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Industry Study

Final Report
Strategic Materials

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Strategic Materials (STRATMAT) 2016

ABSTRACT: Strategic Materials (STRATMAT) are the tangible foundation of virtually every industry, both security and private sector-based, supporting the United States. Simply stated, one cannot obtain weapons, warships, or aircraft, or most of our modern electronic conveniences, without first extracting raw materials from the earth. Assured access to these materials is critical to the continued security of the nation. This report identifies challenges and opportunities related to the supply chain for strategic materials and provides recommendations, such as limited government reform and mutually supportive agreements with allied partners, to ensure continued access for the foreseeable future.

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The STRATMAT team would like to extend a heartfelt thanks to all of the industry, government, academic and international leaders in this area who took time out of their busy schedules to educate, inform and promote creative thought within our team.

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Introduction

"My fear is that a lack of attention to and understanding of critical materials will limit our prosperity and undermine our environment."

- David S. Abraham[1]

Purpose

The 2015 National Security Strategy (NSS) states that in order for the United States (U.S.) to continue leading the world in global prosperity, we must "shape an emerging global economic order that continues to reflect our interests and values."[2] To properly "shape" this future environment, it is critical to understand the industries involved in today's globalized marketplace and how they contribute to economic progress. This report analyzes the various industries involved with strategic materials to determine their context and relationship to national security.

In their most basic form, strategic materials are minerals taken from the earth; containing elements from the periodic table that play a critical role in our everyday lives. From the cars we drive to the smartphones or tablets we use to the military systems that protect our nation, the information and technology-laden age of today creates heavy demand for a wide variety of metals and minerals. As just one example, the typical automobile today contains as many as 39 different non-fuel minerals in various components.[3] More importantly for this study, similar examples exist across the spectrum of high-end weaponry needed for national defense.

Firms that extract many of these materials and the technologies required for processing them are no longer resident domestically, primarily due to economics. This makes the United States dependent on foreign sources for the majority of these critical supply chain inputs. This report addresses whether this dependency represents a significant national security concern and, if so, what aspects of the supply chain include the greatest risks.

Methodology

Between January and May 2016, the STRATMAT team of the Eisenhower School met with domestic and international government and industry representatives; conducted an extensive literature review; and analyzed a variety of issues related to strategic materials. This report provides a synthesis of our collective research, experiences and observations.

Organization and Summary of Findings

The report begins with a definition of "strategic" and "critical" materials, noting the complexity involved in choosing a single definition from the multiple, competing definitions currently in use across government and industry. From there, the report summarizes the team's findings related to three overarching topic areas including market dynamics and domestic issues; national security concerns, and government involvement. More specifically, the discussion of market dynamics and domestic challenges provides an overview of the global mining industry and commodity markets; identifies factors that influence the costs of mining and gives some nations a competitive advantage in the marketplace; and provides insights on the state of U.S. education related to science and technology and its effects on the capacity of the U.S. workforce to support a domestic mining industry. The topic of national security and STRATMAT includes an overview of the value chains for strategic materials; followed by an analysis of supply chain risks and disruption. After providing a case study related to China and disruption of the supply chain for rare earth elements (REE), this section ends with a detailed look at U.S. dependency on Chinese imports of strategic materials. Finally, the government involvement section examines the lack of a unified approach within the government to the strategic materials supply chain; discusses the complexity of permitting and environmental regulations governing the mining industry, and addresses domestic and international opportunities for the United States that would mitigate potential supply chain disruptions. The report concludes with a summary of our overall observations. Four appendices provide greater detail on some of the topics discussed in the report, including classification of strategic and critical materials across government agencies; a review of global, non-fuel, mining and mineral deposits; a figure of the periodic table identifying the REEs specifically, and an in-depth look at one potential area for innovation in the future – Mining Space.

The ultimate result of our study, provided under the policy recommendations section, is the identification of four measures the United States should take to mitigate the risk of future supply disruptions for strategic materials. First, the United States government (USG) should seek streamlined policies and whole-of-government solutions that realize efficiencies in materials requirements, improve permitting timelines and improve research and development (R&D) focus on the domestic industry. Second, targeted incentives and advocacy to increase strategic materials-related higher education degrees as well as vocational careers would secure a U.S. position as a leader in the human capital element of the industry. Third, the USG should pursue acquisition reform that better incentivizes the defense industrial base to assist in the assured access of critical material supply. Lastly, the USG should make efficient use of allied partnerships and secure access to strategic materials as a hedge against an uncertain future that is certain at some point to jeopardize existing supply chain process and material flow.

Strategic Materials Industry Definition

Initially, the STRATMAT team focused on the processes involved in identifying deposits and extracting raw materials (e.g., non-fuel rocks and minerals). The team explored the relationship of national security, the geographic location of material deposits, and the mining industry in depth. After only a short period, it became readily apparent that the supply chain for strategic materials encompasses a much broader set of steps than simply ore extraction (Figure 1). Once mined, a raw material typically goes through value-adding processing to make the constituent minerals more useful to the end user. These processes include beneficiation (process to produce a higher concentration of metal ore or oxide), smelting (melting the ore to produce higher concentrations or pure metal), and alloying (combining multiple distinct metals to enhance the basic product). It is important to recognize that a mineral's value to the USG is dependent on what form the mineral must be in to be useful to the end user. For example, the rare earth element (REE) neodymium is not very useful as an ore or concentrate but is highly desirable when combined with iron and boron to create a neodymium-iron-boron magnet used in modern electronics.

Further, defining what makes a material "strategic" or "critical" is challenging; no standardized U.S. government definition exists, and different agencies use different approaches to make this determination. The result is multiple, often competing definitions and subsequent conflicting recommendations relative to which materials represent concerns for the United States (as summarized in Appendix A). Because these definitions should frame our thinking about strategic materials and national security, the team ultimately selected the definition set forth in the 2011 National Defense Authorization Act (NDAA) as the basis for the analyses in this report:

> "S*trategic materials are non-fuel materials (A) upon which the production or sustainment of military (or other national security) equipment is dependent; and (B) the supply of which could be restricted by actions or events outside the control of the Government of the United States.*"[4]

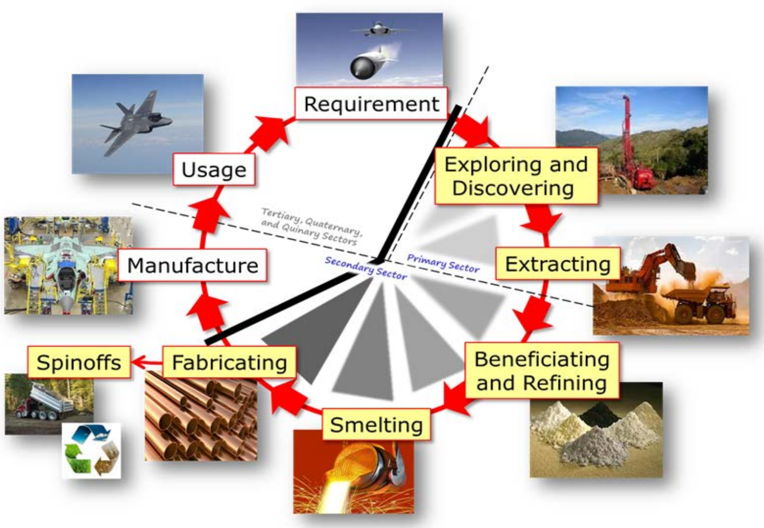


Figure 1 – Strategic Materials Industry Cycle[5]

Market Dynamics and Domestic Challenges

Our studies identified several markets involved in strategic materials, each tied to a key part of the supply chain. The majority of our effort during the term focused on extraction and the challenges faced by the mining industry. This section synthesizes our collective observations about the global mining industry, the economics of mining, and challenges currently facing the United States domestic mining industry, with particular emphasis on the education sector.

Mining Industry Analytics

This industry study examined the global availability of mineral commodities and processed materials, with particular focus on copper (as a representative base metal) and REEs. Specific to this study, strategic materials are produced from the interaction of the mining, metals, and manufacturing industries. The mining industry extracts raw materials from the ground. The metals industry separates metallic elements from ores, turning them into manufacturing inputs such as specialty alloys. Finally, the manufacturing industry fabricates or casts metals into specific components. Some companies are vertically integrated across industries, as they produce ore, metals, and semi-fabricated products, while others focus on single industries such as mining. Within the strategic materials process, each material is extracted and processed through a combination of multinational companies, state-owned enterprises (SOE), and artisanal mining companies, which complicates any single market analysis. Accordingly, this market analysis will focus specifically on mining in order to better understand the beginning of the value chain for strategic materials.

Within the competitive spectrum (Figure 2), the market for materials, such as the base metals are in almost perfect competition. The materials naturally exist throughout the globe and companies enter and exit this market on a regular basis with very little impact on price; moreover, a number of these companies have complete vertical integration from extraction to processing. Conversely, while REEs are globally abundant, extraction and processing are very expensive, which creates a very high barrier to entry. Currently, China is the global leader in REE processing and this processing is the only means by which to produce a final raw material usable for manufacturing.

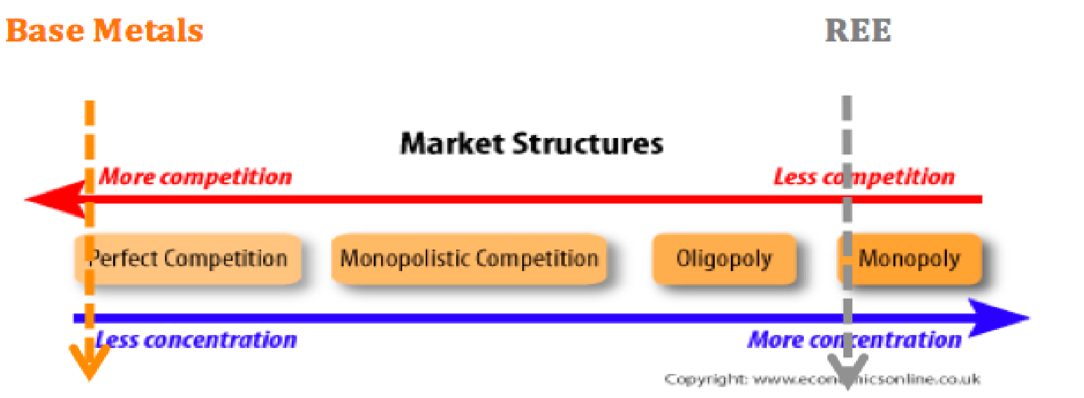


Figure 2: Market Structures[6]

Overall, many industries associated with strategic materials are in an economic downturn due to low commodity prices, which are a result of slowing global growth. Mineral prices are intrinsically linked to growth, particularly in developing nations as the construction and manufacturing industries are the driving forces behind the demand for raw material. Across the board, mineral prices began to rapidly increase in 2005, mostly due to the accelerated rise of China. There was a slight drop in prices in 2009 in response to the global recession but, by 2010, prices were spiking at unprecedented levels. These price spikes led to healthy cash flows and increased profit margins.[7]

This rapid growth and profitability encouraged entrance into the mining industry as the commodity prices now made a number of exploration projects economically viable. It also encouraged a number of the major companies to initiate multi-year capital expenditure projects within their existing extraction and processing facilities. Across the companies that were studied, long term debt financing was used extensively in the 2012-2013 timeframe to initiate these capital projects. While financing of capital expenditures normally adds long-term value to a company, prices started to sag in 2014 and then declined rapidly in 2015 negating this effect. This sharp and unexpected, decline created a major downturn and left the industry significantly leveraged with limited means to pay for their capital projects. While the accepted debt ratio is 2 percent for the mining industry, which is much higher than other industries, all of the companies studied are above this ratio today.[8;9] As a result, mining companies are forced to reduce their operating costs to manage their debt; in some cases, they have had to sell off portions of their operations or put their facilities in care and maintenance.

