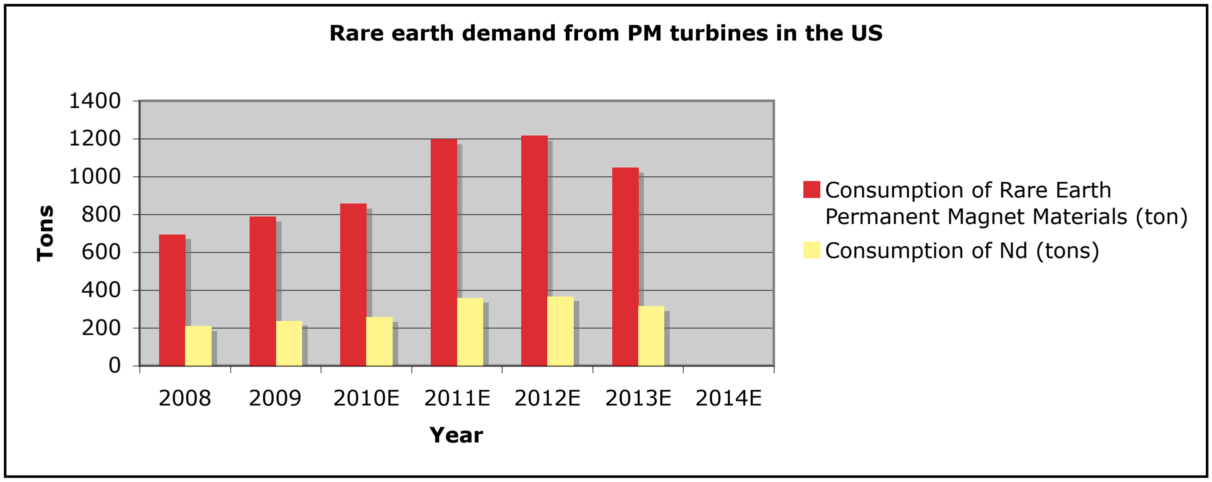
Even utilizing the same size blades, a PM wind turbine offers more power, has a lower weight and only about half the number of parts as its geared counterpart. According to wind turbine manufacturers, reducing the complexity of the design increases both the reliability and profitability of the turbine; it is less vulnerable to breaking down (creating downtime) and easier to repair when anything does go wrong. Furthermore, the turbine's compact design enables the nacelle (the cover housing that contains the drive train and generator) to be transported using standard vehicles commonly available in most major markets.[211] These advantages have fuelled a flood of recent investment in PM wind turbine technologies, and spell future growth within this segment of the wind industry.

Future Trends and Substitutes

Although U.S. government projections of the growth of future wind generation are inconsistent, sources agree that the proportion of wind turbines utilizing rare earth permanent magnets will rise as wind capacity is added. By industry estimates, there were only 400 units per annum in the U.S. in 2008, representing only 2 percent of the market; however, some sources expect this number to grow to 4,300 units per annum or 16 percent of the market in 2020.[212] Another source estimates that although 80 percent of wind turbines in the U.S. do not use neodymium magnets today, the industry's switch from geared electromagnetic induction wind turbines to direct drive PM turbines will require an additional 3,000-5,000 metric tons of neodymium by 2014.[213] Acting on the assumption that no more than 15 percent of newly added grid-connected capacity will come from PM turbines, the figure below depicts the expected rise in demand for PM material (NdFeB) and for Neodymium oxide under the DOE's most conservative scenario for the wind industry growth in the U.S.

[211] Eva-Marie Baumann, "New Siemens Direct Drive wind turbine ready for sale." Siemens Energy, 20 April 2010, http://www.siemens.com/press/en/presspicture/index.php?view=list&division=&tag=soere20091205
[212] Lynas Corporation 2010.
[213] Tuer 2009.

