RIETI Policy Discussion Paper Series 12-P-005

The Battle for New Resources: Minor minerals in green technologies

ABRAHAM, David
Former Visiting Scholar, RIETI

Research Institute of Economy, Trade & Industry, IAA
The Research Institute of Economy, Trade and Industry
http://www.rieti.go.jp/en/

RIETI Policy Discussion Paper Series 12-P-005
March 2012

The Battle for New Resources: Minor minerals in green technologies

David S. ABRAHAM*
Former Visiting Scholar, RIETI

Abstract

Emerging green technologies are the most significant and realistic path to reducing global dependence on polluting fossil fuels while simultaneously decreasing the reliance of many countries on oil-rich regimes to meet their energy needs. However, as nations begin to rely on green energy products, they are trading one set of resource dependencies for another. Wind and sun produce energy, but rare minerals like neodymium and tellurium are essential in applications to harness that power. To the extent countries begin to rely on these green energy sources to produce, use, and store power, the geopolitical significance of rare minerals rises. It highlights an emerging reality: the battle for new resources. Despite the importance of green technology to the future of global power generation, very little analysis to date has outlined the geopolitical repercussions of shifting reliance on traditional fossil fuels to an undefined mix of alternative energy sources. Previous research assumes that green technology adoption is limited by its current high cost; will free societies from dependency on countries producing fossil fuels; and is a panacea for reducing environmental degradation caused by those fossil fuels. Green technology therefore can make countries more energy secure. However the reality is stark: the world cannot meet projected green technology demands with its current rare mineral resource supply. There are steps that countries can take to address increasing minor metal demands including R&D investments, recycling, and encouraging better product design. But shortages of some minerals are inevitable and will impact geopolitical relations.

Keywords: Rare earth minerals, minor minerals, natural resource security, alternative energy, China, Japan, the United States
JEL classification: Q34, Q27, O33

* The author would like to thank Eli Kintisch, Massachusetts Institute of Technology, Roderick Eggert, Colorado School of Mines, as well as staff at the Ministry of Economy, Trade and Industry and the United States Department of Energy for comments and thoughts during the writing of this paper.
E-mail: davidabrahamst@yahoo.com

Introduction

Emerging green technologies are the most significant and realistic path to reducing global dependence on polluting fossil fuels while simultaneously decreasing the reliance of many countries on unsavory oil-rich regimes to meet their energy needs. However, as nations begin to rely on green energy products, they are trading one set of resource dependencies for another.

Wind and sun produce energy, but rare minerals like neodymium and tellurium are essential in applications to harness that power. To the extent countries begin to rely on these green energy sources to produce, use and store power, the geopolitical significance of rare minerals rises; it highlights an emerging reality: The battle for new resources.

Despite the importance of green technology to the future of global power generation, very little analysis to date has outlined the geopolitical repercussions of shifting reliance on traditional fossil fuels to an undefined mix of alternative energy sources.[1] Previous research assumes that green technology adoption is limited by its current high cost; will free societies from dependency on countries producing fossil fuels; and is a panacea for reducing environmental degradation caused by those fossil fuels. Green technology therefore can make countries more energy secure. However, the reality is stark: the world cannot meet projected green technology demands with its current rare mineral resource supply.[2]

This paper will frame the current struggle to access minor minerals, materials crucial for green energy production. It will review the market dynamics of the minor mineral trade and delve into the influences shaping a growing geopolitical competition between nations and companies as they face the challenges of meeting a changing energy landscape. Previous research views natural resource security from the vantage of a specific country or region. This paper attempts to examine natural resource security challenges more broadly. It contributes to the current research by highlighting specific geopolitical concerns as well as offering policy solutions.

I. Natural resource security and minor minerals

Just a few years ago, few apart from traders, industry analysts, and government officials had heard of minor (or rare) minerals. Minor minerals are used in small quantities in numerous high tech and green applications due to their unique magnetic and mineral properties. Their irreplaceability makes them the yeast in the world's high tech bakeries and their increased use adds a new complexity to ensuring today's resource supply lines. Individual minor minerals have production levels of less than 150,000 tonnes annually -- some less than 1,000 tonnes.[3] By comparison, base metals, such as copper, are produced at 16 million tonnes annually.[4] Minor minerals had been so easy to obtain less than five years ago that one mineral trader joked he could nearly "name his own

[1]This paper examines two main aspects of green technology: products designed to be more energy efficient such as fluorescent lighting, and new power generation sources, such as wind turbines, which shift reliance away from fossil fuels to alternative sources.

[2] See Department of Energy (2011). The DOE Critical Materials Study points to a number of elements including yttrium, dysprosium, europium and terbium that the world is currently in deficit and future supplies appear inadequate to meet future demand. Jack Lifton, a well-known analyst of such metals, coined the term technology metals to describe them. See http://www.techmetalsresearch.com/what-are-technology-metals/. Some analysts refer to these elements as critical materials or technology metals due to their end use in high-tech equipment from missiles to wind turbines and because of their unique electromagnetic properties

[3] See USGS (2011). 2009 Minerals Yearbook. Minor metals have historically been considered metals that do not trade on the London Metal Exchange.

[4] USGS Commodity Reports (2012).

price" when he bought them.[5] Even some executives whose green technology products relied on minerals such as dysprosium, lithium and selenium had little idea of their importance or their supply concerns.[6] But that changed in the late summer of 2010 when China restricted official exports of vital rare earth minerals -- a subset of 17 elements on the periodic table -- to Japan after a territorial conflict.

Over the past decade, Beijing began systematically taking control of the country's minor mineral market through production and export regulations. Through these policies as well as geological good fortune and fortuitous market timing, China became the largest producer (and consumer) of many of these minor minerals (See Chart 1). Other than metal traders and some government officials, few had taken notice of China's increasing market dominance until the 2010 export ban and subsequent mineral price increases (See Chart 2).

The Japanese government inferred that Beijing had used mineral trade as an offensive weapon. Tokyo was able to direct global attention to resource vulnerabilities and rally global governments to encourage China to resume mineral exports to Japan. Natural resource security had become both a geopolitical and economic concern around the world. Not since the late 1970s -- when oil price shocks emanating from the Middle East and cobalt supply shortages from war in Africa brought forth concerns about mineral resources -- had the world taken a serious look at its resource supply chains.

Natural resource security threatens the growth of the green economy. Almost 90% of business leaders in the renewable energy sector believe that their businesses are affected by mineral and metal scarcity, ranking it first among six other industries including automotive and high tech.[7] Many alternative energy technologies, such as wind turbines, hybrid vehicles and solar panels, use a technical cocktail of minor metals to drive their performance. For example, a new hybrid vehicle alone uses nearly ten rare earth elements in at least 8 different components (See Chart 3).[8] Developed countries in particular are now consuming ever increasing amounts of minor minerals in products such as lithium batteries, indium coated computer screens and rare earth batteries for wind turbine applications (See Chart 4). The growth in demand for green technologies in particular will lead to an increased need for a greater variety and quantity of minor minerals than the world has previously produced.[9] Even as manufacturers attempt to reduce reliance on difficult to access minor minerals due to supply and cost concerns, heightened demand for green technologies will strain the ability of supply chains to meet global minor mineral needs.

II. The future growth of green technology

Green technology will play a critical role in power generation as countries seek to decrease dependence on imported fuels, strengthen their energy independence and reduce the use of polluting fuels. Although global energy use is projected to increase by one third by 2030, the growth of green applications will expand more quickly (See Chart 5).[10] And due to government policies, some nations will see much faster green energy adoption rates than others.

[5] Private conversation with Japanese mineral trader.
[6] See Congressional Record Public Law, Ike Skelton National Defense Authorization Act of 2011, PL 111-383. Even the US military had difficulty determining which vital minerals were needed for critical defense applications.
[7] See PWC (2011).
[8] See Oakdene Hollins (2010).
[9] The neodymium-iron-boron battery is mixed with dysprosium to allow it to work at higher temperatures.
[10] See International Energy Agency, (2011a) World Energy Outlook.

Adoption rates of specific technologies depend on numerous factors including government policies; carbon emissions costs; the price of fossil fuels; global economic growth; power generation costs; and the cost of manufacturing green energy technology equipment. In addition, advances in other technologies such as battery storage can increase the demand for green energy technologies. Since most green energy sources rely on intermittent power sources such as the sun and wind, cost effective storage of power increases green energy reliability and therefore its adoption rates. All these factors interact and complicate the ability to predict the actual growth path of a particular technology, let alone the entire field.[11]

Using recent history as an indicator, double digit growth rates are set to continue for power generation technologies that replace fossil fuels as countries try to meet climate goals. Over the past three years, solar capacity has grown annually at the rate of roughly 40%. The industry expects at least double digit growth and as much as 30% annual growth over the medium term.[12] By 2020, the European Photovoltaic Industry Association projects annual installations of 281 GW of solar power capacity, compared to the total current global solar PV installations of almost 40 GW (See Chart 6).[13] Similarly, the Global Wind Energy Council predicts wind power could expand from 93 GW in 2007 to between 572 GW and 2,341 GW by 2030 (See Chart 7).[14]

The sales of more energy-efficient products, most using minor minerals, are also poised to experience similar growth. For example, the International Energy Agency estimates by 2030 demand for additional lighting will increase 55% from 2005. The lighting sector, which consumes nearly 20% of all electricity demand in the US, is experiencing a drastic shift in technologies. Consumers are switching to more energy efficient products due largely to government efficiency mandates to increase the use of energy-saving floursecent, Light Emitting Diodes (LED) and Organic LEDs.[15] Production of compact flourescent lightbulbs has already increased according to the latest IEA (See Chart 8). The market is set to expand globally over the next few years when regulations force a shift away from old lighting technologies.[16]

Broad green energy mandates, like California's resolution to obtain 33% of its energy from renewable sources by 2020, will further increase demand for green technology.[17] Germany's decision to phase out nuclear power after Japan's Fukushima nuclear power plant meltdown in 2011 also adds pressure on other energy sources to restore the 21.4 GW shortfall in Germany's previous power capacity.[18] Much of the shortfall can be made up by traditional fuels, but alternative energy innovators will be under pressure to develop green energy applications to ensure Germany can still meet its climate goals. If other countries follow suit, there will be additional pressure on green technologies. Since green technology is on a smaller scale than more conventional power generation sources, closure of one nuclear power facility necessitates the use of approximately

---

[11] See Department of Energy (2011), US Critical Materials Strategy, p. 79. The US Department of Energy notes "over the period from 2010–2025, the rate of future technology deployment for wind turbines, advanced vehicles, photovoltaic power systems and high-efficiency lighting is highly uncertain."

[12] See Electric Power Research Institute/Greenpeace (2008).

[13] See European Photovoltaic Industry Association (2011).

[14] See Global Wind Energy Council (2011).

[15] See International Energy Agency (2010).

[16] See International Energy Agency (2010). Although recent industry statistics in the US indicate a flattening in demand over the past year, demand will likely increase once regulations necessitating a switch to more energy saving lighting take effect during the next few years.

[17] See McGreevy, P. (2011).

[18] See Dempsey, J. and Ewing, J. (2011), German Federal Environment Agency (2011).

2,000 wind turbines to compensate for the loss (See Chart 9).[19] Therefore, a significant amount of new resources is needed to replace large traditional power plants.

Due to its size and its regulatory opacity, the growth of green technology in China will shape the industry. Beijing is set to commit roughly $1.5 trillion, or almost 5% of GDP annually, to grow "strategic industries." This list of industries includes information technology and high-end equipment manufacturing, but also advanced materials, alternative-fuel cars, and new energy technologies. Beijing's goal is to drastically raise productivity so that these strategic industries contribute 15% of the country's GDP growth by 2020, up from 5% today.[20]

Based on Beijing's continued desire to reduce the country's reliance on imported fossil fuels, Chinese solar and wind companies are likely to receive sizeable government largesse. This support has the potential to spur growth and drive Chinese alternative energy development and innovation as well as increase demand for minerals. Green electric generation has much room for growth in China since solar and wind sources account for less than one percent of power generation (See Chart 10).[21]

III. The amount of minor metals used in green technology

Solar, wind and new lighting technologies require specific components made from minor minerals such as rare earth magnets for wind turbines and next generation vehicles, and phosphors for lighting technologies. For example, neodymium and dysprosium are at the core of powerful magnets because of their strong magnetic properties. Fluorescent energy-saving bulbs need rare earth phosphors to produce certain light.

Growth in green technology will necessitate production of more of these minor minerals, but predicting the demand for specific minor metals over the next twenty years is more guesswork than science. According to the US Department of Energy, **"**the market dynamics that affect REEs (Rare Earth Elements) and other key materials vital to the commercialization of clean energy technologies are not captured by traditional economic models or simple economic analyses."[22] As with predicting the future growth of green energy applications, estimating future resource use hinges on assumptions about future government policy, technology advances and the state of the economy. Additionally, estimates are affected by developments that reduce the resource intensity of products.