Although mining strategies will vary greatly depending on the market and the mineral, some commonalities do exist. Utilizing the Porter's Five Forces model below, a generalized picture of the factors affecting the industry begins to emerge.

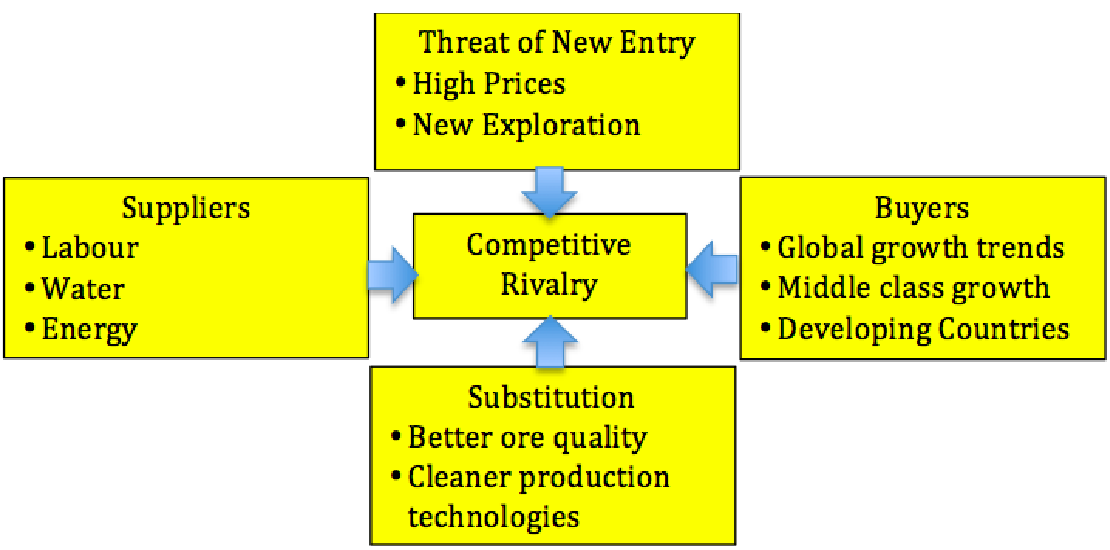


Figure 3: Porter's Five Forces Model[10]

Economics of Mining

As compared to the rest of the world and most notably China and Brazil, the economics of mining in the United States are very unfavorable. Besides needing to obtain the high upfront capital that all mining ventures require, mining companies in the United States face significant additional costs, including higher wages and taxes, compliance with high safety standards, and a lengthy and costly permitting and approval process. Together, these costs put mining companies operating in the United States at a competitive disadvantage compared to other parts of the world. In this section, the costs associated with mining in the United States are compared to China, who is arguably the dominant player in the mining industry today.[11]

The Upfront Costs

Prior to the initiation of mining operations in the United States, mining companies must navigate a complex permitting and approval process that may take more than 10 years to complete. Significant cost burdens placed on mine operators upfront during this process include: costs of environmental studies, permitting fees, legal fees, and administrative fees. Due to the difficulty and uncertainty of the process timeline or outcome, and the potential for lawsuits or expensive mitigation measures, investors are reluctant to invest, making it difficult to raise necessary capital. Further, the longer the period from investment to payoff, the lower the present value of the investment (i.e. less attractive to investors).

Mines in the United States must also set aside money (or purchase bonds) upfront to pay for the reclamation of the site after the mine ceases operations. This is due to the legacy of abandoned mines in the United States that now require government funding for closure and/or cleanup. These costs may run into the hundreds of millions of dollars.[12] Chinese mines do not require reclamation payments, instead placing the burden back on the Chinese government.[13, 14]

Wages and Taxes

A Chinese miner makes an average of $154 per month compared to over $6,000 per month for a typical American miner.[15;16] Using this metric alone, a U.S. miner would need to be roughly 40 times more productive than their Chinese counterpart to even out the disparity in wages. Further, miners in the United States expect a benefits package to include health care, disability insurance, and (often times) a pension plan. Mine operators in China do not incur that expense.[17]

In addition to the gross wage imbalance, a U.S. mine operator also incurs significantly higher tax burdens. As an example, a corporation operating in China pays roughly 25 percent in corporate taxes as compared to 39.2 percent in the United States.[18;19] Combining wages, benefits, and comparative tax burdens, a U.S. mining operation must now be over 50-60 times as productive as their Chinese competitor to reach equivalency. While automation and best practices can make up some of this gap, it cannot hope to close it entirely.

Safety

Another glaring example of economic disparity between the United States and Chinese mining is the cost to comply with safety regulations. Given a low safety standard, Chinese miners are 117 times more likely to die in a mining-related accident than their U.S. counterparts.[20] U.S. mining safety standards are among the strictest in the world, resulting in dramatically lower rates of injury and mortality, but come with a high price tag. Expensive safeguards such as toxic gas monitors, personal protective equipment, escape shafts, and refuges significantly add to the operations and maintenance costs of mining.[21] Additionally, dedicated safety personnel are another financial burden on mine operators and add to the non-producing (but necessary) count of mine employees.

Bottom Line

Even if all environmental, safety, and bureaucratic obstacles were removed from the mining industry, U.S. mining companies would still have to deal with the aforementioned effect of low commodity prices; a factor, which affects the global industry. The compilation of these variables places hard rock mining in the United States at a severe economic disadvantage in comparison to many other areas of the world. As long as the current financial metrics exist, transportation costs remain low, and the products are of comparable quality, there is little chance of the United States developing a robust mining sector comparable to countries such as China.

Workforce Education

Risk exists to two distinct elements of the educational support of domestic mining. First, due to aging demographics and a lack of federal research funding, college mining engineering programs are at risk of wholesale closure. Second, a current shortage of basic vocational-level skilled workers in the mineral extraction industry is causing cost inflation and decreased productivity.

Throughout this survey of STRATMAT, industry and academic leaders expressed concern over the lack of domestic undergraduate mining and materials engineering programs. However, our analysis does not support that domestic graduation rates are insufficient; but, instead points to the lack of USG research grants as strangling school's financial viability. Presently, there are 8,300 mining and geological engineers employed in the United States.[22] The United States Department of Labor's Bureau of Statistics (BLS) estimates that from 2014 to 2024, the growth rate for new mining and geological engineers will be six percent.[23] Concurrently, the expected growth in demand of materials engineers is only one percent.[24] U.S. undergraduate mining engineering and metallurgical schools can support these low growth rates but this support is contingent on their continued offering of mining engineering programs. That, however, is not a certainty.

The replacement rate of professors and other faculty at U.S. mining schools is lagging due to aging demographics within the current workforce and the tendency for engineers with bachelor degrees to go to work rather than pursue a graduate degree. The lack of value placed on graduate degrees by the United States mining industry is marginalizing the primary driver to pursue graduate and postgraduate degrees and, in turn, is slowly eliminating the number of programs offered. The impetus to pursue master's and doctoral degrees in mining engineering for use in the United States is typically in support of academic pursuits as opposed to commercial aspirations. According to Dr. Rajive Ganguli, a Professor at the University of Alaska's College of Engineering and Mines, the closing of the United States Bureau of Mines (USBM) in March of 1996 was an inflection point in U.S. mining higher education. Closure of USBM resulted in a significant decrease in federal research grants for universities.[25] Since only a third of a college program's revenue comes from tuition, this loss of federal research funding had an immediate and negative effect on many mining engineering programs' ability to stay financially viable and as a result, many universities who relied on research grants closed their programs.[26]

Graduate and doctoral programs (and associated faculty) are needed to maintain U.S. intellectual capital in mineral extraction. One panel of mining engineering experts emphasizes that a sustained effort is needed to recapitalize the faculty of American universities.[27] Federal funding and research grants should align with efforts to increase participation in graduate-level programs in mining engineering, faculty retention and career development, and appropriate postgraduate research funding.[28]

Vocational Programs

From a vocational perspective, new approaches are needed to encourage the development of a skilled vocational workforce in the United States. Job training, scholarships, high school outreach, and public perception campaigns are needed to reconstitute the country's technically skilled workforce. Discussions with the minerals extraction and manufacturing industry, academia, and professionals universally point to a dearth in vocational skills in the United States workforce. The lack of quality mechanics, electricians, and Computer Numerical Control (CNC) operators were specifically cited as a concern across industry.

The United States Bureau of Labor and Statistics (BLS) predicts an average growth rate for all occupations in the United States from 2014-2024 to be seven percent. However, they project that Labor Industrial Machinery Mechanics, Machinery Maintenance Workers, and Millwrights growth rates will be 16 percent, almost double the national average.[29] This robust growth rate and the promise of higher salaries should be enticing workers; however, this has not happened to date. This market failure is likely in part due to negative public perception. One company this group visited described a program in which the company partnered with a local high school to encourage vocational work. The company officials described how they were rebuffed by parents who were angry that their child was being offered a career path that did not include college. This company was offering almost $20 an hour as a starting salary (along with the promise of future raises), yet could not find enough individuals interested in their program.

As Nicholas Wyman writes in Forbes, vocational training in high schools has been curtailed in the United States as a cost-savings measure just at a time when the country's manufacturing base is in need of qualified (but advanced) vocational technicians.[30] He asserts, though, that most technicians pursue further education later in their career, obviating parents' concern that vocational skills preclude a college degree.

Government policies that reverse funding reductions for vocational training in high schools are needed. The White House reports that President Obama, through the

Trade Adjustment Community College and Career Training (TACCCT) program, has invested over $2 billion of federal funds in education and training programs based on inputs from employers and industry.[31] This type of financial support, aligned with industry's needs, is necessary to reverse the trend of people dogmatically pursuing college vice vocational training.

Efforts to counter the negative association with vocational training are more complex. Countless editorials and opinion pieces have been written asserting a stigma associated with high school vocational training and how our populace perceives that participating students are not college worthy. In 2014, the Council of Chief State School Officers (CCSSO) released a report outlining this stigma and strategies to counter these biases.[32] State and federal policies meant to encourage vocational training should consider employing similar strategies.

Higher education and a skilled workforce underpin the United States' competitiveness across all industries, including mining. Unfortunately, budget cutbacks, demographics, public perception, and a market failure between industry and academia have contributed to an erosion of educational support to the mining industry.

National Security and STRATMAT

The preceding section provided a good baseline understanding of mining market dynamics and the challenges facing the U.S. mining industry. With this baseline, the following section analyzes the complexity of strategic materials supply chains and how significant dependence on any one country is a potential national security concern.