Projected NdFeB and Nd Demand From U.S. Wind Industry Growth



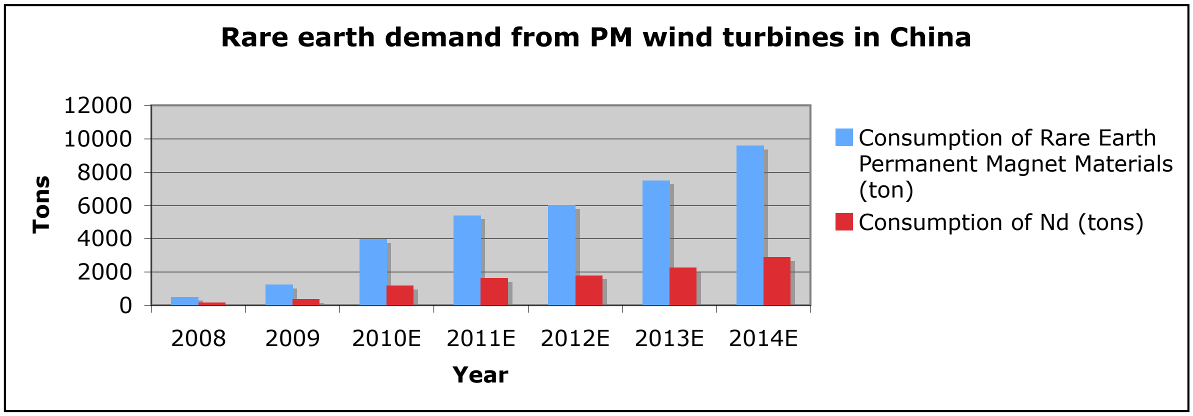
Source: U.S. Energy Information Agency (2010) and Hatch (2010)

According to the reference case presented in the DOE's Annual Energy Outlook 2010 (which conservatively estimates no growth in the year 2014 due to the expiration of a federal incentive scheme), grid-connected wind-powered generating capacity is expected to rise from 24.9 GW in 2008 to 64 GW in 2014.[214] Even assuming that no more than 15 percent of added capacity in any given year will stem from PM-based turbine models, it is evident that U.S. demand for REEs (and particularly for neodymium oxide) will be significantly higher in the next few years than it has ever been the past.[215]

In China, the country with the highest annual growth rate for installed wind capacity, new direct-drive PM wind turbines are projected to capture an even greater segment of the market. In 2009, direct-drive permanent magnet units made up about 15 percent of new added wind power capacity in China, but this figure is expected to rise to 20 percent in 2010. By 2014, direct-drive permanent magnet units are expected to make up over 50 percent of new added wind capacity in China.[216] China has an official target of reaching 100GW of wind capacity by 2020, and is on pace to meet that goal.[217] Even as the growth of wind power installed capacity slows down, the average compound annual growth rate of direct-drive permanent magnet units is expected to be 28 percent in China. (See figure below for data on forecast growth in China's wind industry—and related REE requirements—as PM-based designs expand over the next four years).

[214] U.S. Energy Information Agency, *Annual Energy Outlook 2010*, Department of Energy, 2010, http://www.eia.doe.gov/oiaf/aeo/electricity.html.
[215] Gareth Hatch, "Siemens Launches Permanent Magnet-based Gearless Wind Turbine." Technology Metals Research, 2010 http://seekingalpha.com/user/466501/comment/996431.
[216] ResearchInChina, "China Rare Earth Permanent Magnet Industry Report, 2009-2010," accessed November 21, 2010, http://www.researchinchina.com/Htmls/Report/2010/5875.html.
[217] Harvey 2010.

NdFeB demand in China's wind power industry



Source: ResearchInChina (2010)

Key industry players forecast that magnets (a broader application of which PM wind turbines represent only one end product type) will be the key growth driver for REE demand in 2014.[218] They predict at 12 percent growth rate in demand per annum for REE used in magnets. That translates to a 2014 demand of 50,000 metric tons, which represents 28 percent of total predicted demand for REE.[219] The global wind energy sector could consume 9,000 to 13,500 tons of rare earth oxides (REO) globally in 2014, increasing demand of Nd and Pr by 20-30 percent from current levels and challenging already tight supply chains.[220]

[218] Lynas Corporation 2010.
[219] Ibid.
[220] Smith 2010.