In the most comprehensive study published on mineral demands of green technologies, the US Department of Energy's 2011 Critical Materials Strategy lays out future scenarios. However, they likely understate potential demand (See Chart 11-12).[23] First, the agency assumes that all non-green technologies that use minor metals would increase at the rate of growth of the global economy. In other words, the Department does not take into account likely improvements in high tech gadgetry whether for future iPads or defense systems, or the invention of new products that rely on minor metals, that would grow more quickly than the world's economy. These technologies are poised to use more minor metals as they too rely on the more efficient conducting properties that minor metals provide. Second, the agency did not have the resources to examine the impact of certain green technologies, e.g., grid storage batteries, magnetic refrigeration and fuel cells, which could

[19] See Electric Power Research institute (2011).
[20] See Abraham, D.S., and Ludlow, M. (2011).
[21] See International Energy Agency (2009).
[22] See Department of Energy (2010), US Critical Materials Strategy, p. 90.
[23] The Strategy states that due to enormous market uncertainties it is difficult to make definitive predictions.

have a large market impact with a technological breakthrough.[24] Despite these shortcomings, the paper concludes with a stark reality: the world cannot meet its future green technology demands with its current mineral resource supply.[25]

IV. Market supply risks in meeting green technology needs

Green technology advocates and some market analysts often work on the premise that the primary constraint to adopting green generation technology will be its higher total operating costs compared to current generation costs. The underlying assumption is that if the mineral market is left solely to supply and demand forces, sufficient minerals will be produced to meet green energy needs. Analysts have often overlooked the availability of these minerals and have not acknowledged the variety and number of them needed to make individual green technology products.

Previously, there has been little awareness of the environmental toll green technologies have and how this impact may prevent the development of an adequate supply of needed minerals. For example, Lynas Corporation's rare earth processing plant in Malaysia has had difficulty gaining permission to start permanent operations due to large public opposition to the radioactive waste the plant produces.[26] Similarly, China's stated rationale for reducing certain rare mineral production and exports is to reduce the tremendous environmental damage operations have had on the country.

In addition, the presence of a particular mineral in the ground does not mean that it can be mined or will eventually find its way into a wind turbine since a number of factors, from mineral concentration to its deposit location, determine the feasibility of extraction.[27] Also, knowing the global availability of particular resources in the ground is far from an exact science. Estimates are made on imperfect data. Although increased prices will lead to greater resource finds as they stimulate exploration and the development of more efficient mining techniques, estimating the total amount of certain global resources is subject to great uncertainty. Sometimes these estimates are overstated. For example, despite the transparency and abundance of data available for the domestic US shale gas market, the US government recently cut its forecast of shale gas resources by 40% in one year.[28] Such a reduction in a visible and well-known resource highlights the inherent difficulty of predicting available supplies especially those resources in the opaque, minor mineral market with operations in obscure regions of the globe.

---

[24] See Department of Energy (2011), US Critical Materials Strategy, p. 8. DOE expects commercialization of these products to be far in the future or does not expect them to have a large impact.

[25] See Department of Energy (2011). The US Critical Materials Strategy points to a number of elements (yttrium, dysprosium, europium) that the world is currently in deficit and future supplies appear inadequate to meet future demand.

[26] See Reuters (2012). Malaysia Approves Temporary License for Lynas Rare Earths Plant.

[27] See Wadia, et al. (2009). Although not a minor mineral, silicon is the second most commonly available element in the earth's crust at 28% of the earth's crust by mass. However, it costs roughly $1.70 per kg to mine from the ground while iron, approximately 4% of the crust, is far cheaper at $.03kg due to energy costs and mining methods.

[28] See Urbina (2012). New Report by Agency Lowers Estimates of Natural Gas in U.S. The government estimated that the US has 482 trillion cubic feet of shale gas, a reduction of 827 trillion cubic feet from the previous estimate a year earlier due to newer data.

Numerous obstacles and risks can prevent the right mineral in the right grade from reaching the right producer at the right time. Increased specifications, quantities and numbers of minerals demanded by suppliers add pressure on supply chains to meet the needs of green technology manufacturers. The text box below analyzes the risks in meeting future green energy demand.

Risks to supply

First, many minor metals are mined as by-products of more abundant and more easily accessed base metals. For example, copper must be mined in a specific manner to produce the by-product tellurium. This co-mining situation subjugates tellurium production to the whims of the copper markets due to the differing sizes of the markets. In 2010, the total market for tellurium was exponentially smaller, roughly 200 to 500 tons were produced; tens of thousands of times less than the amount of copper produced.[29] If the price of copper drops, and miners decide to produce less, there is little economic incentive to mine for tellurium regardless of its price. In addition to base metals being more common, they are often easier to process than the secondary elements located with them (See Chart 13).[30]

Other minor minerals are mined in groups such as rare earth elements, with some minerals far more common than others. To produce neodymium, for example, lanthanum, a more common element, must also be produced. This skews profit margins because ensuring supplies of less common elements creates a glut and lowers the price of more commonly found ones. Such a scenario makes it difficult for certain mines to survive if they produce less of those elements which are in demand. Since demand is not static due to the evolving resource needs of emerging technologies, maintaining profitable, stable long-term supply chains to meet potential demand for all rare earth elements will prove challenging.

Mining operations are also becoming more expensive to run due to the cost of electricity, mining supplies, labor and raw materials which are increasing at a rate higher than general inflation (See Chart 14). In addition, costs are rising as mining operations must move to increasingly more remote locations because easier to access and higher mineral ore grade have already been mined. This leads to more expensive green technology inputs and higher process costs for green tech applications. Not only is cost increasing, mines and processing supply chains can take up to fifteen years to establish. Increased mineral demands, especially ones that are not anticipated, may be met only with a time lag.

What is more, because of the capital-intensive nature of mining and the volatile price of metals, especially minor ones, many investors prefer to invest in the stability and size of the base metal market rather than invest in rare metals market. In addition, since market demand in minor minerals will continue to be volatile due to its small size, a glut of minerals and a fall in their price for several years could force mines to shutter leaving countries vulnerable to an upswing in demand.

For example, in 2000, a supply shortage of tantalum, due to increased use of mobile phones and inadequate supply chain capacity, led to capacitor shortages.[31] The supply shortages subsided with the economic slowdown and as more supply came online. Although this incident had

[29] See Moss et al. (2011), p. 148 and Phillips, D. (2010).

[30] See Department of Energy (2010), US Critical Materials Strategy, p. 92. The process is even more complicated for rare earths due to their technical processing needs. "The iron produced as a primary product in the Baotou (China) mines is less valuable by weight than the REE byproducts, but annual iron production represents more than 100 times the value of the bastnasite ore [the ore which contains rare earth elements in Baotou]. The iron is also more easily separated from the ore and processed into a marketable commodity."

[31] See CNET (2000). Parts shortage may be boon for ceramic capacitors.

few long-term repercussions, this type of shortage is likely to become more common and severe due to obstructive trade policies, mining restrictions and increasing and irregular resource demands due to emerging technologies.

In addition, processing certain minor metals can be very complex. Separating rare earth minerals from ore and processing them to a useful end-state is not standard or simple and can produce radioactive material. This makes establishing a supply chain subject to not-in-my-backyard concerns of residents. The processing of rare earths has led some analysts to comment that these substances are as much chemical as they are mineral.

Finally, a dearth of trained geologists, especially in the US, threatens the ability to develop supply. It takes years of on-the-job training for geologists and engineers to develop mines and processing systems. Over the next 15 years, the mining industry will lose more than half of its senior skilled workers.[32] A lack of qualified geologists will strain the capacity of US firms to develop mines.[33] Japan's lack of domestic mining operations has similarly reduced the country's capacity to develop mining projects globally.[34]

V. Geopolitical supply risks in meeting green technology needs

China dominates the rare earth market as it produces 97% of all rare earth elements even though possessing just less than 40% of known reserves. But China does not just have a controlling influence on the rare earth market, it also dominates the production of numerous other minor minerals, such as antinomy and indium. Production and export quotas as well as export certification; higher export pricing and increasingly stringent environmental regulations to reduce environmental damage have helped the central government gain greater control over the natural resource sector. These practices put non-Chinese based green technology companies, relying on these minerals, at a disadvantage due to supply risks.

Some politicians assume that with enough pressure China may soon relent and loosen its export controls. This month the US, the EU and Japan announced they would proceed in a case challenging China's rare earth mineral export policies at the World Trade Organization (WTO). This case comes after a decision earlier this year in which the WTO found China's export controls of other minerals in violation of trade rules. Beijing's use of export controls and its monopolistic rare earth producing position are at the heart of a strategy to attract foreign technology and to build world-class companies that create jobs. Government officials eye firms like Hitachi, once a mining company but now a top-tier electronics and infrastructure conglomerate, as a role model for its industrial development. Chinese officials attract foreign companies to build operations in-country by offering unrestricted access to domestic resource supply. Beijing hopes its domestic industries will benefit from foreign firms' advanced technologies and eventually dominate their markets globally, especially in green technologies.

The difficulty in dealing with natural resource policy globally is that there is no effective international forum to address these issues. Legal action through the WTO is a blunt foreign policy tool that has limited ability to influence another country's natural resource policy. Although the recent WTO decision may change China's management tools, such as export quotas, the ruling will not change Beijing's strategy of heavy government influence in the mining sector and using domestic resources to build advanced technology sectors. The government began to consolidate control of

[32] See Mining and Engineering (2012). p. 22.
[33] Conversations with academics at Colorado School of Mines.
[34] See Ministry of Economy, Trade and Industry (2011).

the market over the past few years into the hands of large state-controlled firms. In a sign of increasing control, state-owned producers such as Minmetals stopped all production last year for several months, despite high prices, and still had a near 100% increase in profits for the year. Consolidation also helps to reduce black market exports, which were more than 30% of all rare earth exports.[35] Beijing's control of the market has produced uncertainty around future supplies outside China. This confusion has led a number of companies to establish an operational presence in the country. Beijing's strategy has already succeeded to some degree even if the government now modifies its trade policy. Regardless of China's export controls, the world still faces a critical shortfall of certain minor minerals essential to green technologies (Chart 15).

Beijing sees sovereign risks as well. China has indicated its dysprosium and other rare mineral supply is limited and the world needs to start finding sources elsewhere. However, Chinese government officials feel other nations, especially in the West, have thwarted its effort to increase supply of minerals by rejecting China's investments.[36] Although China is a major supplier and consumer of minerals, sovereign risk in the mineral sector is not limited to the country. Other nations have major influence over the market for certain minerals (Chart 16).

Regulations in resource producing countries -- such as demands to process minerals domestically -- also pose a risk. For example, Indonesia's 2008 requirement that domestic minerals be processed within the country, rather than being exported, complicates the ability for companies to increase supply to meet growing mineral demand. It raises the price of production as firms have to build expensive new facilities.[37]

Instability and the potential for conflict erupting near mining operations is always a sovereign risk especially in developing countries. Conflicts, most notably those in the 1970 and 1980s involving groups in the Democratic Republic of the Congo and neighboring countries, have historically added instability to supply lines. Simmering conflicts in resource rich nations can stop the supply of minerals to the market or make it difficult to bring in professional assistance to mining operations to efficiently extract as much resource as possible. Instability is particularly damaging in the minor minerals market where a country or just a few mines usually meet the world's needs. Strikes, as well, including a strike this February at a South African platinum mine, raise supply risks and also the cost of minerals.[39] Finally, regulations in developed countries, such as a provision in US financial regulations that bans companies from buying "conflict minerals," also increases supply risk as it prohibits companies operating in the US from buying minerals from certain countries.[40]

Concentration in the mining sector

Antimony operations in Lengshuijiang, Hunan Province, China produce roughly 60% of the world's antimony; nearly 85% of the world's niobium comes from the Araxá Deposit in Brazil; and Sociedad Química y Minera de Chile S.A. and Chemetall SCL operating at the Salar de Atacama in Chile produce 65% of the global supply of lithium.[38]

[35] Personal interviews with Chinese officials

[36] See Jiao (2011). "In 2009, China Nonferrous Metals Mining Group Co Ltd was blocked from buying a controlling stake in rare earths miner Lynas Corp. Australia also stymied China Minmetals Corporation's bid for Oz Minerals' Prominent Hill copper and gold mine because the mine was too close to a defense rocket range."

[37] See Reuters (2008). Indonesia Parliament Passes New Coal Mining Law.

[38] See USGS Mineral Reports, Antimony (2012), Global Metals and Mining Website (2012), and Goonan (2012) p, 5.

[39] See Cooke, C., & Wild, F (2012). Impala Dispute Deepens as Workers Demand Equal Pay Rises.

[40] See Brookings (2011). Section 1502, of the Dodd-Frank Wall Street Reform and Consumer Protection Act, imposes reporting requirements on companies operating in the US to certify that minerals were not acquired in areas of conflict.

VI. Previous studies on supply risk for green technology

Previous studies have examined supply concerns of minor minerals. Many take a country or regional perspective such as those from the US government or the European Commission. Chart 17 highlights conclusions from several reports that analyzed supply risks for several minerals. What is most notable is that despite similar analysis, the studies have very different mineral security concerns depending on the assumptions of the authors (Chart 17).