Value Chains and Security of Supply

Finished goods, such as weapons systems, sit at the end of a long "value chain." Industrial processes such as mining, metallurgical separation, semi-fabrication, fabrication, and assembly add increasing value at each stage of the chain, ultimately transforming raw materials into components of sophisticated military technologies. For much of U.S. history, value chains have been domestically contained, inasmuch as the mining, metals, and manufacturing industries were fixtures of the national economy. Given the inherent security of this arrangement, the United States has largely been left to principally worry about those raw inputs that it could not, for geological reasons, source domestically.[33]

However, with the globalization of trade, value chains have geographically fragmented, a fact that greatly complicates the security of supply problem. Due to falling transportation costs and other factors, much of the mining, metals, and manufacturing industries once resident in the United States have displaced to Asia and elsewhere. For the first time since the mercantilist period, the largest mineral consuming countries are not the largest mineral producers.[34] In other words, while the "downstream" end of the value chain – the finishing of goods, such as key weapons' components - likely occurs in the post-industrialized West, the "upstream" stage of production - the extraction of ores and the separation and processing of metals - is now more likely to occur in Africa, South America, or China.

This situation introduces significant potential risk. Inasmuch as mineral and metal producing regions may be politically or socially unstable, the entire value chain is vulnerable to disruption. Furthermore, in many cases, mining and metals industries outside the United States are either state-owned enterprises or are otherwise heavily influenced by national governments.[35] Because these operations are responsive to political rather than market forces, or at least, responsive to political *and* market forces, they may be used as geostrategic levers to counter U.S. interests and competitive advantage.

For instance, by curtailing the production and supply of specific rare metals, state producers can induce scarcity and artificially drive higher prices, thereby compelling U.S. or European "downstream" stages of the value chain – with their respective technologies – to relocate closer to state sources of upstream supply.[36] This example describes China's approach to rare earth elements, and it provides a credible explanation for why the nation wants to gain tighter control on its currently unregulated, artisanal rare earth production.[37] Of course, in times of conflict or war, it stands to reason that a belligerent metal producer could just as easily turn off the spigot completely.

The vulnerability of non-domestic value chains is further complicated by modern technology's "material complexity."[38] According to a recent paper on the subject, "A century ago, or even half a century ago, less than 12 materials were in wide use: wood, brick, iron, copper, gold, silver, and a few plastics."[39] Today, the most commonplace technologies are drawn from a "rich materials pallet."[40] For instance, a "computer chip ... employs 60 different elements" of the periodic table, selected for their very specific qualities and performance.[41] In practice, then, contemporary technologies have a wider spectrum of supply vulnerability; in the case of the computer chip, for example, a shortage of any of its 60 elements could substantively degrade performance.

In some cases – particularly with highly sophisticated technologies, including those preferred by the U.S. military – the performance edge rests on only a few rare metals that are used in small amounts, and which have no known substitutes. These rare metals include heavy REEs, often used to make permanent magnets, and a number of specialty metals, such as titanium, used to make high performance alloys. While these metals are not necessarily rare in geological terms, they are often insufficiently concentrated to make extraction economically viable.

The exception to the profitability problem is when rare metals are naturally occurring within base metal deposits.[42] Because this geological good-fortune is uncommon, the rare earths and specialty metals markets are often nearly monopolistic. As a result, it is likely that many defense value chains are diamond shaped, often with a single rare earth supplier on one end and single specialty manufacturer on the other.[43] Given the previously noted mercantilist trend, this single supplier may be a potentially hostile or unstable government, an ally of such a government, or a small actor in a hostile government's backyard.[44]

Making matters worse is a potential problem of declining supply inventories among defense-related companies. In order to compete on price, businesses have sought to reduce their production costs. In recent years, this situation has promoted "just-in-time logistics," a method of keeping inventory costs at a bare minimum.[45] With reduced in-house stores, defense companies may be particularly vulnerable to short-term supply shocks.

Supply Disruptions: A Rare Earth Elements Example

If one focuses on scarcity of supply, or supply disruption, as a component of criticality for metals and minerals, then China's recent involvement with REEs offers a historical example of this variable's significance. REEs consist of 17 elements (reference Appendix C), which despite their name are actually more abundant in the earth than gold and silver. It is the low concentration of REEs in most deposits, which makes extraction and refinement difficult and expensive, that gives these elements the designation of 'rare.'[46] The importance of REEs is attributable to the fact that, although only present in small amounts, these minerals and metals are found in most current electronic devices upon which the average citizen has become increasingly reliant. To further compound the issue, there exists a near-monopoly on the extraction and refinement of REEs. Not only is China the largest producer with nearly 95 percent of the supply, but they are also the largest consumer at 60 percent of demand. Simply put, REEs, largely controlled by China, are directly impacted by changes in Chinese production and export of the minerals and associated refined products, which can result in unexpected supply constriction.[47]

This type of effect was witnessed in 2010. During September of that year, China abruptly issued a “de facto ban” on the export of REEs, specifically to Japan, following a territorial dispute in the South China Sea.[48] While China denied that an actual ban occurred, contracts with Japanese producers were cancelled and REE prices spiked; an example being neodymium – an element critical to magnet production – which rose from $30.24 per kilogram in 2007 to $340 per kilogram in 2011.[49] Considering vehicle makers’ and electronic producers’ reliance on rare earth magnets, the export ban had a significant impact on those markets and for other end products reliant on REEs. While short lived and primarily only resulting in higher prices, the incident highlights the potential supply risks that arise from dependence on a single source of materials vital to home-country production, especially when the source is not well understood or has different interests.

The 2010 incident was just one illustration of a series of policies and actions from the Chinese government that continue to threaten global REE supply today. Leading up to the incident with Japan, the Chinese government had taken actions to control REE production to protect supply for their own growing demand, cutting exports by 6-7 percent each year from 2006 to 2009.[50] Additionally, following the 2010 crisis, the Chinese government shut down numerous production facilities in 2011 in an attempt to enforce pollution control and eliminate illegal production outside of sanctioned sites, citing concern of growing environmental impact.[51] The result of these policies, and, specifically, the 2010 incident with Japan, rendered the realization that China was building a monopoly in REE markets, which could have serious effects on global economies and the national security of other countries.

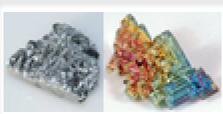
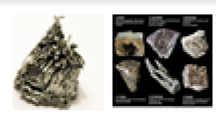
China’s actions highlighted the vulnerability of supply chains based on a single provider. Following the crisis, Japan has worked to enhance their upstream REE supply chain, spending $490 million to increase REE production through technology and $370 million on foreign investment to diversify sources.[52] Additionally, companies in Japan with a reliance on REEs have sought out production in Vietnam, India, and Kazakhstan and negotiated long-term contracts with producers in Australia, incentivizing increased production abroad.[53] In the case of the Japanese, these actions, along with a stabilized demand and supply for REEs, has quieted concerns for now. However, China still controls the majority of production for the minerals, and as the global economy recovers from recent slowdowns, growing demand will likely exert additional pressure on countries and companies, which have not taken action to diversify their supply.

U.S. Resource Dependency on China - Cause for Concern?

The 2010 incident and China’s minerals supply chain development and policies have also served as a call for the United States to reevaluate material reliance. The United States economy, especially its manufacturing sector, is dependent on the supply of raw and semi-finished materials used to make products. While the United States has extensive mineral resources and is a leading global materials producer, a high percentage of materials critical to national manufacturing and the Department of Defense (DoD) are imported from China (Figure 1). Over the past several years, China is uniquely positioned as the leading producer of the most non-fuel mineral commodities and over 50 percent of the global supply of 11 key materials (Figure 2).[54] Most notably, China is, by far, the leader in REEs (including scandium and yttrium), accounting for over 90 percent of global production and over 40 percent of known reserves.[55] The Bayan Obo deposit in Inner Mongolia is considered to be the world's largest rare earth deposit and provides 40-50 percent of the world's REEs.[56]

The United States accounts for only 15 percent of REE global consumption – and the DoD only about one percent of the U.S. consumption – however, there are very limited readily available alternatives outside of China to meet all critical technology requirements.[57] China is the only country that produces over 50 percent of the global production of more than one material used extensively in U.S. manufacturing. Four of these materials – antimony, REEs, tungsten, and yttrium (sometimes considered an REE) – are also difficult to substitute without significantly increasing the cost or decreasing the performance of the products they are used to make, thus increasing the supply risk.[58] As a result, U.S. manufacturers are vulnerable to restrictions or disruptions that limit their access to these materials. This is a growing concern in light of the anticipated rise in global demand for REE-based products and other materials over the next 10-20 years (Figure 3) and China's plan to reduce production in order to decrease stress on its reserves and maintain control of market prices.[59;60]

Although China is mineral rich, the country's industry strength lies not only in its domestic reserves and mineral extraction, but also in its development of a vertically integrated supply chain.[61] Beyond dependence on China for raw ore, the United States is nearly 100 percent reliant on China for processing minerals as well, particularly in the production of rare earth metals for end-use manufacturing.[62] China has continued to integrate downstream operations in order to produce and sell more value-added products. Therefore, even for the materials in which China does not dominate mining, the country often has the competitive advantage in the downstream processing of the materials, thus forging U.S. dependence. While reliance on international sources in and of itself does not constitute supply risk, extensive dependence on China, a competitive near-peer that has internal challenges and political and policy conflicts with the United States, could ultimately pose a supply risk, if alternate sources are not secured.

antimony	53%	germanium	54%
arsenic	89%	rare earths	54%
barite	51%	scandium	100%
bismuth	61%	yttrium	76%

Figure 1. U.S. Material Import Reliance on China (over 50%)[63]

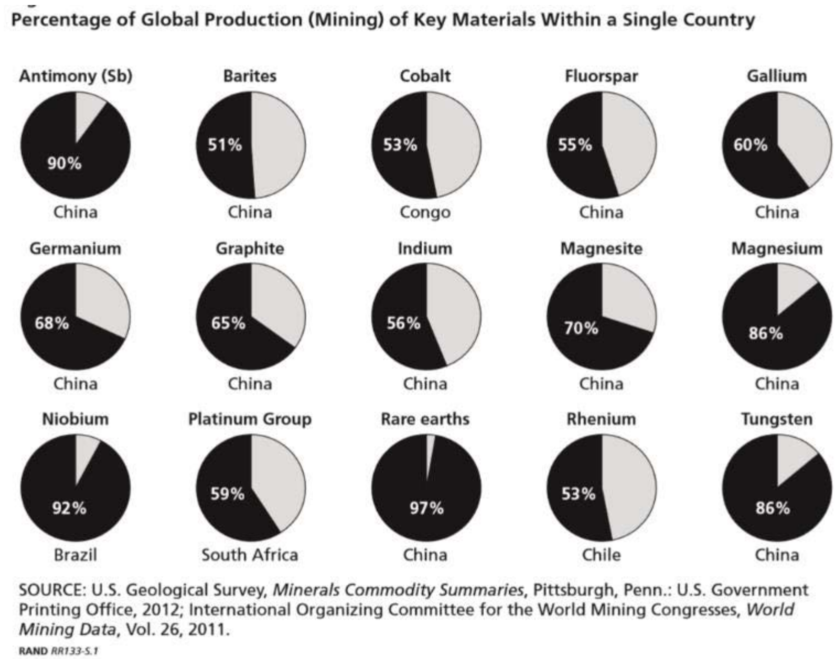


Figure 2. Global Production of Key Materials[64]

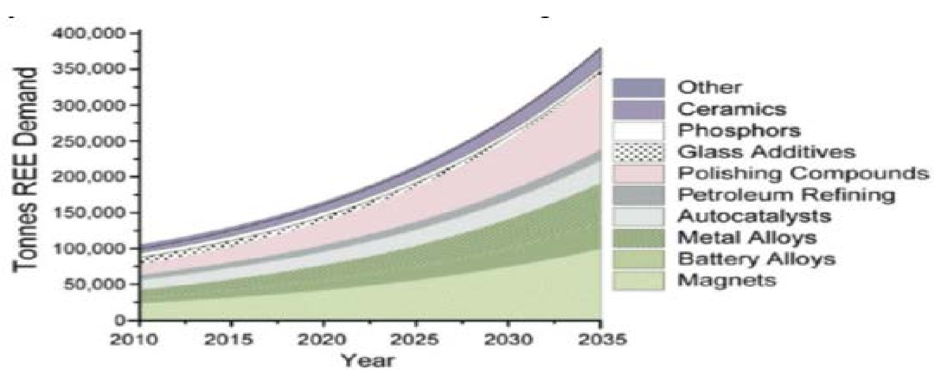


Figure 3. Rare Earth Element Product Demand Growth[65]

Government Involvement in Strategic Material: Domestically and Abroad

In this next section, we analyze current government leadership and involvement in the strategic materials sector, competing priorities between mining and environmental stewardship through the lens of the permitting and environmental review process, and broad opportunities for the United States to consider to ensure long-term access to resources.