Future Trends and Substitutes

Many leading wind turbine manufacturers have begun to use rare-earth based permanent magnet generators (PMGs), including Siemens, Vestas, and Goldwind, China's largest wind turbine manufacturer.[221] GE and Siemens have each made massive investments in PM wind energy, and are forging ahead to refine PM technologies.[222] Additionally, PM turbines are expected to account for an increasingly significant proportion of offshore wind developments, since these are particularly expensive and difficult to maintain and repair.

As of yet, there are no viable alternatives to the use of REE in PM wind turbines. The use of neodymium enables weight and size reductions, since magnets with neodymium have a magnetic force nine times stronger than conventional magnets. Heavier turbines need stronger foundations, which mean fortified concrete and higher costs. The most similar alternatives, which are more costly than REE-based PMGs today, are made from samarium and cobalt or from samarium, praseodymium, cobalt and iron.[223]

Recent industry reports suggest that some magnet makers are developing a technique called grain boundary diffusion alloying, which enables the reduction of the dysprosium content of NdFeB magnets.[224] However, it seems that there are no substitutes for neodymium in permanent super magnets, despite years of study. Save resurgence among non-PMG-based gearbox wind turbines, a rapidly growing level of demand for REE to support the addition of wind power capacity appears inevitable.

---

[221] Ros Davidson, "China to cut export of rare-earth metals," Windpower Monthly, October 19, 2010, http://www.windpowermonthly.com/news/1035867/China-cut-export-rare-earth-metals/.
[222] Siemens 2010.
[223] Emilio Godoy, "Rare Metals Could Trigger Next Trade War," Business Mirror. June 28, 2009, accessed November 23, 2010 at http://www.molycorp.com/06_29_09_rare_metals_trigger_trade_war.asp
[224] Tuer 2009.

FUEL CELLS

Market Overview

Fuel cells are essentially chemical batteries that convert fuel, such as hydrogen or natural gas, into electrical energy. Unlike a battery, fuel cells do not lose their charge as long as there is constant access to fuel. Fuel cells have a number of practical applications, from stationary power generation systems to transportation to consumer electronics. According to the DOE, fuel cells have "efficiencies, reliabilities, and environmental performance unmatched by conventional electricity generating approaches."[225] Because combustion is avoided, fuel cells offer a pollution-free alternative to conventional combustion generation, such as a combined cycle natural gas plant.[226]

REEs in SOFCs

While most SOFCs contain some level of REEs, the specific quantity required is technology dependent. SOFCs can either be assembled as flat plates (planar) or rolled tubes (tubular).[227] The table below includes the specific REEs in each type of SOFC.

REE Content by Fuel Cell Type

Fuel Cell Type	Rare Earth Element (g/kW)			
	Lanthanum	Yttrium	Cerium	Gadolinium/Samarium
SOFC (PlanarAnode-Supported)	9.5	21	2	<0.6
SOFC (Tubular Cathode Supported)	1400	19	-	-
Application	Provides electronic conductivity	Used as a dopant to stabilize zirconia	Used between cell layers to prevent unwanted reactions	Used as dopants for cerium

Source: Adapted from NETL (2010)

[225] "Future Fuel Cells R&D," U.S. Department of Energy, last modified April 23, 2010, http://www.fossil.energy.gov/programs/powersystems/fuelcells/.
[226] National Energy Technology Laboratory, *Fuel Cell Handbook (Seventh Edition)*, accessed November 20, 2010, http://www.netl.doe.gov/technologies/coalpower/fuelcells/seca/pubs/FCHandbook7.pdf.
[227] "Future Fuel Cells R&D," U.S. Department of Energy, last modified April 23, 2010, http://www.fossil.energy.gov/programs/powersystems/fuelcells/.