Hoenderdaal (2011) examines many of the assumptions needed to make supply adequacy predictions for dysprosium. He thoroughly analyzes future dysprosium use by calculating the resource intensity of current green technologies as well as the growth in their deployment. He develops several scenarios that incorporate future recycling predictions. His results confirm what other analysts have projected - over the medium term the world is short of dysprosium. However, over the next forty years, he shows the total amount of dysprosium demand will not exceed the world's resources. [41] His assumption is that dysprosium resources are significant enough over the long-term to meet demand (See Chart 18-19).

However, what is missing from the analysis is a discussion of the supply constraints emanating from economic, political and environmental realities which make getting the right amount of resources to the right place at the right time at a reasonable cost extremely complex as noted above. In addition to supply constraints, unique properties of dysprosium make it likely to be used in numerous potential technologies, creating additional future supply needs. (Dysprosium and other rare earth elements face deficits--See Chart 20).

VII. Future geopolitical and market developments

The lines for the battle over new resources and green technology are shaping up along national lines, between China and Japan over rare earths; between the US and China over subsidies to the solar industry; between Korea and Japan in developing lithium resources in Bolivia. Some of these disagreements, such as the rare earth conflict between Japan and China, are paradoxically positive for long-term natural resource security: the conflict highlighted the increasing shortage of certain rare earth elements and spurred investment in new projects that will increase long-term supply capacity. It also highlighted the increasing reliance on minor metals for products the world now relies upon and restarted the discussion on government's role in natural resource security. [42]

There are several recent trends that are set to continue in the minor minerals market that will impact green technology deployment.

[41] See Hoenderdaal (2011). p 68.

[42] Complete resource depletion is not a geopolitical concern, rather it is limited supply. (Paradoxically, if minerals are depleted, there is little geopolitical risk as countries will not include accessing non-existent resources into their foreign policy objectives.)

Increasing government role in supporting production abroad

The increasing willingness of national governments to support mining investments abroad shows they have little confidence that global markets will be able to ensure their long-term domestic supply needs. Broad national plans, like that of Japan, which explicitly state that domestic companies must supply a percentage of mineral resources to the country, try to address fears that the current market dynamic will not meet the country's future resource needs.[43] Japan feels national companies would be more willing to sell to their home markets if supplies were to become limited. However, it is unclear if this strategy will work as profit motives create incentives to sell to the highest bidder regardless of nationality.

> **An increase in one government spending can be good for all**
>
> In a world of plenty -- or at least in surplus -- government expenditures aimed at increasing a country's own domestic security actually enhance global resource security. Investments that develop resources for one nation, generally increase global supplies for all and add redundancies to enhance supply chain robustness. For example, the more China or Japan invests in rare earth projects overseas, the greater the amounts of rare earth elements available. Over time, the increasing supply makes it more difficult for one country to dominate the market.

There is greater geopolitical rather than market significance to countries adopting a government-led approach to natural resource investment abroad. When investing countries buy access to resources, they also purchase influence over the recipient country's policies. Mineral exploration is a capital-intensive investment, with much of the funds often going through the government, especially in developing countries. In addition, to the direct investment, often investing countries provide foreign assistance in the form of roads or other infrastructure. These two sources of funds benefit the leadership of recipient countries as they use the investments to tout the benefits of their leadership to citizens and potentially entrench their regimes.

As one country builds investments in a resource rich nation, it makes it difficult for other countries without similar arrangements to push their strategic, economic and business interests. For example, China's investments in Sudan have given China greater political leverage in the country, and it has complicated the efforts of other countries to push their agenda in the region. [44]

Increasing regulations and taxes

The mining and processing sector is facing increasing environmental scrutiny and regulations. This is part of a continuing trend; as nations become wealthier, they demand higher levels of regulatory scrutiny to balance environmental and economic goals. The selection of Lynas Corporation's rare earth processing facility in Malaysia avoids tighter regulations and opposition in Australia where many of the minerals are mined and in Japan where they are consumed.

Australia's recent mining tax also highlights a trend by governments to try and capture more revenue from the natural resource sector, especially as mineral prices have risen. Australia's Mineral Resource Rent Tax increases taxes on profits of firms mining iron ore and coal. The Mineral Resource Rent Tax replaces a far more aggressive proposed tax that would have taxed profits of all

---

[43] See Ministry of Economy, Trade and Industry (2011).

[44] A government-led strategy to "lock-up" resources carries inherent risks over the long-term. When investments are seen as being used by corrupt officials; lead to egregious human rights or environmental violations; or support a regime that was just thrown out of power, a backlash is likely against the particular investment or the country in general. China is now facing difficulty in its relations with Southern Sudan due to its seen role in assisting Khartoum.

mining firms.[45] Tighter national regulations and taxes may be necessary, but they add to the final cost of minerals and may make some mining operations unprofitable, jeopardizing future supplies and subsequently the deployment of green technology.

Difficulty in meeting ambitious climate targets

Without access to sufficient rare minerals, climate goals for reduced CO2 emissions will not be met. Climate goals hinge upon developing new sources of energy or more energy efficient products. Without access to a reliable supply of minor metals to make these products, manufacturers will either not produce an intended product line or use sub-optimal substitutes in their products. Researchers from MIT found that if the world keeps on a trajectory to limit atmospheric carbon dioxide emissions at 450 ppm, demand for neodymium over the next 25 years may grow by more than 700% and dysprosium by more than 2600%.[46] Such growth rates will be a challenge for industry to meet as historic growth rates for all rare earths have been around 6.5% annually.[47] Tighter supplies increase costs for producing green technology, limiting deployment options and ultimately forcing a continued reliance on fossil fuels.[48]

Rich resource deposits in specific countries could give their leaders oversized influence

Saudi Arabia and Venezuela have developed outsized global foreign policy roles solely because of the world's reliance on the oil and gas they produce. Resource dependent nations focus on these country's leadership and policy decisions and are more willing to develop accommodative foreign policies to keep the resources flowing. Likewise, a concentration of an economically viable rare mineral within a country can lead resource dependent nations and companies to court its leaders.

For example, Germany and Kazakhstan signed a $4 billion agreement to ensure German access to Kazakh resources, including rare earth minerals, as well as to assist German companies in entering the Kazakh market.[49] Human rights groups immediately criticized the deal over Kazakhstan's lack of press freedom and poor human rights record. German Chancellor Angela Merkel defended the agreement stating, "German foreign policy is always value-based, and so when discussing economic interests we also talk about human rights, the adherence to democratic principles."[50] Despite her lip service to German principles, Germany's economic interest subjugated its "value-based" foreign policy. Berlin's agreement also follows a similar deal with Mongolia last October. Such bilateral deals put pressure on other resource dependent nations to make similar arrangements, strengthening the hand of the leadership of resource rich nations. (Likewise, Japan has also delivered sizeable foreign aid for similar resource objectives to Kazakhstan and Mongolia.)

When countries put aside their values for resources, they undermine their efforts globally to push their foreign policy agenda. Berlin may yet find a way to use the deal to forward its human rights agenda. But more likely, Germany will find it increasingly difficult to push for transparency and accountability globally -- as the German-based NGO Transparency International encourages -- when it signs deals with nations like Kazakhstan. Signing such agreements makes for stronger

[45] See The Age (2010). RSPT v MRRT - The Differences.
[46] See Alonso, et al. (2012).
[47] Ibid.
[48] For example, gallium and indium have properties that could assist future solar applications, but according to René Kleijn, a chemist at Leiden University in the Netherlands, these applications "would not be heavily utilized because of a lack of available mineral resources." See The New Scientist (2007).
[49] See Eddy, M. (2012). Germany and Kazakhstan Sign Rare Earths Agreement.
[50] See Tanquintic-Misa, E (2012). Germany, Kazakhstan Sign $4B Rare Earths, Technology Agreement Deal.

natural resource security and provides business opportunities for German firms abroad, but it outsources morals to foreign leadership. The more dear natural resources become, the more such deals will proliferate.

A world of second-best technologies

Due to potential mineral shortfalls and fears of limited supplies, companies, governments and universities are not solely focused on improving current green energy designs. Rather, they are spending R&D resources on finding alternatives to certain rare minerals -- or developing second-best technologies. For example, Japan has allocated more than $1 billion in funding since 2010 to reduce its reliance on rare minerals or find new supplies. It is part of a strategy to reduce reliance on certain rare earth elements by up to 80% and minerals like indium and platinum group metals by 50%.[54] Such a focus on reducing reliance can make a nation more natural resource secure by reducing imports, but it also is a heavy handed government response that can cede efforts to improve current product design that rely on minor metals to other countries or companies. Breakthroughs using current designs may be easier and can leave companies and countries that focus on alternative product design behind the technological curve.

The threat of a shortfall can be just as damaging to the development of future green technologies as an actual shortage. Due to high capital costs, manufacturers cannot easily modify supply chains once developed. If manufacturers feel the supply for their products cannot be reliably secured or costs rise too high, companies will try to develop a different mineral standard, sacrificing product quality and efficiency for reliability of supply.

Difficulties in alleviating supply concerns

Gearless wind turbines need magnets made from neodymium and dysprosium. At recent resource intensities, producing 1 MW of power can require nearly 186 kg of neodymium and 36 kg of dysprosium per turbine.[51] Even though both minerals are in short supply, many companies are trying to cut the use of dysprosium in magnets as only 1,675 tonnes was produced in 2010, less than what the market demands.[52] Promising potential technologies to replace dysprosium do not necessarily alleviate supply concerns. Second-best alternative magnets use samarium, which faces great resource limitations and currently produces less effective magnets.[53]

Companies will seek partnerships and will shift production locations creating an unequal playing field for global competitors

Mining companies are moving further up the supply chain while manufacturing firms are moving further down. For example, in November 2011, Molycorp, the US-based rare earth mining company, Daido Steel and Mitsubishi Corporation signed an agreement to open a facility in Japan to make magnets for automotive and household purposes, using minerals produced by Molycorp.[55] In addition, other downstream manufacturing companies are acquiring direct stakes in producers. For example, Toyota Tsusho, an arm of the Toyota Motor Company, has committed to equity stakes in

[51] See Department of Energy (2010). Alonso et al. (2012) uses 171 kg per MW in calculations.
[52] See Kingsnorth (2011).
[53] See Hoenderdaal (2011), p 26.
[54] See Lawrence Livermore National Laboratory (2011).
[55] See MolyCorp (2011). Molycorp, Daido Steel, & Mitsubishi Corporation Announce Joint Venture To Manufacture Sintered NdFeB Rare Earth Magnets.

projects in Canada and India while Mitsubishi has taken stakes in lithium operations in Argentina.[56]

These agreements increase supply security for manufacturers and provide a stable buyer for mining firms. However, as these arrangements proliferate, often with support from governments, companies without secure minor metal supply chains will rely upon volatile markets and on a decreasing supply of openly traded minerals to meet their mineral needs. In the event of mineral shortages, these companies will be heavily exposed to market pricing and have difficulty finding supplies. To prevent future supply chain disruptions, some companies that make products used in green technologies may move their production operations. Showa Denko and Santoku Corporation recently moved to China to assure future mineral supplies.[57] Such a move increases a firm's supply chain security, but also the likelihood that innovations may fall into the hands of foreign competitors.

Technology and high prices will reduce demand for some minerals, but overall minor mineral demand will increase

Advances in technology have failed to drive the world to develop broad sustainable mineral consumption practices. Rather it has made the world more reliant on natural resources and minor minerals, not less. The world uses more than 27 times more ore and industrial materials now than roughly 100 years ago, while citizens in countries that consume more than the global average for any particular metal, consume more than the average for all metals.[58] This means when individuals get wealthier they demand more of all resources. And as wealth begins to trickle down to a middle class that will grow 2.5 times in the next generation to almost 5 billion people, more people will soon afford the technology and energy intensive lifestyle previously the sole province of Western countries.[59] According to the International Energy Agency, IT, communication, and consumer electronics, which now comprise 15% of global residential electricity consumption, "will double by 2022 and increase threefold by 2030."[60]

What technology has been far better at doing than reducing resource use is shifting reliance from one mineral to another, creating other dependencies. In the late 1970s and the early 1980s, General Motors and Sumitomo sought to reduce their reliance on cobalt due to supply concerns from what was then Zaire.[61] In 1983, they found a substitute for cobalt to use in their batteries. Neodymium, a once relatively abundant rare earth mineral, fit the bill. It is paradoxical that today's anxieties over rare earth mineral supply are due in part to an attempt to reduce reliance on another critical mineral. It is therefore, likely, that as technology advances and new products develop, new minerals will soon be facing critical shortfalls.

No doubt advances in R&D will reduce minor metal demand in existing technologies, although it is unclear where and when a breakthrough will come. For example, Benjamin Wiley, a material scientist at Duke University, found using copper nanowire produces the same conductive properties as indium tin oxide and would reduce the need for indium. This alternative to indium could drive down the price of emerging solar technologies and make green technology applications

[56] See Brown (2011). Lithium Resource in Argentina Attracting Analyst Interest and Kosich (2011). Toyota subsidiary to invest in Kipawa Heavy REE Deposit.
[57] See Bradsher (2011). Chasing Rare Earths, Foreign Companies Expand in China.
[58] See Graedel (2010), p. 20905.
[59] See Kharas (2010) p. 5.
[60] See International Energy Agency Website. http://www.iea.org/journalists/fastfacts.asp.
[61] See Sichel (2008).

less reliant on indium and less beholden to China, a primary supplying nation.[62] Hundreds of such promising applications are on the horizon.