Whole of Government Minerals Leadership

Within the U.S. government, there are a myriad of players in the world of STRATMAT, many of who are working in isolation or cross-purposes to each other due to a lack of centralized leadership. Based on laws dating back to 1939, responsibility for U.S. strategy regarding strategic materials has spread across multiple government departments and agencies. The White House, DoD, Department of Commerce (DoC), Department of Energy (DoE), and Department of Interior (DoI) all play critical if somewhat duplicative roles without centralized leadership guiding the overall process. In spite of these challenges, with significant streamlining of current policies and minor re-assignment of some governmental roles between agencies, it is possible to have effective leadership in mineral security to position the United States for future success.

From a broad perspective, the main issue facing the United States is assured access to key materials for both prosperity and security. To that end, the Subcommittee on Critical and Strategic Mineral Supply Chains, a subordinate office of the White House's Office of Science and Technology Policy, is tasked with examining the raw commodities and the downstream supply chains to ascertain global supply disruptions. The data obtained from these analyses is utilized to determine the criticality of the mineral and possible risk mitigation procedures.[66]

For the DoD, the key legislation driving defense action is the Strategic and Critical Materials Stockpiling Act, which took effect in 1939. This law directs DoD efforts by authorizing the acquisition and retention of strategic and critical materials for national defense.[67] The Office of the Secretary of Defense for Acquisition, Technology and Logistics (OSD AT&L) has the primary responsibility for tasks relating to the stockpile, and within this office are multiple sub-divisions with varying duties that range from focusing on security of supply to maintaining connections with the Defense Industrial Base (DIB). Actual management of the stockpile is delegated to the Defense Logistics Agency (DLA).[68]

In addition to the DoD, other U.S. governmental departments have key responsibilities in the process. The DoC and DoE also have committees looking at similar issues, particularly from the demand side. Within the DoC, the Interagency Market Impact Committee (MIC) examines the economic impact, both domestically and internationally, on the acquisition and disposal of materials within the stockpile. The MIC works closely with DoD, but not the aforementioned White House subcommittee.[69] From a manufacturing perspective, the Critical Materials Institute (CMI) within the DoE focuses on process improvements in clean energy technology and searches for viable substitutes with a view to diversifying supply chains and forecasting mineral criticality. To achieve this role, the CMI has a very strong industry linkage with both end-use manufacturers as well as upstream raw material producers.[70]

While there are a number of agencies studying the supply and demand signals, the DoI is solely focused on the collation of raw material data. Originally, the Bureau of Mines was responsible for both the collation and analysis of this data, but with their dissolution in 1996, the collation task moved to the United States Geological Survey (USGS) without the analysis task.[71] Since then, respective government departments have done independent analysis as it pertains to their field. The American Minerals Security Act of 2015 proposes the reinvigoration of this function under USGS leadership to enable a comprehensive picture of mineral security.[72]

Ultimately, the greatest challenge for any organization is unity of effort. On the subject of critical and strategic materials, this topical issue crosses a multitude of government departments and affects a wide variety of interests. Because of this, Congressional legislation often oversteps jurisdictional lines, creating inevitable gaps in oversight and ultimately leadership. The net result is a number of U.S. government departments working in different directions that pertain to their own field, but without a national effort to determine a holistic picture of strategic materials security concerns. Executive direction on a methodology of analysis would enable a unified approach, which would drive each department to develop action plans that informs the supply and demand issues pertaining to their portions of the industry.

Permitting and Environmental Regulation

The U.S. mining and manufacturing industries are subject to strict permitting and environmental regulations, in part due to a legacy of environmental damage and abandonment of mines prior to the 1970s. Although modern mining and manufacturing operations have significantly improved their environmental footprint in the past several decades, the regulatory regime has become stricter and more difficult to navigate. Robert Matthews noted, “mine building often draws more opposition in the United States...due to mining's checkered history and reputation for pollution, abandonment and sometimes-shoddy management. Mining companies in the United States have cleaned up their management for the most part, but reputations haven't caught up.”[73]

The United States has one of the longest permitting processes globally, with approvals for new mines often requiring upwards of 10 years, depending on the complexity of the project. The process is expensive, both from the industry and regulatory perspective. The length of the process and uncertainty of outcomes discourages investment in U.S. mining operations, and contributes to the offshoring of mining and manufacturing and increased U.S. import dependency.

The differences between public and private decision-making are a source of frustration for mining companies, who emphasize the need for faster, more responsive processes with strict deadlines for review, comment, and participation.[74] In Congressional testimony given to the Subcommittee on Energy and Natural Resources by Chris R. Hamilton, Senior Vice President and Chairman of the West Virginia Coal Association, Mr. Hamilton stated that one-third of all coal mines operating in the U.S. in 2008 closed by 2013.[75] The reasons cited for the closures were “baseless regulatory changes." The same effects can be seen throughout the critical minerals industry in the United States. Some laws provide opportunities for opponents to delay, stop, or require such substantive mitigation that projects become economically unfeasible. Although litigation risk is moderate, even one successful outcome has significant ramifications making the regulatory agencies conservative in their approach, which leads to stricter regulation.[76]

Further, industry complaints typically regard the implementation of environmental laws, not the intent. Overall, there is widespread concurrence regarding the need to conduct mining in an environmentally responsible manner. A National Research Council (NRC) study found that, "improvements in the implementation of existing regulations present the greatest opportunity for improving environmental protection and the efficiency of the regulatory process."[77]

Similarly, the Northwest Mining Association (NWMA), commented on draft guidance to improve the environmental review process, stating:

> NWMA wants to emphasize that substantive U.S. environmental law and regulations are not the problem -- it is the process of obtaining agency permits and approvals. Our members take great pride in protecting the environment while producing the minerals America needs. The U.S. mining industry is the most environmentally responsible mining industry in the world. Mining and environmental protection are compatible...[78]

There is room for improvement in all facets of the process, with work required from both industry and government. Mining companies often do not understand the process and submit poorly prepared permit applications documents. There is a tendency for "scope creep" with companies changing a project's scope while a permit is in review, requiring additional information and delaying the process. Further, companies resist sharing information with the public, working with regulators to identify meaningful alternatives to issues, or incorporating measures to reduce the environmental impact.

Agencies have inadequate resources to deal with the permit workload, and stovepipes exist within agencies such that there is little coordination to streamline or de-conflict process steps, particularly between federal, state, and local regulations.[79] The absence of a central coordinator for the process has also led some agencies, like the Environmental Protection Agency, to exceed their mandates and attempt to impose stricter regulation.[80] The need for land management agencies, like the Bureau of Land Management and the U.S. Forest Service, to balance competing public uses of federal lands can result in fewer lands being open for mining development. An aging workforce and high personnel turnover within permitting and regulatory agencies also means there are few qualified members to perform regulatory responsibilities.[81;82] The workload quickly overwhelms the staff in meeting timelines.

Regulatory reform and process improvement are needed to address all of these issues. Streamlining of the permitting and environmental review process, including efforts to increase stakeholder coordination early in the process, represents a significant opportunity to reduce the wait time required to stand up a new operation. Process improvements could also help attract investors, many of whom are turned away by the significant level of government involvement.[83]

Broad Opportunities to Influence United States Access to STRATMAT

While the price of commodities remains low and the global mining sector is at the bottom of a super cycle, there is still significant opportunity for the United States to influence both domestic and foreign mining operations. The key for the nation will be to switch to growth while many others are downsizing and restructuring. During this time, America can lead with its expertise and incentivize companies to invest both domestically and abroad and use innovation to solve some of the risks in the global mining sector. While truly innovative advances in mining, such as mining resources in outer space, may be far off (reference Appendix D), solutions to the most current pressing challenges like decreased productivity, access to energy and social license to operate issues are possible with the help of U.S. companies. Addressing these issues will simultaneously enable foreign mining operations to exponentially build upon substantial mineral reserves and create new opportunities for U.S. investment overseas resulting in more assured access to strategic materials than exists today.

Productivity, Access to Energy and Social License to Operate Issues

Diminishing productivity is a rising concern within the industry. Nearly every company visited or studied by the STRATMAT team noted declining productivity as a key issue to address in 2016. Despite significant efforts, there still remains substantial room for improvement; true innovation is required to create a new culture of productivity in the mining industry following the commodities bust. U.S. companies, especially those effective at analyzing data, monitoring performance and understanding productivity and output could contribute significantly to solutions. These companies have the potential to drive the next metals and minerals cycle.

Access to energy and water for mining operations is also a significant issue, especially for operations in more underdeveloped countries (see Appendix B). Ineffective infrastructure and lack of investment have severely impacted mining operators' ability to produce and refine extracted ore. In countries with rising economic means, the increasing affluence of the local population places greater pressure on limited energy and water resources; this is true even in portions of the United States. Whatever the cause, industry access to energy and water remains an area that U.S. companies could significantly contribute to in an effort to sustain foreign operations. Innovation in this area could come in the form of renewable energy applications, for which the United States has already demonstrated significant global predominance, de-intensifying energy intense applications in mining operations, or encouraging national energy providers to partner with host nation energy operations to create synergistic operations.

A third, and perhaps the most daunting concern raised by mining operators is pressure resulting from social license to operate (SLTO) issues. SLTO is a multi-stakeholder issue that requires partnership, collaboration and negotiation from a broad spectrum of interest groups. Often, political and economic decisions are at odds with community interests and clashes result in protests and work stoppages that shut down mining operations and threaten the health and safety of mining employees. National interest groups, especially those with a proven track record of providing amenable solutions to SLTO issues, should be encouraged and incentivized to engage in both domestic and international discussion.

Beyond the issues described above, another opportunity lies in foreign direct investment to help bolster foreign mining outputs. Due to the downturn in commodity prices, there is an entire portfolio of substantial global mining assets that are ripe for acquisition. Industry analyses and company briefs conducted on several top companies in the mining industry revealed that many, if not all, are engaged in active downsizing and de-leveraging of key assets; seizing such an opportunity may provide incentives for companies to retain or make new investments in minerals and mining operations overseas. [84] Lastly, such an action would not only bolster production in countries where reserves and ore grades remain high, but would also ensure national access to critical mineral supplies, a key national security concern as previously mentioned.