Future Trends and Substitutes

Recent innovations in fuel cell technology, such as the high profile debut of Bloom Energy's Bloom Energy Server™, an SOFC which claims to use no REEs, may offer opportunities to produce fuel cells without the use of REEs, or with significantly smaller quantities. Bloom systems are currently being installed at a number of high profile companies, including Wal-Mart, Google and FedEx. Adobe Systems recently put twelve 100 kW systems on top of their parking garage.[228]

While certain REEs can be substituted, often the substitution involves another REE or a much higher cost option.[229] Thus, it does not appear that substitution is currently an attractive option, although if REE prices increase significantly it is possible that alternatives should be revisited. However, NETL projects significant reductions in the amount of REEs necessary on a kW basis. Increases in power density, reduction in layer thicknesses, and changes in layer composition may all lead to reductions in REE demand.[230]

EFFICIENT LIGHTING

Market Overview

The lighting end-use sector is a major consumer of energy, accounting for 19 percent of electricity demand worldwide in 2005.[231] Two key lighting technologies often cited for their significant energy savings potential are Compact Fluorescent Lamps (CFLs) and Light-Emitting Diodes (LEDs). CFLs are primarily used for residential applications, replacing incumbent incandescent lighting technology, while LED lighting has broad applications in the residential and commercial sectors, aviation, and outdoor lighting.

---

[228] Woody, T. (2010). "Short on Roof Space? Adobe Plants Fuel Cells." New York Times, September 28, 2010, http://green.blogs.nytimes.com/2010/09/28/short-on-roof-space-adobe-plants-fuel-cells/.

[229] NETL 2010.

[230] NETL 2010.

[231] OECD/IEA, "Transforming Global Markets for Clean Energy Products: Energy Efficient Equipment, Vehicles and Solar Photovoltaics," International Energy Agency, 2010.

The CFL market in particular has seen significant growth over the last few decades. CFL technology was not an immediate success, due to quality inconsistencies when it was first introduced in the 1970s. However as the technology improved, the market saw substantial growth, from 83 million in global CFL sales in 1990 to over 4 billion CFLs produced in 2009, and China is currently responsible for more than 90 percent of this production.[232] Looking forward, this market has significant growth potential as many countries have established regulations that will phase out most incandescent lights.

LED technology is still relatively new compared to CFLs, representing only about 7 percent of emerging lighting technologies as of 2009.[233] However, given the experience of CFLs, it is likely that as the technology improves and becomes more affordable for a wider base of consumers, this technology could also see large growth in the future.

Future Trends and Substitutes

Overall production of fluorescent powders containing REE is dominated by China, and it is estimated that annual demand for fluorescent powder is approximately 10,000 metric tons, growing to about 60,000 metric tons by 2015.[234] Given the anticipated growth in the efficient lighting market, demand for yttrium, europium, and terbium are expected to double, according to Lynas Corporation. Furthermore, the U.S. Geological Survey cites existing shortages of europium and terbium for phosphors.[235]

Yttrium is the most widely used REE in phosphors, and there are no elements that can act as substitutes for this application. Given that Yttrium comprises a significant portion of the total REE used in phosphors, supply concerns could become a serious issue over time as the industry grows. With a lack of substitutes for one of the key elements, recycling may be a longer-term solution. Currently many CFL recycling programs exist, but their primary goal is safety (since CFLs contain a small amount of mercury), so a focus on processes to recycle the rare earth phosphors would be needed.

---

[232] OECD/IEA 2010.
[233] "Emerging Lighting Technologies and the Global Market," MarketsandMarkets, accessed November 30, 2010, http://www.marketsandmarkets.com/Market-Reports/emerging-lighting-technologies-and-global-market-120.html.
[234] "Research Report on Chinese Rare Earth Industry, 2010-2011," Research and Markets, accessed November 29, 2010, http://www.researchandmarkets.com/research/74ebdf/research_report_on.
[235] USGS 2008 Minerals Yearbook.