The more prices increase, the more likely substitution, alternatives and advances in recycling can lessen minor metal demand. For example, Japan has reduced its reliance on the rare earth minerals of cerium and lanthanum for polishing glass over the past year, choosing to rely instead upon zirconium.[63] But there are limits to using substitute minor metals or decreasing the amount of a minor metal in a particular application before it no longer functions.

VIII. Policies nations can develop to increase access to minor minerals for green technology

To develop robust global supply chains to meet the increasing demand of minor minerals, the world will need more mines; ensure enough exploration and processing systems and have an educated work force to design supply chain infrastructure.[64] Governments can develop straightforward policies such as subsidizing mineral production or enhancing recycling efforts to increase supplies, but more creative solutions should also be considered. Below is a list of policy options that governments should consider to address their own natural resource security needs, while balancing market and economic impacts.

Recycling and design for recycling

End-of-life recycling rates of rare minerals are low, in many cases below one percent.[65] Recycling for minor minerals is more complex and costly than for aluminum cans for several reasons. First, minor metals are used in such small quantities that it is expensive to recycle significant amounts. For example, in a two-by-four foot thin film solar panel there is only roughly 8 grams of tellurium.[66] Second, minor metals are in many diverse products. Collecting and sorting them is a logistical feat that increases the costs of recycling. In addition, it is often not always evident what elements are in a particular product until the recycling process begins. Third, extracting rare metals from the original product is time-consuming and expensive as products are not designed with recycling in mind. Fourth, rare metal recycling can be hazardous due to dioxins in some products. Finally, many of the products that contain significant amounts of rare metals -- such as wind turbines and electric vehicles -- remain in use, so the metal is not available to recycle.

To overcome these obstacles, recycling initiatives will need a mix of government incentives and regulations to work. Governments should encourage best practices in the efficient use and the recovery of minor minerals at manufacturing facilities as well as support research in recycling technologies. Next, focus should be on recycling those products which are in widespread use like mobile phones and applications that use resources in high amounts. Finally, governments should develop regulations that shift the responsibility for recycling of high tech products to manufacturers from consumers. Such a responsibility (or incentive) would encourage companies to use less rare metals and would create incentives for them to design products that can be disassembled more quickly thereby decreasing the cost of recycling.

Effective product design can also extend the life of products by making them easier for consumers to replace a broken part or upgrade to a newer edition. For example, instead of buying a complete new product such as a computer, new designs could allow consumers to change certain

---

[62] See Kaften, C. W. (2011). "Copper nanowire to help drive solar cell production costs down."
[63] Conversations with rare earth trader.
[64] See Citigroup (2005). China - The Engine of a Commodities Super Cycle.
[65] See United Nations Development Programme (2011a).
[66] See Wesoff (2010). First Solar to Acquire 5N Plus to Access Tellurium.

hardware as simply as they currently replace batteries in mobile phones. Such replacement design increases the life of products while reducing material demand.

Invest in educating scientists and alternative technologies

Supporting university mining programs would be a good first step to alleviate human resource shortages and ensure a steady stream of geologists to develop mining operations globally. In 2010, the US rare-earth industry employed only 1,500 people, down from 25,000 before 1980; this compares to over 100,000 people in China.[67] It is not just the rare earth industry that lacks experienced workers or newly minted graduates. Luka Erceg, head of Simbol Materials a lithium extraction company, stated that because no university in the US offers geothermal energy degrees, it has taken him nearly a year to find qualified candidates.[68] Tokyo also is concerned about the lack of qualified geologists and mining engineers. The Ministry of Economy, Trade and Industry noted in December 2011 that, "the government will reinforce the system for human resources development in collaboration with resource development companies and universities."[69]

In addition to training geologists, governments should continue promoting joint research projects with industry that decrease the mineral intensity of specific applications, such as magnets. For example, governments (and foundations) can sponsor research and support contests aimed at producing breakthroughs in alternative technologies that use common metals. Joint research programs between universities in different nations could be encouraged to help foster innovations in developing alternative technologies that do not rely on minor minerals.

Collect and Disseminate Research

The United States Geological Survey and the Department of Energy produce the most comprehensive open source information on minor minerals. The information helps bring transparency to opaque markets thereby informing investment and trade decisions. But their data is far from complete. These agencies could benefit from additional funding for more analysis, while other governments should enhance or develop domestic agencies to produce market data. In addition, where feasible, governments should find ways to align themselves more closely with research companies and institutions. Sharing of information will be difficult as it is often proprietary, but a clear sense of technologies being developed is needed to provide accurate mineral market projections and scenarios. A more complete picture of the market would help identify bottlenecks and enhance security of global minor mineral markets.

Instead of using dysprosium, use insulation. Countries must redouble efforts to reduce domestic energy demand through investment and regulations. Broad conservation measures -- such as improving the efficiency of the US energy grid to stem electricity losses or improving the energy efficiency of Japan's poorly insulated housing stock -- reduce energy demand and the need for alternative energy. As Francois-Xavier Lienhart, the head of the housing builder Saint-Gobain Asia-Pacific in Japan stated, "It is far easier to put extra insulation in the wall of a house than to install a solar panel."[70] It is also less expensive. Likewise, it is far easier for nations to make insulation than it is to ensure access to tellurium to make solar panels.

[67] See Quinones, M. (2012), Push to Rebuild Depleted U.S. Workforce Begins in the Classroom.
[68] Ibid.
[69] See Japan Ministry of Economy, Trade and Industry (2011).
[70] Conference held at the Research Institute of Economy, Trade and Industry, November 1, 2011.

Subsidize mineral production

Governments can develop tax incentives to spur domestic production; provide insurance to reduce risk for domestic and international mining investments; or help facilitate private investment in the mining sector through taking debt or equity stakes in companies. Less traditional incentives, such as setting price floors, can ensure production and investment during volatile pricing. This may become a viable policy option when the price of one or two co-mined minerals drop, but the production of another may be needed. Although such government subsidies are costly, they create incentives for supply increases and must be weighed against the potential loss of industrial output due to a lack of minor mineral supply.

Labeling for use of rare metals

Many countries rate the energy efficiency of products to encourage companies to produce energy saving products and to educate consumers. Consumers then can use these rankings to make informed purchasing decisions regarding the impact of the product on themselves, society and the environment. Likewise, governments should require manufacturers to list critical resource elements in their products. A listing of minerals would allow consumers to decide which product to use based on resource use. Governments could then push a more resource conscious society and encourage customers (through taxation or campaigns) to buy products that have low levels of difficult to obtain metals as well as to recycle them.

Stockpile components

Instead of stockpiling minerals themselves as many governments already do, they should focus on maximizing the resources currently in use in society. Developed countries have some of the largest "reserves" of metals currently in use from hybrid vehicles to lights, according to Tokyo Foundation's Hiranuma Hikaru, who examined the Japanese market.[71] Current recycling technologies and supply chains cannot efficiently extract minor metals from current products. Most are thrown away. According to the US Environmental Protection Agency, the US discarded 75% of 2.4 million tons of electronics in 2009, without any form of recycling.[72] To reduce this waste, governments should consider safely stockpiling components of computers, LCD screens and other products that contain useful elements. Stockpiling would add to a country's resource reserves by saving products until recycling techniques to extract the highest amount of resources from the products are sufficiently developed.

Develop the International Mineral Resource Association

After the first oil shock in the 1970s, the International Energy Administration was formed to develop a response to major disruptions in the flow of oil. Over time, the organization has advanced, aiming to ensure the stable supply of energy to member nations and, "promote diversity, efficiency and flexibility within all energy sectors."[73]

It is time for nations to begin to think about developing an international agency to ensure the smooth flow of natural resources between nations. An international agency that collects statistics, writes market reports and provides a consistent forum to address natural resource

---

[71] Presentation at Foreign Press Center of Japan, October 28, 2011 and conversations with Yuji Nishikawa of Metal Economics Research Institute of Japan.

[72] See US Environmental Protection Website. http://www.epa.gov/epawaste/conserve/materials/ecycling/manage.htm.

[73] See International Energy Agency Website. http://www.iea.org/about/index.asp.

concerns between producing and consuming nations is much in need. The agency would also provide a forum for nations to discuss concerns on natural resource trade and investment issues.

IX. Conclusion

Many in resource dependent countries myopically focus on enhancing energy security as if energy is somehow unrelated to mining. Energy production -- whether from oil, gas or coal; or from green sources such as solar or wind -- relies on minerals.[74] The notion of energy security is outdated. Governments now must look holistically at natural resource security and understand that the intricate web of energy supply chains all start below the earth.

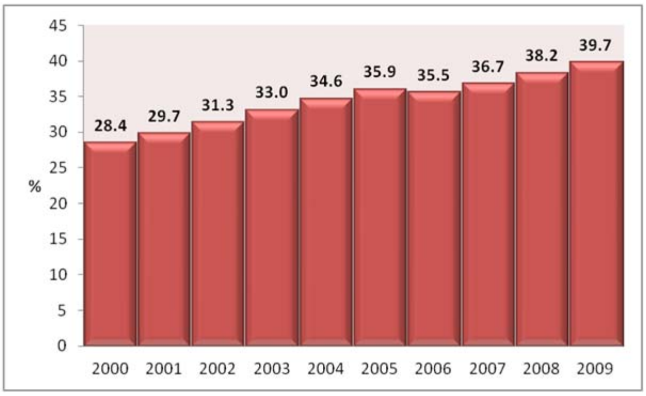
Due to the length of time required to develop and enhance mining supply chains, policymakers must now start looking at the global supply chains of our energy sources because every link is crucial. Addressing the battle for new resources will require a more engaged role for governments.

A good policy mix will include encouraging more efficient use of minerals; investment in research; and support in supply chain development. Despite these steps, shortages will eventually and inevitably occur and price volatility could shutter operations that will be needed to meet future mineral needs. Supply chains are so interconnected that floods in Thailand, conflict in the Congo and a tsunami in Japan affect the availability of green technology inputs globally. Having alternative mining and processing locations as well as clarity of supply can do more to protect an individual country's natural resource security at less cost than mining domestically.

There are enough supplies of most all minor minerals in the earth's crust to meet the demand for green technology. The problem is that sometimes they are in remote locales, in the purview of restrictive regimes or in very low concentrations. Governments must realize that a minor metal shortfall can have major strategic implications for companies and countries. Without an increase in minor mineral supply to meet growing technology demands, green energy technology will fail to become a reliable, cost effective technology to meet growing energy needs. To ensure adequate supplies of minor mineral resources, the entire mineral production supply chain needs to be examined. In the balance is the future of green energy.

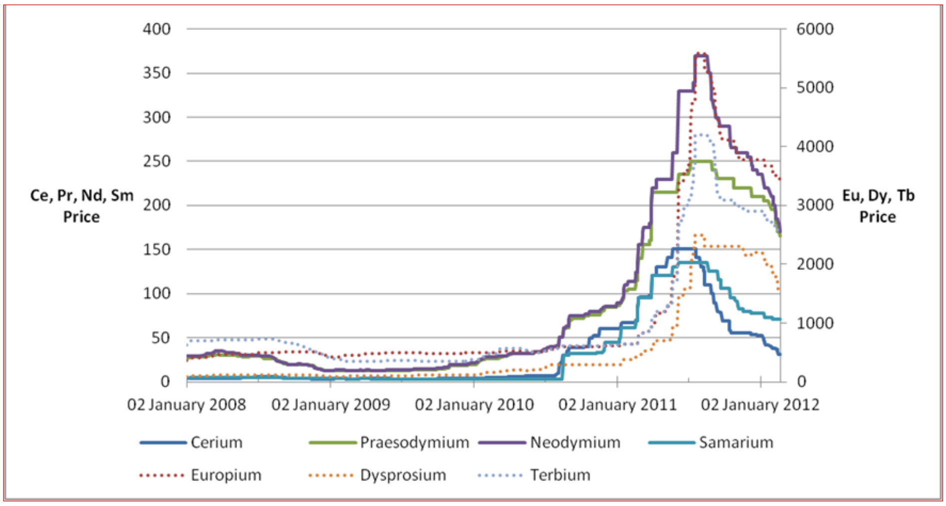
[74] Even to drill for oil, a minor mineral, tungsten, is needed.