Foreign direct investment is not without risk, however. As political and economic stability improves in some countries, concern over resource nationalism continues to rise. Host nations, either thinking that they are not receiving their “fair share” from mining companies, or in an attempt to protect their own national security and interests, are exerting significant political pressure to retain assets previously sold to foreign investors.[85] The end result could be even stronger regulations, higher taxes and other obstacles that would prevent foreign investment in mining operations overseas. While the U.S. government and private investors will need to manage these risks, foreign direct investment and economic diplomacy with foreign nations could create a core conglomerate of allied partnerships to ensure access to critical minerals.

Education versus Employment

As discussed in other portions of this report, national investment in the human capital aspect of the mining industry is lacking. Science, Technology, Engineering, and Mathematics (STEM) education programs, while critical for generating engineers and scientists, have failed to address the technical and vocational needs that feed the mining industry. As a result, the available labor force for U.S. mining jobs is severely depleted. The BLS reports fewer than 100,000 people are employed in the natural resources and mining fields and close to 36 percent of available jobs remain vacant for longer than three months. The technical roles, like crewmember, crew foreman and field supervisor are the hardest to fill.[86] To compound the issue, many U.S. mineworkers emigrated to other countries when the North American market started to slow in 2012. The end result has been a technical vacuum that may take years to regenerate.

While STEM programs restructure to address this concern, more near-term solutions may exist to revitalize mining knowledge within the nation. For example, incentives designed to attract foreign mining experts who have been affected by downsizing in other countries have the potential to provide the U.S. sector of the industry with a significant boost. Such an effort may require relaxing some immigration laws and creating special worker visas for individuals with needed technical expertise.

Conclusion

Strategic materials are essential to modern technologies. More pertinently, they are also in critical weapons systems such as the Joint Strike Fighter, the V-22 Osprey and every U.S. Navy aircraft carrier in service. In a very real sense, the nation is dependent on access to these strategic materials and the United States government should develop suitable policy initiatives to guarantee security of supply. Some recommendations have greater potential to alleviate risk, and those are spelled out in detail in the remaining pages of this document. Regardless of which direction the government takes, it is clear that the United States requires greater leadership in the strategic materials industrial sector if the nation is to remain a viable economic leader in the future.

Policy Recommendations for Continued Access to Strategic Minerals

1) Streamline U.S. policy to create efficiencies

A) Single government entity for whole-of-government solutions to STRATMAT

Dating back to 1939, a number of legislative mandates were generated to respond to different threats to security. However, many of these mandates remain department-specific today, leading to lack of coordination, duplication, and often-conflicting efforts to address security threats. To counter this trend, national security policies on critical and strategic materials require a unified effort with a single point of leadership. Unity of effort is required to have sustainable mineral security; a clear national picture will enable the United States, writ large, to make the necessary decisions to assure its needs can be met in times of crisis. A single government entity would collect and analyze the data necessary for a comprehensive national picture of mineral security to enable future decision-making.

B) Single government entity to coordinate/track permitting and environmental review process

A review of studies and Congressional testimony from the last 20 years provides a long list of proposed reforms to improve the environmental review process and permit times for new mines within the United States. One such solution is the proposed *American Mineral Security Act of 2015* which requires that federal agencies,

> ...avoid duplication of effort, prevent unnecessary paperwork, and minimize delays in the administration of applicable laws and the issuance of permits and authorizations necessary to explore for, develop, and produce critical minerals and to construct mineral manufacturing facilities in accordance with applicable environmental and land management laws.[87]

Passage of this act would streamline the existing permitting process and has the potential to stimulate more substantial investment in the U.S. mining industry.

C) Single government entity for science/technology and whole-of-government R&D efforts

There is also a need to coordinate whole of government science and technology efforts related to strategic materials. Currently, the President's Office of Science and Technology provides grants for research related to a variety of topics, including substitutes and new uses for strategic materials. The DoE provides grants related to REE research, as these elements have multiple energy-related uses. Other agencies, like the Defense Advanced Research Projects Agency (DARPA) and DoE's Advanced Research Projects Agency – Energy, (ARPA-E) also provide research funds or incentivize research ventures for topics that overlap strategic materials issues. Most of these agencies are unaware of the research efforts funded by others, increasing the potential for duplication. Having a single office that tracks relevant research efforts would yield multiple benefits, such as reduced duplication of effort, research synergies, scalability of research, and better alignment of research projects to national interests.

2) Targeting human capital for STRAMAT

A) Research & development funding to incentivize mining higher education and prevent the loss of domestic mining engineering programs

Maintaining university mining programs is essential to preserving U.S. intellectual capital related to the mining industry. Universities depend on R&D funding to retain and develop new faculty necessary for domestic mining engineering schools, particularly for graduate and doctoral programs. Active research also attracts new students and additional investment. Renewal of government grants similar to what the USBM previously sponsored merits consideration by U.S. policymakers who are concerned with offshoring of mining and manufacturing operations. Providing research funding to universities would encourage institutions to maintain facilities, hire faculty and attract students. Robust research programs add to the body of knowledge on mining technology and areas for innovation, and provide a repository of knowledge.

B) Encourage vocational education as viable career path

Federal and state government policies should focus on encouraging the development of a skilled vocational workforce using tools, such as job training, scholarships, high school outreach, and public perception campaigns. Government policies reversing the reduction in funding in high schools is also recommended. While funding programs such as TACCCT are making a difference, without a change in the perception of the value of vocational workers, the current shortfall will continue. Efforts to counter the negative association with vocational training are more complex. High schools and communities need to educate communities on the value added benefits vocational training provides in supporting the economy, as well as the high-tech opportunities trained workers can access (few trades are truly ‘blue-collar’ work today). The 2014 CCSSO’s vocational strategy is an example, recommended for adoption at the federal level, of a program that reinforces the importance of trades in society and U.S. technological superiority.

3) Use acquisition system to promote STRATMAT security

A) Acquisitions reform which compensates for more robust, commercially-held strategic material inventories

To limit DLA stockpiling requirements, the USG can incentivize stockpiling within the DIB. To do this, the United States should reward manufacturers of specific end items containing strategic materials to maintain supply or secure a dedicated source of supply for those said materials. The agreement would stipulate the applicable form or composition of the material (alloy, concentrate, ingot, etc.) and the duration the supply must cover (i.e. 12 months).

B) Incentivize and enable materials substitution and recycling

The United States should incentivize research partners to find viable strategic materials substitutes. One model to examine for wider applicability across government exists today within the DoE. The ARPA-E has worked to find domestically abundant substitute elements for REEs. The program currently has 13 on-going REE alternatives programs. Some programs focus on direct magnetic replacements for REE magnets, while others are looking for magnet replacement technologies. Many of these programs have shown promising results to date. More time is needed to test these technologies to ready them for production and use. In the meantime, interim solutions are necessary to mitigate supply interruptions until these alternatives are domestically available.

The United States should also set conditions for increased recycling of strategic materials. Current reuse and recycling rates of REE, for example, amount to less than one percent due to collection challenges and low concentrations, making efforts economically infeasible. Incentivizing recycling research and promoting 'design for recycling' techniques may increase industry interest and stimulate innovation in recovery efforts.

4) Hedging risk (assured supply) through long term Allies/partnerships

A) Strategic Materials, global partnerships and the National Security Strategy

Since its inception in 1986, the NSS has highlighted U.S. global leadership - one that simultaneously drives national action and informs world perception of American intent. If concerns exist about domestic supply risk, the NSS should specifically address mineral security and outline a detailed plan for assured supply. Such a plan signals to global leaders this critical relationship between strategic materials and security, and U.S. intentions to alleviate supply risk through cooperative allied networks and foreign investment.

B) More FDI in mining industries abroad in order to solve global mining challenges and strengthen U.S.-Allied partnerships with respect to critical mineral supply

The downturn in the global mineral markets has left many mining companies, both domestically and abroad, struggling to address critical labor force and infrastructure needs. The capital to invest is scarce, but if key issues like diminished productivity, access to energy and water, and SLTO are not addressed, these companies will struggle to survive even when the cycle reverses and commodities boom once again. The United States has a real opportunity to lead with its expertise, support struggling foreign mining operations and create investment opportunities that will bring returns back to the U.S. mining sector. The government should consider providing incentives to U.S. companies that invest R&D funds to address some of the key opportunities discussed elsewhere in this report. The outcome will be highly productive operations across the globe and a strengthening of U.S.-Allied partnerships in addressing critical mineral supplies.

C) Continue to promote free trade; break down trade barriers, creating assured access through strategic and economic partnerships

The United States has Free Trade Agreements (FTA) in force with 20 countries. FTAs, such as the TPP and Transatlantic Trade and Investment Partnership (T-TIP), are meant to level the playing field in terms of labor costs and regulatory requirements as well as open up the markets of the signatory nations to each other. Promotion and use of FTAs is one of several ways the United States can hedge against the resource dependence. Especially useful may be increased security of supply arrangements within those FTAs.[88]

Appendix A

Organizational Classifications of "Critical" and "Strategic" Minerals and Materials

Department of Defense – Defense Logistics Agency

Definition: (from the Strategic and Critical Materials Stock Piling Act, 50 U.S.C. 98 et seq) "'strategic and critical materials' means materials that (A) would be needed to supply the military, industrial, and essential civilian needs of the United States during a national emergency, and (B) are not found or produced in the United States in sufficient quantities to meet such need."[89]

Methodology: multi-step "funneling" process as depicted below to calculate gross and net shortfalls of the materials required in the execution of national defense responsibilities as determined through defined "Base Case" and "Alternative Case" conflict scenarios in open and closed U.S. economic and manufacturing environments.

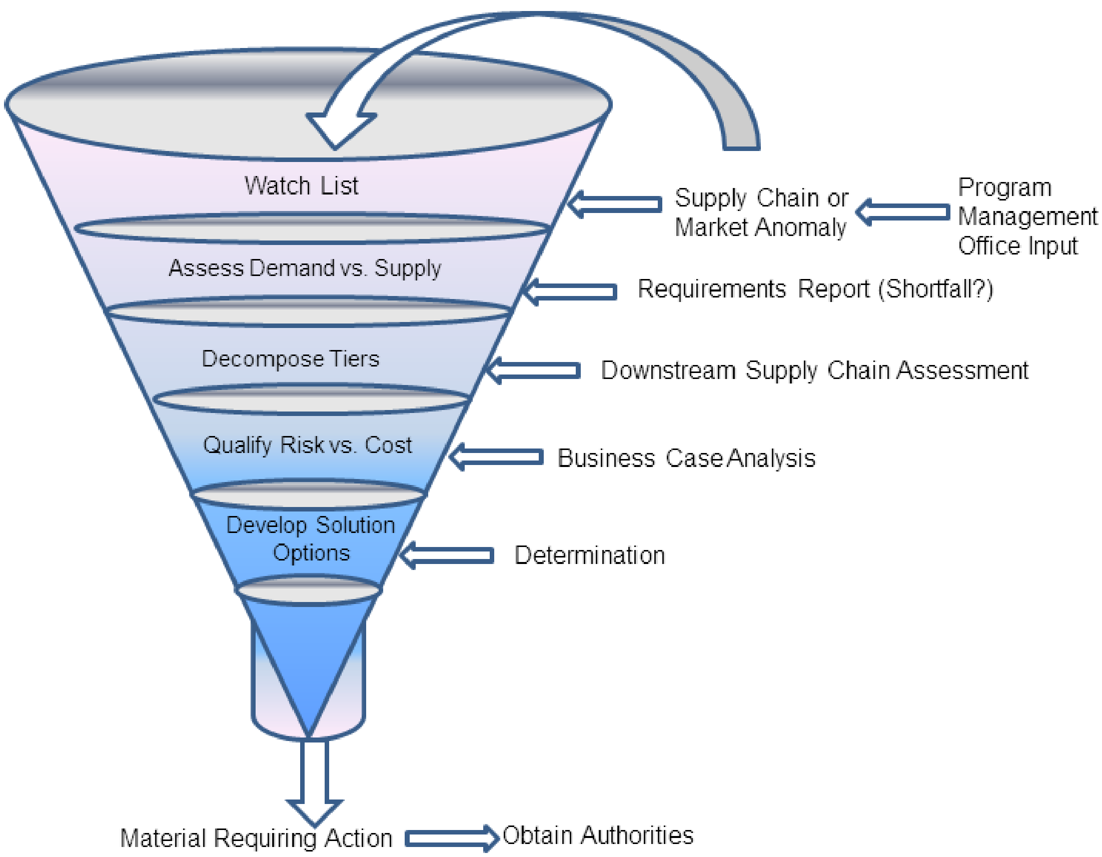


Figure 8: DLA "Funneling" Methodology[90]

National Research Council

Definition: "a critical mineral is one that is both essential in use and subject to supply restriction."[91]

Methodology: a two-dimensional "criticality matrix" as depicted below to measure "the degree of importance of a mineral or, equivalently, the *impact of supply restriction*" and "the degree of *supply risk* or the risk of a supply restriction."[92]

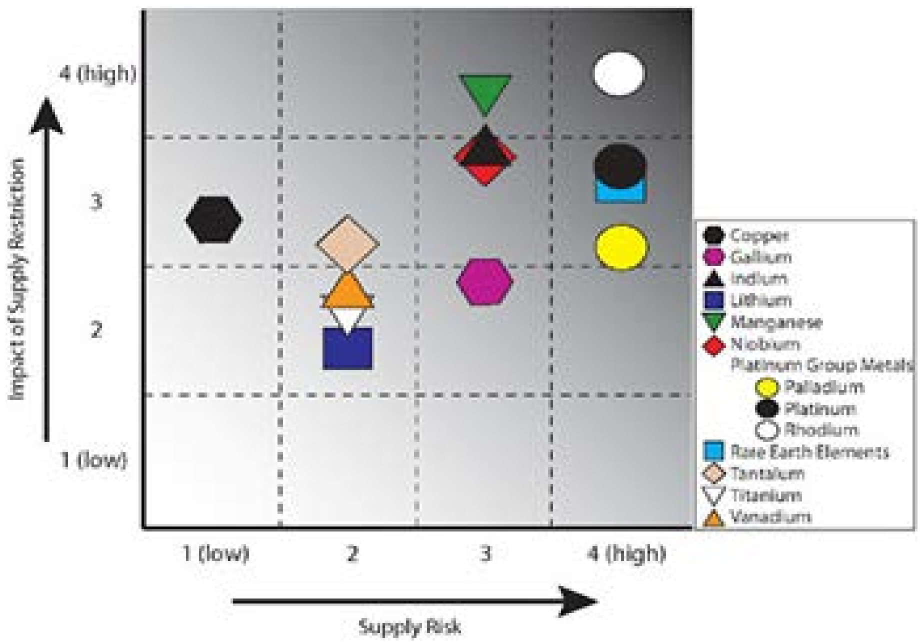


Figure 9: NRC Criticality Matrix[93]

Department of Energy

DOE utilizes the same methodology as presented by the NRC except, the y-axis of the criticality matrix is changed to measure the mineral according to *importance to clean energy*.[94]

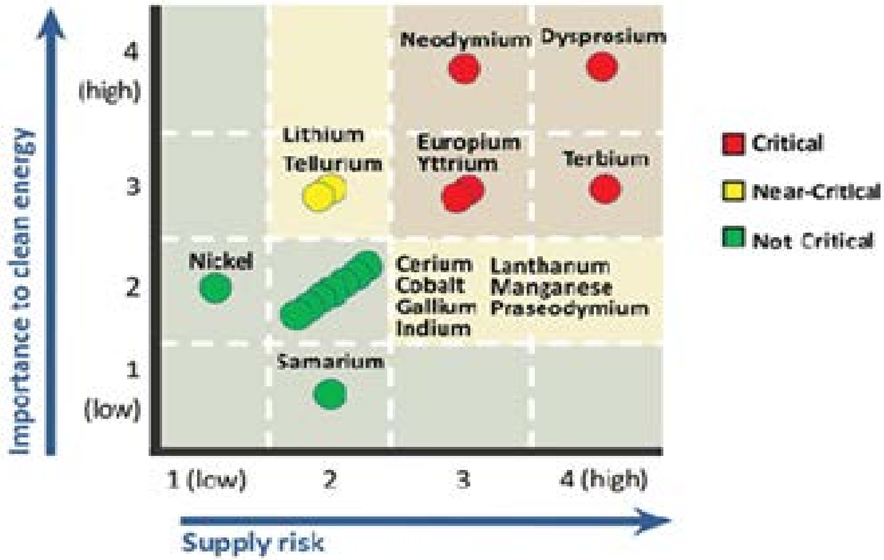


Figure 9: DOE Criticality Matrix[95]

National Science and Technology Council, Office of Science and Technology Policy

Definition: "'critical materials' are those that have a supply chain that is vulnerable to disruption, and serve an essential function in the manufacture of a product, the absence of which would cause significant economic or security consequences...'strategic materials' are regarded as a subset of critical materials and are those that are essential for national security applications."[96]

Methodology: a mathematical calculation based on the geometric mean of three variables assessed on scale of 0 to 1: *supply risk* (i.e., geopolitical production concentration), *production growth* (i.e., mineral's market size) and *market dynamics* (i.e., mineral's price sensitivity).[97]

Appendix B

Global Mining and Minerals Review

The geology of the Earth is predominantly the result of tectonic plate movement creating convergent and divergent boundaries. Continents are mostly single plates moving slowly over time creating young rocks at convergent boundaries and leaving old rocks at divergent boundaries. Mineral deposits are predominantly associated with the type and age of the rock left behind; moreover, there is a strong correlation between the deposit type and the process by which the rocks were created. Minerals are therefore unevenly distributed across the earth, a key point when analyzing these elements as they relate to national security. With this understanding, we now turn to a top level analysis of some significant deposits by continent (excluding Antarctica) and, in some cases, a brief review of challenges in accessing these non-fuel minerals in order to paint the broader context of the strategic challenges involved.

Africa

Geologically, Africa formed the center of the supercontinent known as Pangaea, and much of its bedrock comprises igneous and sedimentary rocks gradually metamorphosed through heat and pressure as Pangaea began to break apart approximately 130 million years ago.[98] The tectonic movements, combined with smaller scale geologic activity such as erosion, earthquakes, and sea level rise and fall, created an extremely complex geological record that varies across the continent. As a result, mineral resources are abundant on the continent, and include uranium, platinum group metals, nickel, bauxite, cobalt, gold, and diamonds.

African countries are expected to experience population growth, economic growth, and urbanization ranging from 40 to 60 percent over the next twenty years; with manufacturing generating 80 percent of the economic growth.[99] Modernization of infrastructure and technology has significant potential to contribute to manufacturing through better utilization of resources.[100] Economic experts note that "the fundamental components of an efficient manufacturing industry—a productive labor force, reliable electricity supply, and efficient transport networks—are lacking across much of the continent and more established manufacturing locales such as India, Vietnam and Bangladesh are still more competitive locations."[101] Nonexistent, corrupt, or oppressive governance creates fragile states and civil unrest, and is likely to lead to the downgrading of Africa's financial rating.[102] Other factors include the lack of employee labor rights, fair wages, proliferation of terrorist organizations and transnational organized crime, unsustainable agricultural methods resulting in shortages of food and water, and environmental degradation related to mine drainage, deforestation, and desertification.[103] The confluence of all factors makes Africa a difficult place to manage risk.

In spite of these factors, the United States views Africa as a strategic opportunity due to its abundance of minerals, oil, and gas. However, other nations have interests in Africa's abundant resources as well and many of those interests run counter to those of the United States. For example, China's interest in Africa to secure resources often undermines international efforts to alleviate poverty, improve human rights and democracy, establish good governance regimes, and encourage sustainable development.[104] With this scale of resource competition, the opportunity to form multilateral engagement and cooperation through mineral and energy security is tremendous. According to the USGS, the United States is heavily import reliant on a number of African commodities to include: manganese (100%), platinum group metals (85%) and chromium (72%).[105] Disruption to the supply chains for these three minerals would affect the ability of the United States to support its manufacturing base, including the manufacture of defense systems.

Europe

The European continent hosts a diverse geologic structure that has been populated and mined for centuries. In spite of long-term mining and extraction of resources there are still considerable deposits in many locations. Further, multiple nations are conducting exploratory activities to seek out new deposits. For example, Bulgaria, Finland, Ireland, Norway, Portugal, Romania, Italy, Slovakia, Spain, Sweden, and the United Kingdom have begun exploration activities in light of new extraction methods.[106] The primary aim for these recent endeavors is to identify deposits, which have never been discovered or produced in the region such as diamonds in Finland and platinum group elements in the United Kingdom.[107]

North America

Geopolitically, Canada and Mexico are significantly different nations with differing abilities to tap into their natural resources. Canada is a developed nation with a stable government, comparable governance structures to the United States and a negligible level of corruption. On the other hand, Mexico is politically stable, but still has significant issues in economic development, due in the most part to corruption and drug-related security risks.[108] Despite these challenges, Mexico has a trove of mineral wealth with significant potential that entices prospective mining corporations willing to accept the risks. In the last decade, the Mexican government transformed their extraction industry from one comprised of predominantly state-owned enterprises to one, which encourages private sector development, including foreign direct investment.[109] By way of contrast, Canada has a healthy mining industry and as of 2015, 57 percent of the world's mining companies were listed on the Toronto Stock Exchange; moreover, the Toronto Venture Exchange accounted for 62 percent of all global mining equity.[110] According to the U.S. Geological Survey, the United States is completely import reliant on a number of non-U.S. North American commodities to include: cesium (100%), rubidium (100%), strontium (100%), and zinc (81%).[111]

South America

Major South American mineral and metals producers are Brazil, Chile, Argentina, Peru, Bolivia, Colombia and Venezuela.[112] While not completely similar in cultural and political characteristics, each of these countries is a developing nation, with relatively low levels of per capita income, industrialization, and economic diversification.[113] One common feature of these countries is their relatively high dependence on extractive industries – mining and oil – as their major source of economic returns and public financing.[114] While drug violence, authoritarian regimes, corruption, and leftist, often anti-American politics, have at times colored the situation of individual South American countries, the region represents an opportunity for future U.S. interests.[115] South America is rich in both natural resources and available labor, including metals, and it is geographically proximate to the United States.[116]

Asia

Asia is a huge landmass with significant variations in geography and mineral deposits. It contains one of the greatest convergent tectonic plate regions forming the Himalayan Mountains as well as numerous older geologic features. In the region, China is by far the dominant force in mineral production, producing most of the world's non-fuel minerals.[117] Several other countries in the region have significant minerals output including India, Turkey, Russia, Kazakhstan, and Vietnam. Other nations in the region have poor outputs because they either lack the natural resource deposits or the physical, economic, and political infrastructure to make use of them.