Chart 1. China's Minor Metal Production as a Share of Global Production Percentage



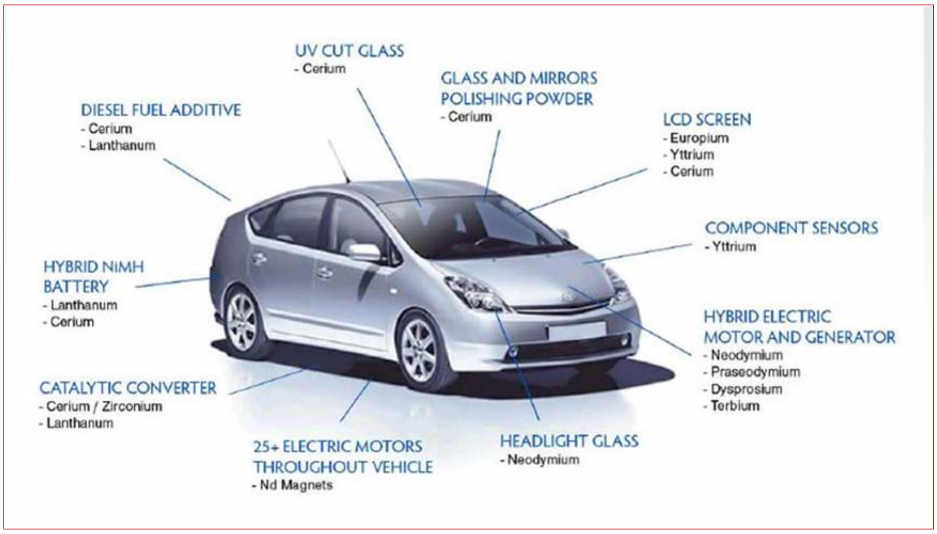
Source: Strategic Metal Investments Ltd.

Chart 2. Selected REEs Prices (US$ per kg)



Source: Generated using data from Asian Metal

Chart 3. REEs in a Hybrid Car



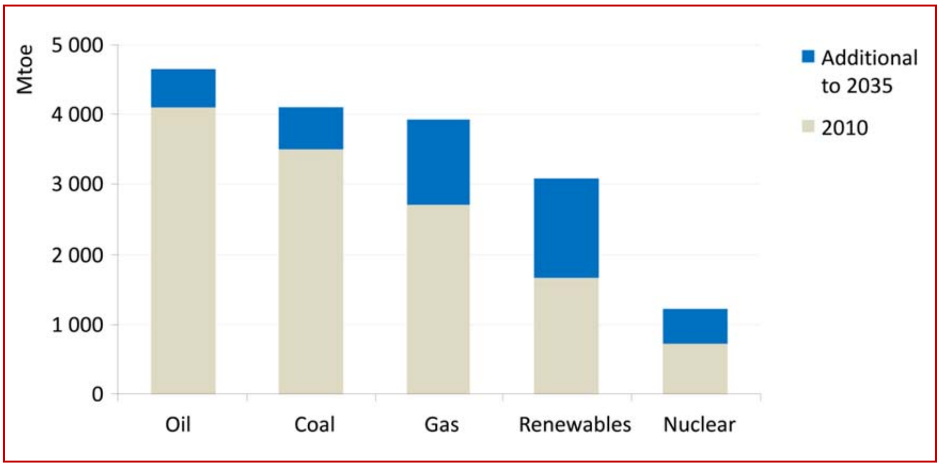
Source: Molycorp

Chart 4. Components and Rare Materials Needed for Green Technology

Technology	Component	Material
Wind	Generator/Batteries	Neodymium Dysprosium
Vehicles	Motors	Neodymium Dysprosium
	Batteries for Electric Vehicles	Lithium Cobalt Rare Earths Cobalt
PV Cells	Thin film PV	Tellurium Gallium Germanium Indium Selenium Cadmium
	CIGS thin film	Indium Gallium
	CdTe thin film	Tellurium Cadmium
Lighting	Phosphors	Rare Earths

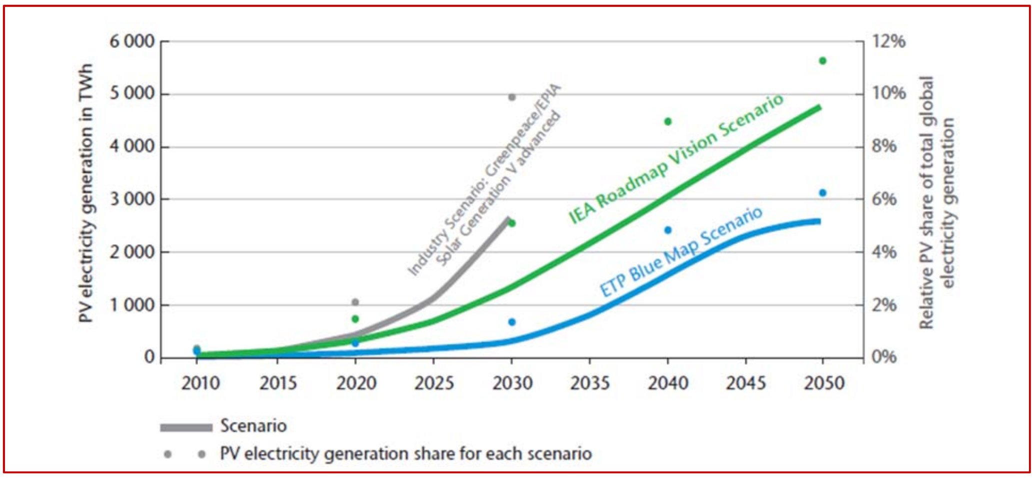
Source: US Geological Survey

Chart 5. World Primary Energy Demand



Source: International Energy Agency (2011)

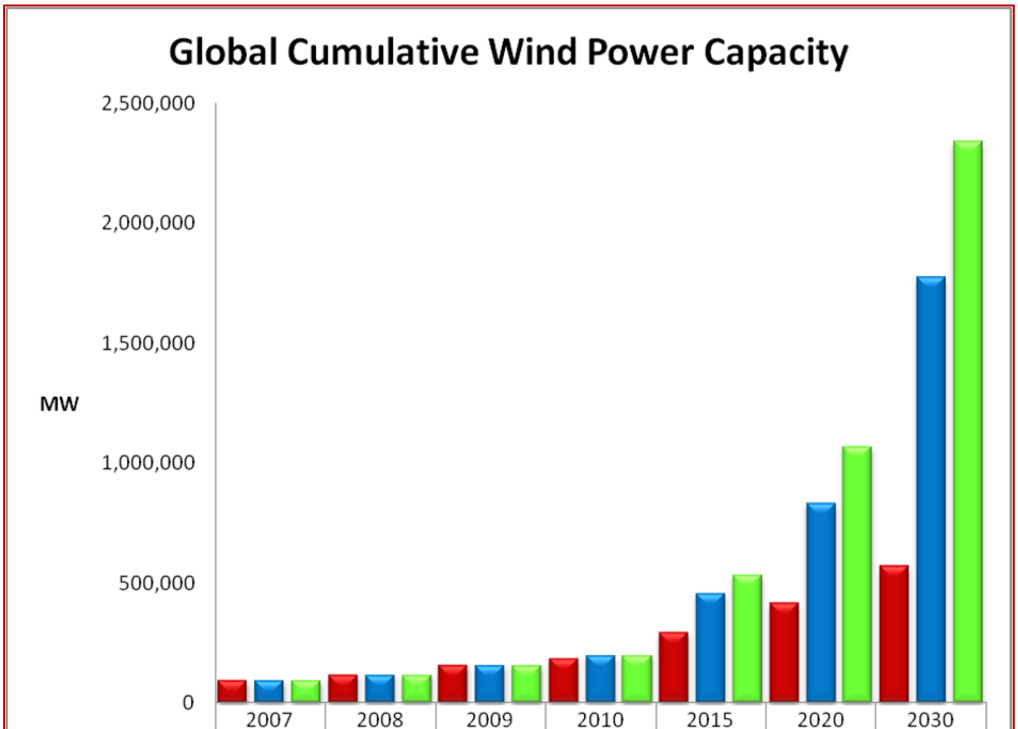
Chart 6. Solar Power Projections to Meet Climate Goals



Source: International Energy Agency

Notes:
- *The Advanced Scenario made by Greenpeace/EPIA assumes that additional support and political commitments will lead to dynamic worldwide growth of solar power.*
- *The IEA Roadmap Vision doubles the level estimated in the ETP BLUE Map scenario. IEA assumes that the recent PV market growth and associated cost reductions triggered by the adoption of PV incentive schemes may increase in a number of countries. The roadmap envisions PV providing 11% of global electricity generation by 2050.*
- *The IEA Energy Technology Perspectives BLUE Map scenario aims to reduce annual CO2 emissions to half of 2005 levels.*

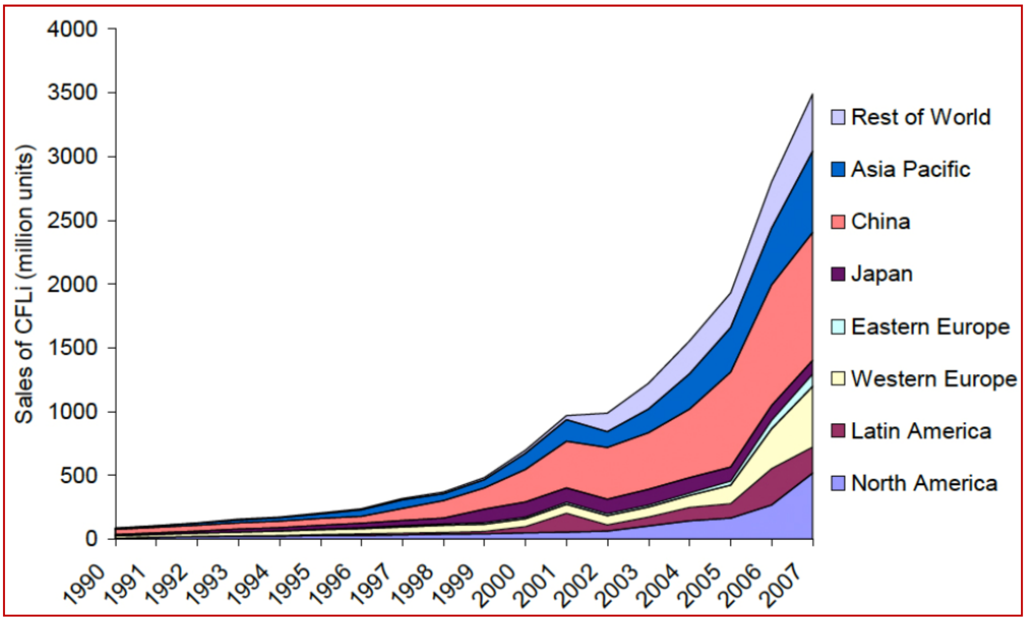
Chart 7. Wind Power Growth Projections



	2007	2008	2009	2010	2015	2020	2030
Reference MW	93,864	120,297	158,505	185,258	295,783	415,433	572,733
Moderate MW	93,864	120,297	158,505	198,717	460,364	832,251	1,777,550
Advanced MW	93,864	120,297	158,505	201,657	533,233	1,071,415	2,341,984

Source: Global Wind Energy Council

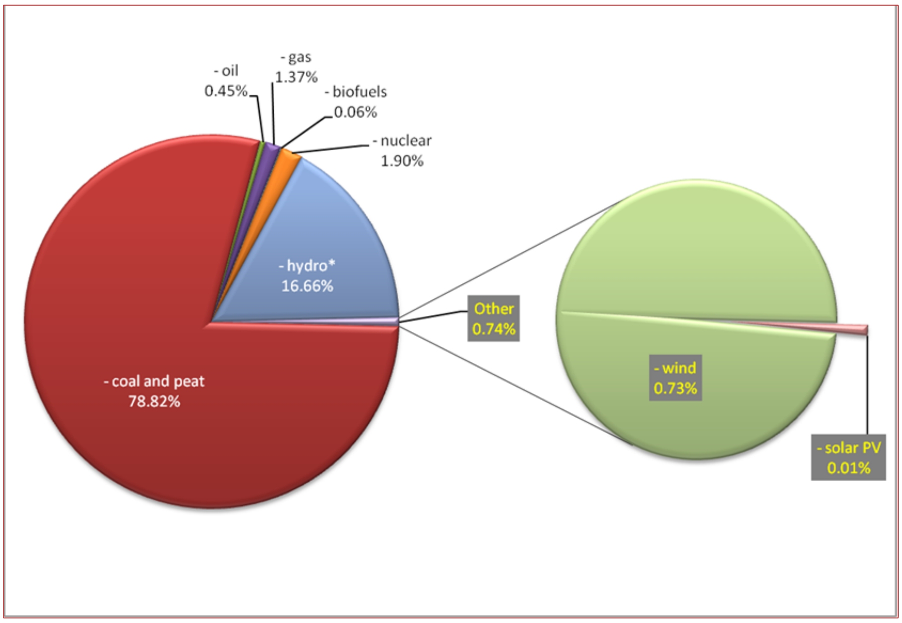
Chart 8. Compact Fluorescent Light Sales 1990-2007