China possesses the world's largest population, the fourth largest land area and is blessed with tremendous mineral resources. China is the world's leading producer for over 30 minerals and accounts for over 85 percent of production of rare earth elements.[118] While the Chinese have entered the globalized market economy, they still rely on state-owned enterprises in areas critical to economic security like the mining sector. The nation is very well vertically integrated and not only leads in mineral extraction but also leads the refining, beneficiation, and smelting business for ores mined abroad. There is some evidence to suggest China uses production controls, export restrictions, mine closings, and company consolidations to exert political pressure on regional neighbors and to encourage foreign companies to relocate to China in order to guarantee access to mineral supplies.[119] This is of particular concern to the United States who relies heavily on Chinese minerals to fuel its economy and provide critical components for high-tech military equipment. China's ongoing territorial expansion and interest in developing mineral resources around the globe only escalates the tension over mineral commodity supplies.

Russia's mining industry, on the other hand, is still emerging from the oppression of the former Soviet Union. During the Cold War years, the nation conducted extensive exploration operations. However, the exploration was focused on commodities required by the centrally planned economy and was not determined by the supply and demand economics of the commodities markets.[120] Today, some western companies have used modern exploration concepts, geologic and tectonic analysis, and mineral deposit models to re-explore hydrothermal gold and silver deposits in the Russian Far East, resulting in reopened or enlarged joint ventures with major western mining companies.[121]

Central Asia hosts several nations that are rich in mineral wealth but are seeking investment to realize their potential. Mongolia sits upon vast quantities of untapped mineral wealth, including large reserves of copper and coal, and has access to cheap labor due to the high rate of unemployment and poverty.[122;123] Mining has long been a staple of Kazakhstan's economy and the nation is actively pursuing foreign investment including a joint venture with the Japanese to export rare earth elements.[124] After decades of conflict, Afghanistan is looking to leverage their potentially large reserves of lithium and rare earth elements along with other base metals to dramatically increase the contribution of mining to their economy.[125] Iran is ranked among the top 15 mineral-rich nations of the world and is aggressively pursuing investment deals with France, Italy, Japan, India, and

China.[126;127;128] These nations pose significant risk for investors however, primarily due to the high levels of public corruption, political instability, and conflict. Particularly in Afghanistan and Iran, decades of war and international sanctions have resulted in extremely poor infrastructure that will require substantial investment to access resources.

Ultimately, the major national security issue with central Asian resources is that they reside in nations that are not historically friendly to the United States or its allies. The ability of these nations to control mineral supplies during a conflict is a concern. Additionally, the vast mineral potential of Afghanistan and Iran could result in substantial funding flowing to terrorist groups operating against the United States or Israel, undermining global security.

Australia and Oceania

The region of Australia and Oceania spans thousands of nautical miles and hundreds of islands. The area is rich in mineral resources, especially coal, copper, gold, nickel, silver, tin, lead, zinc, and bauxite with some supplies of magnesite, titanium, tungsten, uranium, and rare earth elements in Australia.[129] The recent global downturn of commodity prices, especially in coal, has put a significant strain on countries throughout the region who are all highly dependent on income from mineral exports. Despite increases in market volume since 2010, the market value has continued to decline as growth in China slows.

In spite of these challenges, there is significant opportunity for growth and investment in the region. Indonesia has substantial mineral reserves and, with the fourth largest population in the world, there is a strong labor pool for foreign market integration.[130] Further, several countries throughout Oceania such as Papua New Guinea and New Zealand have initiated successful offshore mining operations opening new avenues of opportunity for copper, gold, lead, silver, and zinc.[131] Australia is a veteran minerals exporter and with its expansive resources available, including rare earth elements, will ensure its continued regional importance for some years to come.

For the foreseeable future, the region will face some challenges moving forward. The biggest threats are the global commodity price lows and the duration mining companies can continue operations with declining revenues. Australia is also struggling with high labor wages that are threatening their global competitiveness. This problem is so significant that Price Waterhouse Cooper recently listed the nation as the second least productive mining country in the world in spite of their access to significant resources.[132] Indonesia is facing significant infrastructure shortfalls and lacks the vertical integration for smelting, fabrication, and beneficiation. Attempts to spur investment by banning some unprocessed mineral exports backfired and expanding mining regulations, corruption, and the growing pursuit for resource nationalism have scared off companies who were planning investments.[133] Lastly, while rich in resources, some Oceania islands such as Papua New Guinea are beginning to feel the effects of unregulated mining practices and local communities are protesting health crises, environmental exposures, and human rights violations.

Appendix C

Rare Earth Elements on the Periodic Table

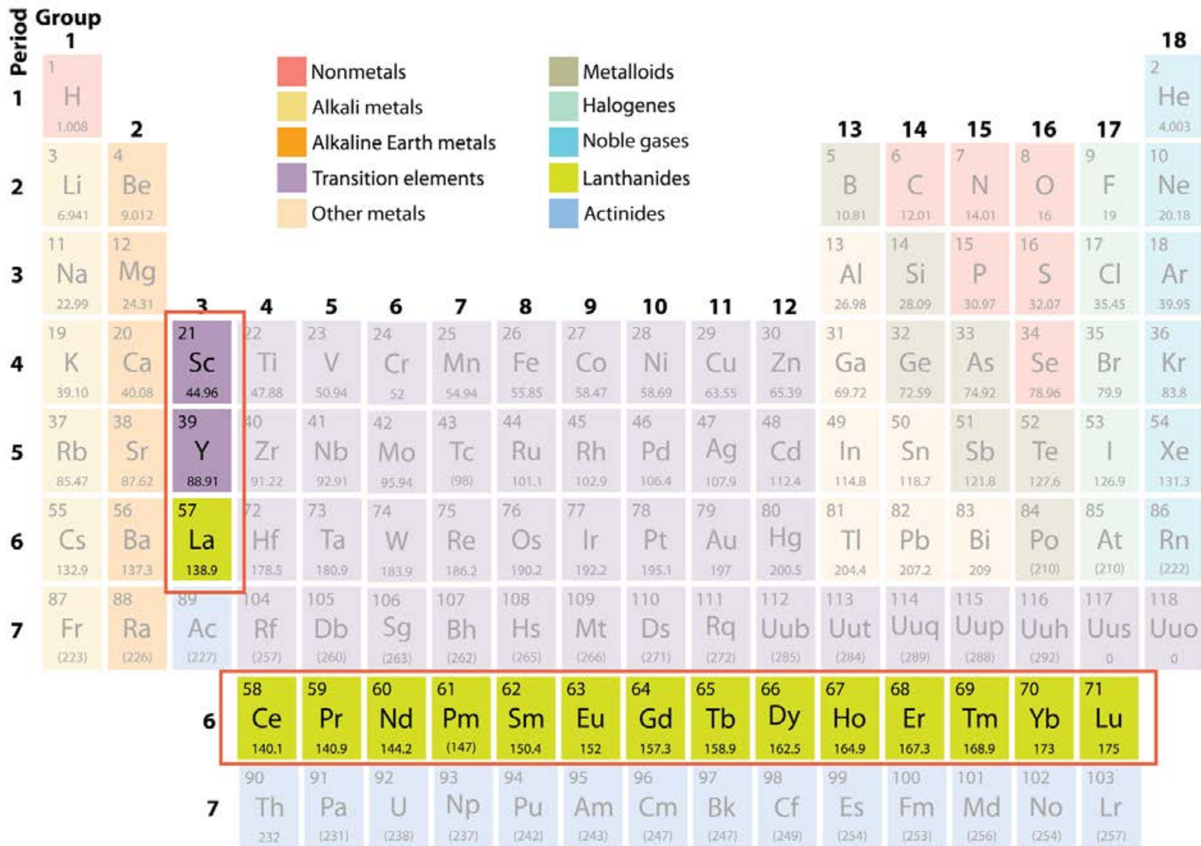


Figure 10: Rare Earth Elements[134]

Appendix D – Mining Space[135]

Lt Col Ryan Gulden, USAF

INTRODUCTION

The future of mining may look vastly different from the open pits and mine shafts of today. Potentially trillions of dollars of minerals are contained in asteroids that are hurtling through space on trajectories that bring them in relatively close proximity to the Earth at some point in their orbit around the sun. The recent growth of commercial space industries has spurred an interest in acquiring these minerals and several adventurous companies believe they have the ability to generate substantial profits by extracting these resources. Technology developments have made asteroid mining increasingly possible and the recovered minerals have the potential to not only change life on Earth but may also provide the building blocks to increase mankind's access to space.

ASTEROID COMPOSITION

NASA estimates there are between 1.1 and 1.9 million asteroids larger than 1 kilometer in diameter with millions of smaller ones. Most of these asteroids are clustered in the main asteroid belt located between Mars and Jupiter. Others, called Trojans, are clustered in the gravitationally stable Lagrangian points in the orbits of the planets in our solar system, primarily Jupiter. Of particular interest to mining are the Near-Earth Asteroids (NEAs) that have orbits that pass close to, or even cross, the orbit of the Earth. As of 2013, NASA had confirmed over 10,000 NEAs with 861 identified as being larger than one kilometer in diameter.[1] As new asteroids continue to be discovered, the number of NEAs could potentially be 100,000.[2] These asteroids are extremely important to asteroid mining companies because they provide opportunities to access materials at greatly reduced costs.

Asteroids are classified into three primary types based on their mineral composition. Carbonaceous (C-type) asteroids account for about 75% of known asteroids and consist of clay and silicate rocks making them dark in appearance. These asteroids also may contain organic materials and volatile substances such as water and methane which may be frozen on or within the asteroid. Seventeen percent of asteroids are stony (S-Type) and comprised of silicate materials, nickel, iron, and magnesium. The remaining 8% of asteroids are metallic (M-type) and comprised primarily of nickel and iron.[3] These asteroids are also believed to contain high concentrations of gold, silver, platinum group metals, and rare earth elements, making them extremely attractive to space miners. Platinum rich asteroids may contain up to 100 grams per ton, making them up to 20 times more concentrated than any deposits on earth. This means that one 500-meter wide asteroid may contain 1.5 times the known world reserves of platinum group metals which equates to 175 times the annual production of platinum.[4]

Extracting materials from asteroids will likely be less intensive than terrestrial mining. Unlike the Earth, asteroids did not go through a molten phase. During this process, all of the heavier metal sank into the Earth's core as it cooled, leaving very little minerals at the surface.[5] In fact, platinum does not naturally occur in the Earth's crust and the orebodies mined today were either deposited by meteors that impacted the Earth after its formation or resulted from magma chamber intrusions from the Earth's mantle.[6] This lack of a molten phase means that minerals such as platinum and rare earth elements are evenly distributed throughout asteroids however, producing high quality ore grades at very shallow depths or even on the surface.[7]

Near-Earth Asteroids are also classified by their orbits. Apollo asteroids orbit the sun in elliptical orbits and spend most of their time outside of Earth's orbit. These account for about 54% of known NEAs. Asteroids in elliptical orbits that are primarily inside Earth's orbit are called Aten asteroids and account for 8% of NEA. The remaining 37% of NEA are Amor asteroids that are in larger orbits that approach but never cross Earth's orbit.[8] These orbits are reflected in Figure 1. The orbits of potential resource asteroids are critical because they determine both the difficulty in getting a spacecraft to rendezvous with the asteroid and the mission plan that must be employed. Because the asteroid and the Earth are travelling in different orbits, there are only specific times when it will be economical, or even possible, to both get to the asteroid and return to earth. This orbital phasing generates a launch window of when the mission must start and also determines how long the spacecraft can loiter with the asteroid conducting mining operations before it must depart for its return to earth orbit. Transit time to these asteroids can be months and with the mining time required, some mission profiles may take years in order to be economically viable. Therefore, the careful selection of orbit friendly ore bodies is critical to the success of space mining.

FEASIBILITY

With all of these valuable materials readily available on asteroids, it is only natural to question if space mining is really possible. The short answer is that it has already been accomplished on a limited scale. The Near Earth Asteroid Rendezvous (NEAR) spacecraft was launched by NASA in 1996 and successfully orbited Eros for a year before landing on the asteroid in February 2001. This mission gained a tremendous amount of data about the composition of the asteroid which seems to have a surface density similar to that of Earth with large craters and boulders.[9] The Curiosity rover continues to examine Mars and was the first to drill into its surface. The extracted pulverized samples were analyzed in an on-board chemistry lab to determine the mineral content.[10] Further, the Japanese Hayabusa spacecraft successfully visited asteroid Itokawa and returned small samples taken from its surface back to Earth.[11] While extremely small in scale, these missions demonstrated all of the technologies necessary to prospect an asteroid to determine its content and retrieve materials from its surface for return to the Earth. All that is needed is to scale up the operation to make it economically viable.

To this end, there are several companies who believe they can turn space mining into a profitable venture. Planetary Resources was founded in Washington in 2009 and is currently a 50-person team.[12] They have developed a series of spacecraft named Arkyd to begin the task of prospecting asteroids to determine their composition and mineral concentration to maximize mining opportunities. Using space as their testbed, each successive vehicle will demonstrate additional capabilities needed to achieve their ultimate objective. Arkyd 3 was launched in July 2015 and tested the avionics, control systems, and software. Arkyd 6 is scheduled to launch in June 2016 and will include a mid-wave infrared sensor to test its ability to find water by examining the Earth.[13] These spacecraft will be followed by the Arkyd 100 and 200 which will demonstrate the ability to examine the Earth with more exotic sensors and demonstrate the ability to rendezvous with an asteroid. A swarm of Arkyd 300 spacecraft will then be deployed to several asteroids of interest to prospect and determine the most viable candidates for commercialization.[14] Planetary Resources is currently interested in eight Apollo and Amor asteroids that show the most potential as ore bodies.[15]

Another space mining company, Deep Space Industries (DSI), is headquartered at the NASA Ames Research Park near San Jose, California. Founded in 2012, they partnered with the Government of Luxembourg to develop the technologies required for space mining. They are currently working on the development of the Prospector-X which will perform the first step of locating and evaluating resources on asteroids.[16] The long-term plan for DSI includes a four step process beginning with prospecting and continuing through harvesting, processing, and eventually manufacturing products in space using the mined materials.[17]

Both companies are still in their infancy but they have significant reasons to be optimistic. About 10% of NEAs are easier to reach than the moon, leaving thousands of potential targets for mining opportunities. Of these, 50% are likely ore bodies that could be profitably mined.[18] Due to the extremely low gravity of asteroids, materials can be moved around easily and significant quantities of materials can be lifted off the surface with very little energy. Numerous techniques for the extraction and processing of ores in space have been identified and information gained from government sponsored explorations will reduce the risks of developing the spacecraft capable of harvesting these resources. Further advances in robotics will continue to make spacecraft and mining tools more autonomous and missions such as the Curiosity rover have demonstrated the ability to effectively monitor and operate vehicles over the vast distances of space. In the end, while there are obviously tremendous challenges that will need to be overcome for space mining to be successful, the technologies are available today to make asteroid mining possible.

BUSINESS MODELS

There are several different models that provide the opportunity for substantial profit from space mining. The key factor is identifying a consumer base willing to purchase the mined materials at a price that exceeds the exorbitant costs of visiting an asteroid and returning the materials to earth orbit. With the content of a single asteroid potentially worth trillions,[19] there is substantial gain to be made given the right opportunities.

The most obvious business model would be to return mined minerals to the surface of the Earth for terrestrial use. This creates a significant challenge in safely decelerating a substantial quantity of mined material in a manner that remains economical. This problem, combined with the high cost of obtaining the processed material from the asteroid, likely restricts this model to only the costliest minerals such as platinum and rare earth elements. Planetary Resources has shown some interest in this model and is planning to investigate an asteroid that is thought to contain more platinum than has ever been mined to date on the Earth.[20]

Even if asteroids are successfully mined, the abundance of material returned to earth would create another problem. The drastic increase in supply of the mineral would cause the price to fall so much that it would undermine the long-term profitability of the endeavor. One way to offset this problem in the short-term would be to establish uptake orders to pre-sell the minerals at a set price. This would guarantee the viability of a single mission but as customers increase their stockpiles with the surplus material this model would likely make future missions unsustainable. In the long-term, this model requires an increase in demand to maintain a price that justifies space mining. One possibility is the elimination of substitutes. Today, industry looks to substitution to remove expensive materials from their products, sometimes accepting a reduced performance to achieve cost savings. If the cost of rare earth elements or platinum, for example, could be reduced through the increased supply from asteroids, then there would be no need for substitution. The increased demand could maintain an equilibrium price that is sufficient to keep space mining viable. Alternatively, new markets could be created to permanently increase the demand for the minerals. One example for platinum is the manufacture of fuel cells. Hydrogen fuel cells are extremely efficient at generating electricity and produce very little pollution but are still very expensive in part because of the platinum required as the catalyst.[21] A healthy supply of platinum from asteroids at reasonable prices could create a whole new industry for low cost fuel cells that could revolutionize energy production and create a more permanent demand for large quantities of platinum.

A second business model would be to sell the mined material to customers on orbit.[22] Any material available in orbit is worth substantially more because of the significant launch costs of getting material off of the Earth. Even a ton of dust from an asteroid could be worth $1 million in orbit if a customer needed it for making concrete for landing pads, shelters, or roads.[23] The most often cited example is the mining of water from celestial bodies to provide on orbit for human consumption, fuel, or shielding against radiation.[24] Loading water on orbit would greatly reduce the launch costs from Earth for both robotic and manned space flight and will likely become a necessity to enable any sustained missions to the moon, Mars, or beyond.

Minerals will also have substantially more value in orbit. Access to raw materials in space would allow the manufacturing of objects that are too large or too heavy to be launched from Earth. Planetary Resources has already demonstrated the concept by using pulverized, powdered material from a meteorite found on the Earth to create objects using a 3D-printer. Access to materials such as iron, silicon, and aluminum in space would allow the creation of virtually any structure without the need to bring any materials off of the planet's surface.[25] An even more audacious option would be to bring an entire asteroid back into a convenient orbit near Earth and mine the asteroid on demand when materials are needed. This could prove highly profitable by eliminating the expensive trips back and forth to mine the asteroid in its original orbit but would create the additional challenges of safely moving an asteroid out of its orbit and preventing the creation of hazardous debris in near-Earth space.

Further, selling materials on orbit requires a substantial space customer base to remain profitable. The growth of the commercial space industry and the resultant reductions in launch costs could dramatically increase opportunities for space tourism or interplanetary travel. However, these missions may not be possible on a large scale without access to materials in space. Similarly, without these missions, space mining may never turn profitable. There is a natural synergy between space mining and the commercial space industry that require combined cultivation for either of them to reach their full potential. It is even possible in the future that one industry may subsume the other to gain more control over the entire value chain.

LEGALITY OF SPACE MINING

One of the biggest concerns for space mining companies involves the legal protections they would be afforded in any extraterrestrial endeavor. Nothing would be more devastating to a company than to go to the expense of retrieving materials from an asteroid and then be told they do not have the right to sell those same resources. In light of these concerns, space mining companies have been struggling to secure venture capital as investors were concerned over the legalities involved in the effort.[26] For United States' companies this concern may have been alleviated by recent law.

The 1967 Outer Space Treaty has been the guiding principle for operations in space since mankind first endeavored to visit celestial bodies. Referred to as the Magna Carta for space, the Outer Space Treaty states in Article 2 "Outer space, including the moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means."[27] The treaty assumes, based on the era when it was written, that space operations would be conducted by nation-states. It also creates a gray area for the extraction of resources. According to the treaty, there can be no claim of sovereignty over a celestial body, but the treaty is silent on the ownership of resources that are extracted from that body.

The Moon Agreement of 1979 attempted to provide more definitive constraints on any nation's activities in space. Article 11 addresses the exploitation of natural resources from space and recommends the formation of an international regime to govern the use of those materials when extraction becomes feasible. Specifically, the regime suggested in the treaty would ensure the equitable sharing of the benefits derived from space resources.[28] This would seem to create a significant challenge for space mining companies if their activities were subject to the ruling of such a regime. However, no space faring nation has signed the Moon Treaty leaving it an interesting point of reference with no enduring legal authorities.[29]

The rapid growth of commercial space entities recently led Congress to initiate a bill to establish legal protections for spacefaring companies. The United States Commercial Space Launch Competitiveness Act was signed into law on November 25, 2015. Title IV contains language originally submitted as the Space Resource Exploration and Utilization Act of 2015 by Representative Bill Posey (whose district encompasses Florida's space coast launch facilities) and Representative Derek Kilmer of Washington (home to Planetary Resources). The law specifically states that any US citizen that is engaged in the commercial recovery of space resources is entitled to ownership of those resources including their possession, transportation, usage, and sale.[30] There is deliberately no claim of ownership over the celestial body itself but the law does ensure the protection for space mining companies. In February 2016, Luxembourg, who hosts one of the world's largest satellite companies (and a primary office of Deep Space Industries), announced its intentions to develop a space mining industry and initiated its own version of asteroid mining legislation modelled after the US law.[31]

The Commercial Space Launch Competitiveness Act seems to have established a legal precedent for space resource extraction. The US Congress took significant steps to ensure compliance with the Outer Space Treaty and the International Institute of Space Law issued a position paper asserting that the use of space resources is legal. The position is similar to the law of the sea that allows for the ownership and usage of caught fish without any assertion of ownership of the sea itself.[32] This certainly seems to clear the way for mining asteroids in their existing orbits. However, companies who intend to move asteroids into a more accessible position near Earth may still face some legal hurdles if they intend to prevent other companies or nations from mining the asteroid that they went to the expense to move. The sole right to extract materials could be considered a claim of sovereignty, which would violate the terms of the Outer Space Treaty. In this case, agreements similar to the rules established by the World Trade Organization that require the sale of mined goods competitively to all customers would probably suffice to eliminate any significant legal challenge.

CONCLUSION

Successful exploration missions by government agencies have demonstrated many of the critical technologies to access asteroidal materials. While recovering these resources on a commercial scale is likely still decades away, the early efforts to develop the necessary technologies appear promising. Using these resources to augment the terrestrial mineral supply may provide some value, but the real benefits will be realized by providing raw materials on orbit. As the commercial space industry continues to grow there will be increasing demand for materials in space to reduce launch costs and allow mankind to push deeper into the solar system. The near future holds the possibility of an off-planet economy where materials are gathered from celestial bodies and converted into useable products having never entered the atmosphere of the Earth. That revolution will be a true hallmark of 21st century mining.

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conducted there are done on orbit. Additionally, when used as an adjective it is hyphenated so astronauts in orbit conduct on-orbit experiments.

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