Source: International Energy Agency

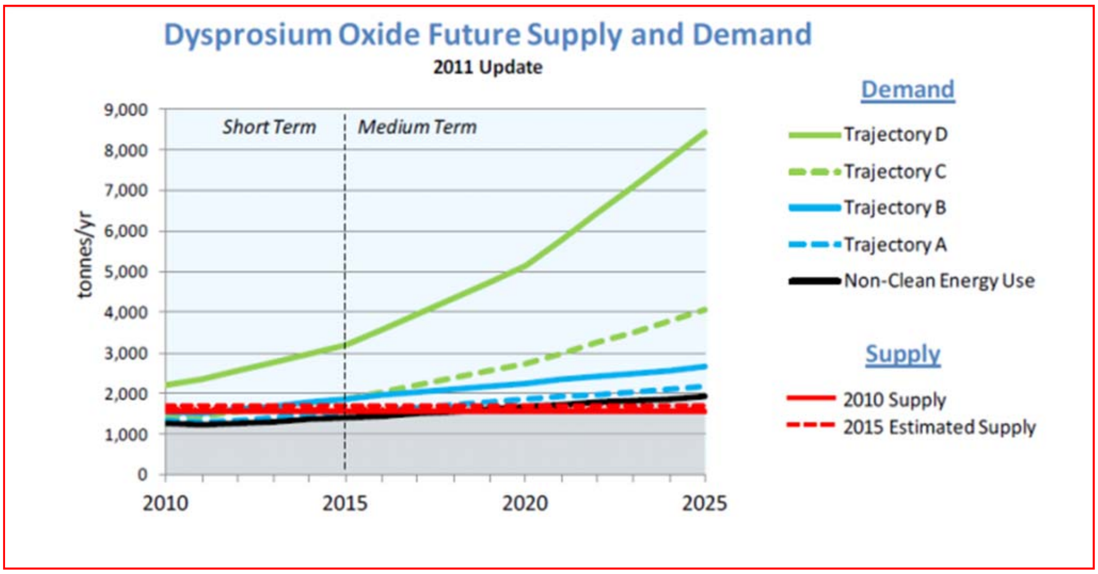
Chart 9. Facilities Needed to Power 1 Million Homes						
Nuclear	Coal	Natural Gas	BioMass	Geothermal	Wind Turbines	Solar PhotoVoltaic
1	**2**	**3**	**20**	**30**	**2,000**	**1,600,000**
Based on average annual household consumption of 12,000 kilowatt hours						
Source: Electric Power Research Institute						

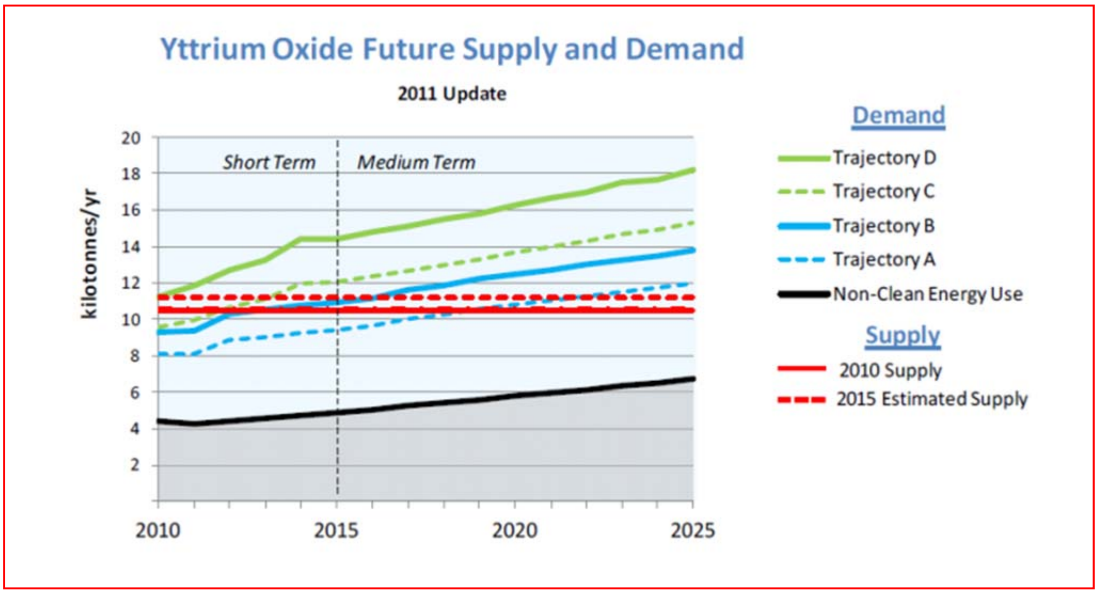
Chart 10. Sources of China Electricity Production in 2009



Source: International Energy Agency

Chart 11-12 Supply and Demand under four different trajectories for dysprosium and yttrium





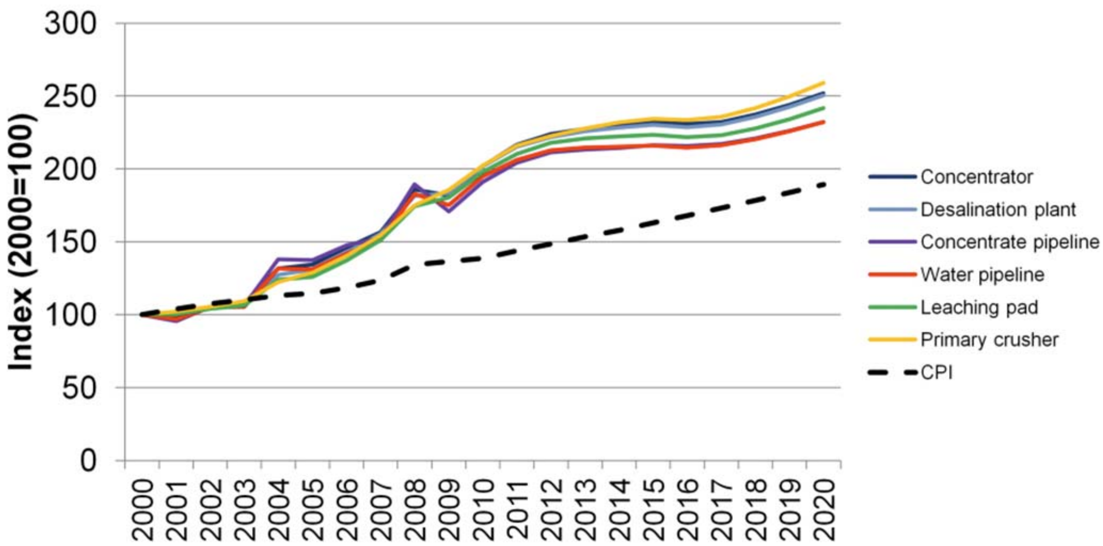
Source: US Department of Energy
Note: Four potential trajectories for demand and estimated future supply. Trajectory D is the upper bound for total mineral demand; Trajectory A is the lower bound. All trajectories include demand for both non-clean energy and green tech applications.

Chart 13.
Several Primary Metals with By-product

Primary Metal	Secondary Metal
Nickel and Copper	Cobalt
Aluminium and Zinc	Gallium
Zinc	Indium
Iron	Rare Earth Elements
Copper	Tellurium

Source: US Department of Energy

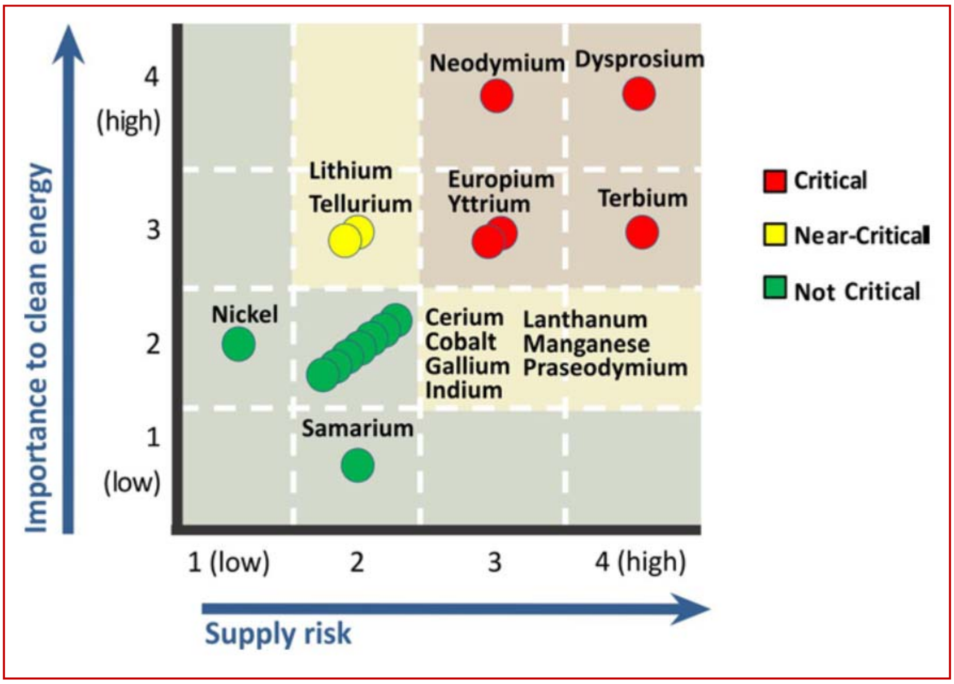
Chart 14. Increasing Capital Investment Costs in the Mining Sector



Source: CRU Strategies

Note: Above analysis only considers costs related to copper projects, but reflects industry trends. As CRU notes, "While there is enough copper in the ground to satisfy future demand, the extraction and production of this copper is going to get more expensive going forward…The cost of building mine sites has increased significantly more than general inflation." Other mineral operations will face similar cost concerns.

Chart 15. Medium Term (2015-1025) Supply Risk of Selected Minerals



Source: US Department of Energy

Note:

1. ***Importance to clean energy** encompasses 1) clean energy demand (75%) and substitutability (25%).*
2. ***Supply risk** is based on five categories: Basic Availability (40%), Competing Technology Demand (10%), Political, Regulatory and Social Factors (20%), Codependence on Other Markets (10%), Producer Diversity (20%).*

Chart 16. Production Location of Elements

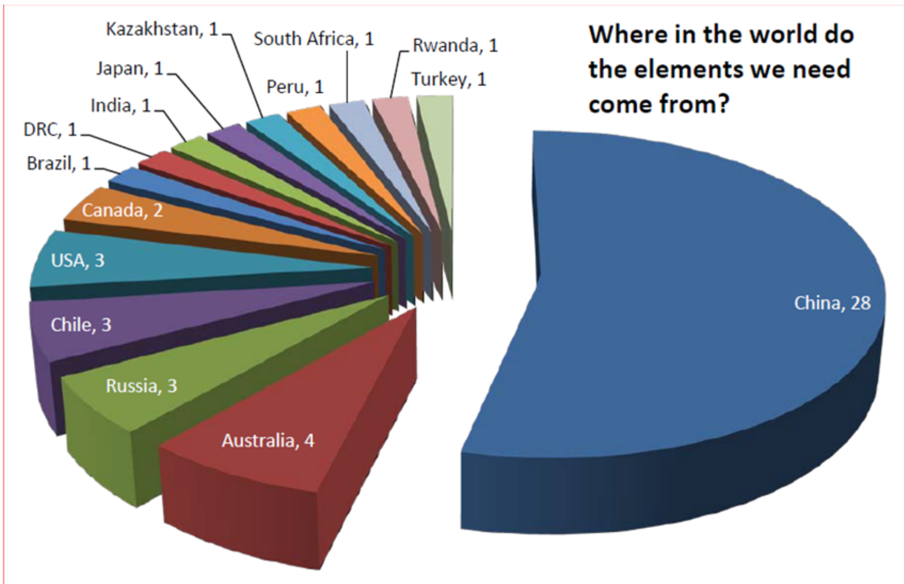


Figure 1. Chart indicates the number of times a country is the leading global producer of an element or element group of economic value.
Source: *BGS World Mineral Statistics*

Source: BGS Risk List 2011

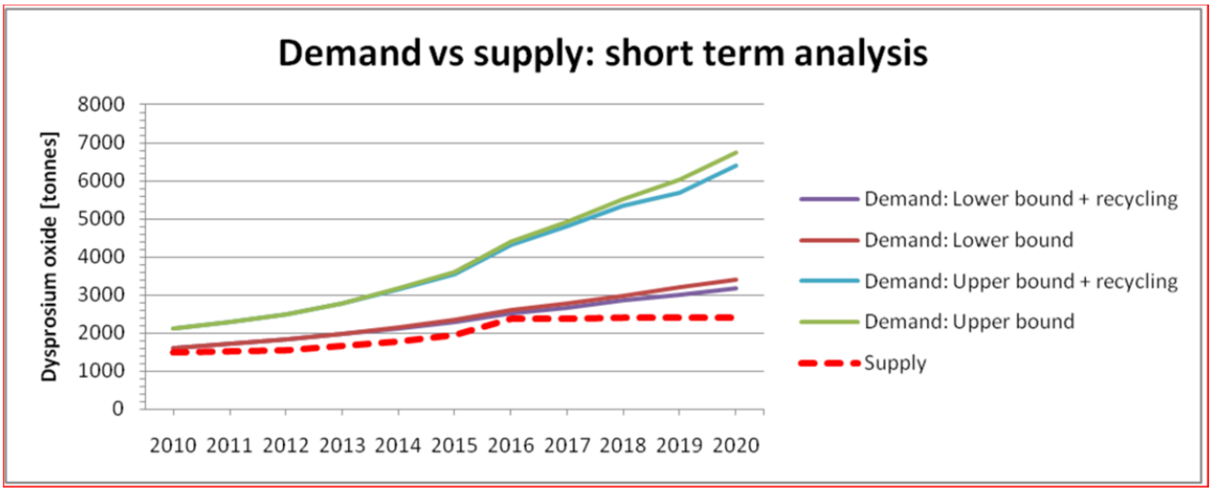
Chart 17. Comparison of Supply Risk from Various Sources

Elements	Supply Risks Assessment in Previous Studies						
	US Department of Energy (2011)	European Commission (2010)	Oeko Institute (2009)	US National Resource Council (2008)	Oakdene Hollins (2008)	British Geological Survey Risk Report (2011)	Institute of Energy and Transport, JRC European Commission (2011)
1. Cadmium	-	-	-	-	Medium	5.5	Low
2. Dysprosium	High (4)	High	Medium	High	-	8.0	High
3. Gallium	Medium (2)	Medium	High	High	Medium	4.5	High
4. Indium	Medium (2)	Medium	High	High	Medium	6.5	High
5. Molybdenum	-	Low	-	-	Medium	6.0	Low
6. Neodymium	Medium (3)	High	Medium	High	-	8.0	High
7. Nickel	Low (1)	Low	-	-	High	4.0	Low
8. Niobium	-	Medium	-	High	High	8.0	Medium
9. Selenium	-	-	-	-	Medium	4.5	Medium
10. Silver	-	Low	-	-	High	6.0	Low
11. Tellurium	Medium (2)	Low	Medium	-	Medium	-	High
12. Tin	-	-	-	-	High	6.0	Medium
13. Vanadium	-	Low	-	Medium	Medium	4.5	Medium

Sources:

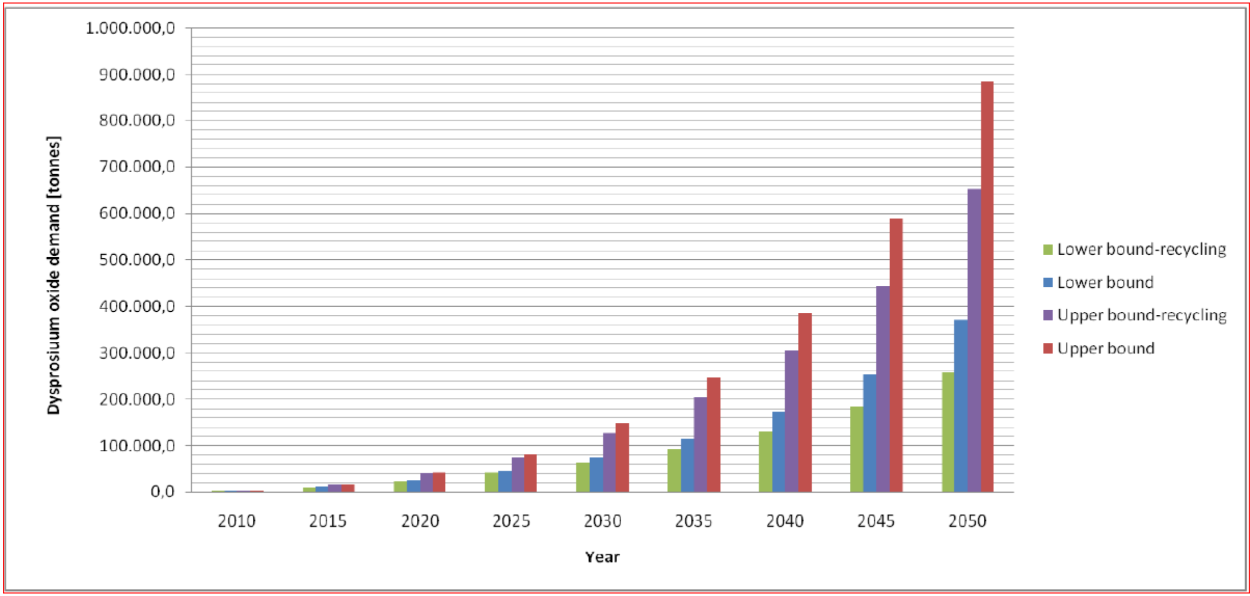
1. *U.S. Department of Energy. (2011). Critical Materials Strategy: December 2011.*
2. *British Geological Survey. (2011). Risk List 2011.*
3. *Institute for Energy and Transport of Joint Research Centre of European Commission. (2011).*
4. *Oakdene Hollins (2011)*

Chart 18. Overview of the Expected Dysprosium Supply and Demand for the Short Term (2010–2020)



Source: Hoenderdaal (2011)

Chart 19. The Cumulative Dysprosium Demand to 2050 for Various Scenarios



Source: Hoenderdaal (2011)

Chart 20. Forecast Global Demand and Supply for Individual Rare Earths be End Use in 2015 (±20%)

RARE EARTH OXIDE	Demand		Supply/Production	
	REO Tonnes	%	REO Tonnes	%
Lanthanum	44,000	25.9%	50,500	26.6%
Cerium	63,700	37.5%	76,000	40.0%
Praseodymium	7,500	4.4%	9,250	4.9%
Neodymium	33,500	19.7%	31,100	16.2%
Samarium	1,250	0.7%	4,000	2.1%
Europium	750	0.4%	500	0.3%
Gadolinium	2,500	1.5%	3,000	1.6%
Terbium	500	0.3%	375	0.2%
Dysprosium	2,000	1.2%	1,675	0.9%
Erbium	1,350	0.8%	900	0.5%
Yttrium	12,750	7.5%	11,200	5.9%
Ho-Tm-Yb-Lu	200	0.1%	1,500	0.8%
Total	**170,000**	**100.0%**	**190,000**	**100.0%**

Source: IMCOA estimates (red numbers in deficit)

Note: The analyses of the Chinese production are based on NRDC, CREIC and IMCOA data on past output; accordingly, while there is no certainty that future production will be in accordance with the past, it is a good indication of future production and the reason for the accuracy of the table being ±20%.

Chart 21. Japanese Imports of Rare Earths Products 2007-2011 (gross tones)

End Use	2007	2008	2009	2010	2011
Polishing Materials	12,850	12,850	12,850	10,000	5,000-8,000
Glass additives	3,240-3,870	2,160-2,770	2,360-2,770	3,700-3,900	1,460-2,620
Phosphors	1,020-1,470	1,020-1,470	870-1,180	1,160-1,190	875-1,230
Catalysts	3,860-4,015	3,840-4,995	3,540-3,650	4,200-4,710	3,850-5,260
Magnets	6,230-6,740	6,460-7,070	3,500-3,810	5,600-5,910	4,300-5,610
Batteries	2,600	2,600	2,600	2,850-3,080	3,050-3,100
Iron & steel & castings	2,000-3,000	1,990-2,990	1,690-2,690	1,800-2,800	1,850-2,850
Ceramics	150-210	150	100-150	200-250	200-300
Others	400-1,100	800-900	400-500	400-900	400-900
Total	**32,350-35,855**	**31,870-34,795**	**27,910-30,200**	**29,910-32,740**	**20,985-29,870**

Source: Roskill's Letter from Japan, April 2011 (quoted in IMCOA, 2011)

Bibliography

Abraham, D. S., Ludlow M. (2011), “China's New Plan for Economic Domination,” *TheAtlantic.com*, May 18, 2011, (accessed at http://www.theatlantic.com/international/archive/2011/05/chinas-new-plan-for-economic-domination/239041/ on November 5, 2011).

Alonso, E. , Sherman, A. M. , Wallington, T. J. , Everson, M. P. , Field, F. R. , Roth, R. , & Kirchain, R. E. (2012), “Evaluating Rare Earth Element Availability: A case with revolutionary demand from clean technologies,” *Environmental Science & Technology*, ACS Publications.

Asian Metal (2012), “AM Metal Prices,” (accessed at http://www.asianmetal.com/price/initPriceListEn.am on February 21, 2012).

Ayogu, M., & Lewis, Z. (2011), “Conflict Minerals: An Assessment of the Dodd-Frank Act,” October 03, 2011, (accessed at http://www.brookings.edu/opinions/2011/1003_conflict_minerals_ayogu.aspx on February 24, 2012).

BBC News - Technology (2010), “Over 5 billion mobile phone connections worldwide,” *BBC News,* July 9, 2010, (accessed at http://www.bbc.co.uk/news/10569081 on February 20, 2012).

Baotou National Rare Earth Hi-Tech Industrial Zone website, (accessed at http://www.rev.cn/en/int.htm on November 16, 2011).

Biello, D. (2006), “Measure of Metal Supply Finds Future Shortage,” January 17, 2006, (accessed at http://www.scientificamerican.com/article.cfm?id=measure-of-metal-supply-f on November 25, 2012).

Bradsher, K. (2011), “Chasing Rare Earths, Foreign Companies Expand in China,” *The New York Times,* August 24, 2011, (accessed at http://www.nytimes.com/2011/08/25/business/global/chasing-rare-earths-foreign-companies-expand-in-china.html?pagewanted=all on February 20, 2012).

Brown, D. (2011), “Lithium Resource in Argentina Attracting Analyst Interest,” *LithiumInvestingNews.com,* June 15, 2011, (accessed at http://lithiuminvestingnews.com/3581/lithium-resource-in-argentina-attracting-analyst-interest/ on February 20, 2012).

China Daily (2011), “Tight Rare Earth Supplies Here to Stay,” September 16, 2011, (accessed at http://www.china.org.cn/business/2011-09/16/content_23429309.htm on November 15, 2011).

Cohen, D. (2007), “Earth's Natural Wealth: An Audit,” May 23, 2007, (accessed at http://www.science.org.au/nova/newscientist/027ns_005.htm on February 20, 2012).

Cooke, C., & Wild, F. (2012), “Impala Protest Deaths Signal Higher Cost for S. Africa Mines,” *Bloomberg,* February 23, 2012, (accessed at http://www.bloomberg.com/news/2012-02-22/impala-platinum-protest-deaths-signal-higher-costs-for-south-africa-mines.html on February 24, 2012).

Crow, J. M. (2010), “Ten Years to Save the Touchscreen,” October 27, 2010, *The New Scientist* (accessed at http://www.newscientist.com/article/mg20827831.000-ten-years-to-save-the-touchscreen.html on November 25, 2011).

CRU Strategies (2011), " Trends in Capital Expenditure," *Presentation of Report delivered in Santiago, Chile,* April 4, 2011.

Dempsey, J. and Ewing, J. (2011), "Germany, in Reversal, Will Close Nuclear Plants by 2022," *The New York Times*, May 30, 2011, (accessed at http://www.nytimes.com/2011/05/31/world/europe/31germany.html?_r=1 on November 8, 2011).

Eddy, M. (2012), "Germany and Kazakhstan Sign Rare Earths Agreement,*" The New York Times,* February 8, 2012, (accessed at http://www.nytimes.com/2012/02/09/business/global/germany-and-kazakhstan-sign-rare-earths-agreement.html?_r=4 on February 20, 2012).

Eggert, R. (2011), Testimony on "Strategic and Critical Minerals Policy: Domestic Minerals Supplies and Demands in a Time of Foreign Supply Disruptions," Subcommittee on Energy and Mineral Resources. Committee on Natural Resources, U.S. House of Representatives, Washington, DC.

Electric Power Research Institute, (2010), "Choosing Electricity Generation Technologies: Generation Technology Reference Card". Charlotte, NC.

European Commission (2010), "Report of the Ad-Hoc Working Group on Defining Critical Raw Materials," 30 July 2010, *Draft*.

European Photovoltaic Industry Association (2011), "Global Market Outlook for Photovoltaics until 2015."

European Photovoltaic Industry Association /GreenPeace (2008), "Solar Generation V – 2008", Brussels.

Fried, I. (2000), "Parts Shortage May be Boon for Ceramic Capacitors*,"* August 31, 2000, (accessed at http://news.cnet.com/Parts-shortage-may-be-boon-for-ceramic-capacitors/2100-1040_3-245222.html on February 20, 2012).

German Federal Environment Agency (2011), "Restructuring Energy Supply in Germany," Dessau-Roßlau.

Global Metals and Mining Website (2012), Niobium, (accessed at http://www.globemetalsandmining.com.au/commodities/niobium on March 5, 2012).

Global Wind Energy Council (2011), "Annual Market Update 2010."

Graedal, T. E., Cao, J. (2010), "Metal Spectra as Indicators of Development," *Proceedings of the National Academy of Sciences*, Vol. 107, No.49, pp. 20905-20910.

Goonan, T. (2012), United States Geological Survey (2012), "Lithium Use in Batteries," on U.S. Department of the Interior, U.S. Geological Survey, Washington DC.

Gordon, R. B., Bertram, M. and Graedel, T.E. (2006), "Metal Stocks and Sustainability," *Proceedings of the National Academy of Sciences*, Vol. 103, No. 5, pp. 1209-1214.

Heap, A. (2005), "China - The Engine of a Commodities Super Cycle*,"* March 31, 2005. Citigroup. (accessed at http://www.fallstreet.com/Commodities_China_Engine0331.pdf on February 20, 2012).

Hoenderdaal, W.H. (2011), "Can a Dysprosium Shortage Threaten the Green Economy," Fraunhofer ISI and Universiteit Utrecht, (accessed at www.energyscience.uu.nl/documents/NWS-S-2011-18.pdf on February 25, 2012).

Humphreys, D. (1995), "Whatever Happened to Security of Supply? Minerals Policy in the Post-Cold War World," *Resources Policy*, Vol. 21, No. 2, pp. 91-97.

Humphreys, D. (2011), Mining Investment Trends and Implications for Minerals Availability, *Presentation to Polinares seminar,* June 1, 2011, Paris.

International Energy Agency website, (accessed at http://www.iea.org/).

International Energy Agency (n.d.), "*A*bout the IEA," (accessed at http://www.iea.org/about/index.asp on February 20, 2012).

_________________________(n.d.), "International Energy Agency: Did you know?" (accessed at http://www.iea.org/journalists/fastfacts.asp on February 20, 2012).

_________________________(2011), "IEA Key World Energy Statistics 2011", Paris.

_________________________(2011a), "World Energy Outlook", Paris.

_________________________(2010), "Guidebook on Energy Efficient Electric Lighting for Buildings," Edited by Halonen L., Tetri, E. and Bhusal, P., (accessed at http://lightinglab.fi/IEAAnnex45/ on November 8, 2011).

_________________________(2010a), "Technology Roadmap: Solar photovoltaic energy," (accessed at http://www.iea.org/papers/2010/pv_roadmap.pdf on February 20, 2012).

_________________________ (2010b), "Phase Out of Incandescent Lamps: Implications for International Supply and Demand for Regulatory Compliant Lamps," OECD/IEA, Paris, (accessed at www.iea.org/papers/2010/phase_out.pdf on February 20, 2012).

_________________________ (2009), Electricity/Heat in China, People's Republic, (accessed at http://www.iea.org/stats/electricitydata.asp?COUNTRY_CODE=CN on February 20, 2012).

Ike Skelton National Defense Authorization Act of 2011, PL 111-383, (accessed at Thomas.gov on November 1, 2011).

Jiao, W. (2011), "China, Australia ties get trade boost," *China Daily*, April 4, 2011, (accessed at http://www.chinadaily.com.cn/bizchina/2011-04/27/content_12405559.htm on March 1, 2012).

Kaften, C. W. (2011), "Copper Nanowire To Help Drive Solar Cell Production Costs Down," *PVMagazine.com*, September 30, 2011, (accessed at http://www.pv-magazine.com/news/details/beitrag/copper-nanowire-to-help-drive-solar-cell-production-costs-down_100004510/ on November 8, 2011).

Kawamoto, H. (2008), "Japan's Policies to be Adopted on Rare Metal Resources," *Science and Technology Trends Quarterly Review,* Vol. 27, pp. 57-76.

Keenan, R. (2011), "Australia Blocked Rare Earth Deal on Supply Concerns," *Bloomberg*, February 15, 2011, (accessed at http://www.bloomberg.com/news/2011-02-14/australia-blocked-china-rare-earth-takeover-on-concern-of-threat-to-supply.html on February 24, 2012).

Kharas, H., Gertz G. (2010), "The New Global Middle Class: A Cross-Over from West to East," Wolfensohn Center for Development at Brookings Institution.

Kingsnorth, D. (2011), "Rare Earths: Reducing Our Dependence on China," *Prepared for Metal Pages Rare Earth Conference*, IMCOA, Beijing 2011.

Kooroshy, J., Korteweg, R. and de Ridder, M. (2010), "Rare Earth Elements and Strategic Mineral Policy," The Hague: The Hague Center for Strategic Studies.

Kosich, D. (2011), "Toyota Subsidiary to Invest in Kipawa Heavy REE Deposit," December 13, 2011, (accessed at http://www.mineweb.com/mineweb/view/mineweb/en/page72102?oid=141528&sn=Detail on February 20, 2012).

Koswanage, N. (2012), "UPDATE 2-Malaysia Approves Temporary Licence for Lynas Rare Earths Plant," *Reuters,* February 1, 2012, (accessed at http://www.reuters.com/article/2012/02/01/australia-lynas-malaysia-idUSL4E8D15KQ20120201 on February 24, 2012).

Lawrence Livermore National Laboratory (2010), "Outcomes of U.S.-Japan Roundtable on Rare Earth Elements R&D for Clean Energy Technologies (18-19 November 2010)."

Lifton, J. (2011), "China Growth Plans & Supply of Neodymium & Dysprosium," *ResourceInvestor.com,* March 4, 2011, (accessed at http://www.resourceinvestor.com/News/2011/3/Pages/Chinese-Domestic-Growth--Supplies-of-Neodymium--Dysprosium.aspx on November 7, 2011).

______ (2011), " Technology Metals Research," (accessed at http://www.techmetalsresearch.com/what-are-technology-metals on November 7, 2011).

______ (2011), "China Growth Plans & Supply of Neodymium & Dysprosium," *ResourceInvestor.com,* March 4, 2011, (accessed at http://www.resourceinvestor.com/News/2011/3/Pages/Chinese-Domestic-Growth--Supplies-of-Neodymium--Dysprosium.aspx on November 7, 2011).

McGreevy, P. (2011), "Renewable Energy: Jerry Brown Signs Law Requiring 33% of Energy Be Renewable by 2020," *Los Angeles Times*, April 13, 2011, (accessed at http://articles.latimes.com/2011/apr/13/local/la-me-renewable-energy-20110413 on November 7, 2011).

Metals Economics Group (2011), "World Exploration Trends: A Special Report from the Metals Economics Group for the PDAC International Convention."

Mining and Engineering Magazine (2012), "Skilled Workforce Shrinking," *Industry Newswatch*, February 2012, p. 22.

Ministry of Economy, Trade and Industry - Japan (2011), "Priority Measures to Ensure Stable Supply of Natural Resources and Fuel," December 20, 2011.

Minor Metals Trade Association (2011), Minor Metals Trade Association Website, (accessed at http://www.mmta.co.uk/metals/ on November 7, 2011).

Molycorp (2011), "Molycorp, Daido Steel, & Mitsubishi Corporation Announce Joint Venture to Manufacture Sintered NdFeB Rare Earth Magnets," November 28, 2011, (accessed at http://us1.campaignarchive2.com/?u=a9e8676e87fad805702b98564&id=3fb697d81e&e=d068c915e8 on February 20, 2012).

Molycorp website, (accessed at http://www.molycorp.com/).

Moss, R.L., Tzimas, E., Kara, H., Willis, P. and Kooroshy, J. (2011), “Critical Metals in Strategic Energy Technologies,” Joint Research Centre, Institute for Energy and Transport, European Commission.

National Research Council (2008), “Minerals Critical Minerals and the U.S. Economy”, Committee on Critical Mineral Impacts on the U.S. Economy, Committee on Earth Resources, Board of Earth Sciences and Resources, Division of Earth and Life Studies, National Academy of Sciences, Washington, DC.

Oakdene Hollins (2010), “Lanthanide Resources and Alternatives.”

Parthemore, C. (2011), “Elements of Security: Mitigating the Risks of U.S. Dependence on Critical Minerals,” Center for a New American Security, Washington DC.

Phillips, D. (2010), “How First Solar's Tellurium Deal Shows the Fragile Economics of Solar Panels,” November 29, 2010, (accessed at http://www.cbsnews.com/8301-505123_162-43240662/how-first-solars-tellurium-deal-shows-the-fragile-economics-of-solar-panels/ on March 03, 2012).

PWC (2011), " Minerals and Metals Scarcity in Manufacturing: The Ticking Timebomb. (accessed at http://www.pwc.com/gx/en/sustainability/research-insights/metal-minerals-scarcity.jhtml/ on March 03, 2012).

Quinones, M. (2012), “Rare Earths: Push to Rebuild Depleted U.S. Workforce Begins in the Classroom,” February 13, 2012, (accessed at http://www.eenews.net/public/Greenwire/2012/02/13/27 on February 20, 2012).

Ragnarsdottir, K.V. (2008), “Rare Metals Getting Rarer,” *Natural Geoscience* 1, pp. 720-721.

Resnick Institute (2011), “Critical Materials for Sustainable Energy Applications,” California Institute of Technology Resnick Institute Report.

Santini, J. (1980), “The Growing Crisis in the Strategic and Critical Minerals of the United States,” *Journal of Legislation,* pp. 63-77.

Senthilingam, M and Whitfield, J. (n.d.), “Chemistry in Its Element – Tantalum,” (accessed at http://www.rsc.org/chemistryworld/podcast/Interactive_Periodic_Table_Transcripts/Tantalum.asp on February 20, 2012).

Sichel, A. (2008), “The Story of Neodymium: Motors Materials and the Search for Supply Security,” *Chorus White Paper*, Choruscars.com.

Strategic Metals Investments Limited (2010), “China’s Growing Role in the Production and Supply of Minor Metals,” (accessed at http://strategic-metal.typepad.com/files/chinas-growing-role-in-the-production-and-supply-of-minor-metals-part-i---apr.-2010.pdf on November 16, 2011).

Sullivan, D. E., Sznopek, J. L., and Wagner, L. A. (2000), “20th Century U.S. Mineral Pries Decline in Constant Dollars,” U.S. Department of the Interior, U.S. Geological Survey: Open File Report 00-389, Washington, DC.

Tanquintic-Misa, E. (2012), “Germany, Kazakhstan Sign $4B Rare Earths, Technology Agreement Deal,” *International Business Times*, February 9, 2012, (accessed at http://au.ibtimes.com/articles/295590/20120209/germany-kazakhstan-china-rare-earths-manufacturing.htm on February 20, 2012).

The Age-Business Day (2010), “RSPT v MRRT - the Differences,” July 2, 2010, (accessed at http://www.theage.com.au/business/rspt-v-mrrt--the-differences-20100702-zs7a.html?rand=1278035409262 on February 24, 2012).

United Nations Environment Programme (2011), “Decoupling Natural Resource Use and Environmental Impacts from Economic Growth,” *A Report to the Working Group on Decoupling to the International Resource Panel and Its Steering Committee*.

United Nations Environment Programme (2011a), Recycling Rates of Metals: A Status Report. Global Metal Flows Working Group at the International Panel on Sustainable Resource Management

U.S. Environmental Protection Agency (2009), “Statistics on the Management of Used and End-of-Life Electronics,” (accessed at http://www.epa.gov/epawaste/conserve/materials/ecycling/manage.htm on February 24, 2012).

United States Geological Survey (2012), “Individual Commodity Reports,” U.S. Department of the Interior, U.S. Geological Survey, Washington DC.

___________________________ (2011), “2009 Minerals Yearbook,” U.S. Department of the Interior, U.S. Geological Survey, Washington DC.

___________________________ (2011), Mineral Commodities Used for the Production of Photovoltaic Cells. Reston, VA, U.S. Department of the Interior.

U.S. Department of Defense (2010), “Strategic and Critical Materials Operations Report to Congress—Operations Under the Strategic and Critical Minerals Stock Piling Act During the Period October 2008 through September 2009,” Washington, DC.

U.S. Department of Energy (2010), “Critical Materials Strategy,” Washington, DC.

_______________________ (2011), “Critical Materials Strategy,” Washington, DC.

U.S. Environmental Protection Agency website, (accessed an http://www.epa.gov/).

United Press International (1982), “Reagan Rejects Mineral Subsidies,” *Florence Times Tri City Daily* February 1, 1982, 113(32), p. 3.

Urbina, I. (2012), “New Report by Agency Lowers Estimates of Natural Gas in U.S. ,” *The New York Times,* January 28, 2012, (accessed at http://www.nytimes.com/2012/01/29/us/new-data-not-so-sunny-on-us-natural-gas-supply.html?_r=1&src=recg on February 20, 2012).

Van Rensburg, W. C .J. (1981), “Global Competition for Strategic Mineral Supplies,” *Resources Policy,* Vol. 7, No. 1, pp. 4-13.

Wade, P. (2010), “Phase Out of Incandescent Lamps: Implications for International Supply and Demand for Regulatory Compliant Lamps,” *International Energy Agency Energy Efficiency Series*, Information/Organisation for Economic Co-operation and Development.

Wadia, C., Alivistavos, A. P., Kamnen, D. M. (2009). "Materials Availability Expands the Opportunity for Large-Scale Photovoltaics Deployment," *Environmental Science Technology*. Vol. 43, No. 6, pp. 2072-2077.

Wesoff, E. (2010), "First Solar to Acquire 5N Plus to Access Tellurium?" October 18, 2010, (accessed at http://www.greentechmedia.com/articles/read/first-solar-looking-to-acquire-5n-plus-to-access-tellurium/ on February 20, 2012).

Wulandari, F., and Ali, M. (2008), "UPDATE 2-Indonesia Parliament Passes New Coal Mining Law" *Reuters,* December 16, 2008, (accessed at http://uk.reuters.com/article/2008/12/16/indonesia-mining-idUKJAK38656520081216 on February 20, 2012).

Yasuhiro, K., Fujinaga, K., Nakamura, K., Takaya, Y., Kitamura, K., Ohta, J., Toda, R., Nakashima, T. and Iwamori, H. (2011), "Deep-Sea Mud in the Pacific Ocean as a Potential Resource for Rare-Earth Elements," *Nature Geoscience*. Online Edition: 2011 / 7 / 4 at 2:00. (accessed at http://www.t.u-tokyo.ac.jp/pdf/2011/110704_katoE.pdf on November 8, 2011).