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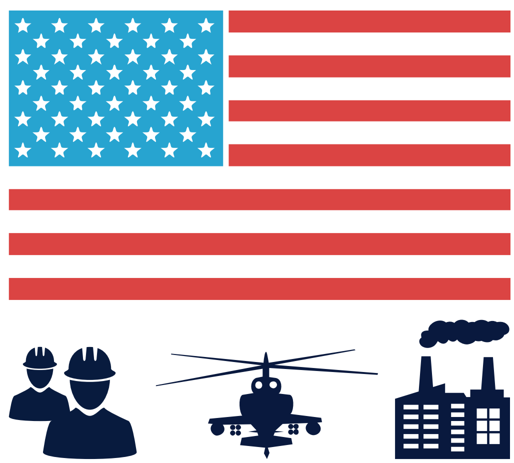
REMAKING AMERICAN SECURITY



SUPPLY CHAIN VULNERABILITIES & NATIONAL SECURITY RISKS ACROSS THE U.S. DEFENSE INDUSTRIAL BASE

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ALLIANCE FOR american manufacturing

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CHAPTER 3 • SPECIALTY METALS

EXECUTIVE SUMMARY

Specialty metals are used in countless ways, including high-strength alloys, semiconductors, consumer electronics, batteries, and armor plate, to name a few. The United States possesses significant reserves of many specialty metals, with an estimated value of $6.2 trillion. However, it currently imports over $5 billion worth of minerals annually, and is almost completely dependent on foreign sources for 19 key specialty metals.

Industrial metals are a group of specialty metals that are most often added to base metals to form alloys. These metals play critical roles in many steel alloys, adding hardness, heat resistance, and strength. They are often highly reactive transition metals and require complex and expensive extraction processes. In a few cases they can only be extracted as byproducts of other metals. As such, production is dictated by production of their carrier metals, resulting in limited supply and mounting demand.

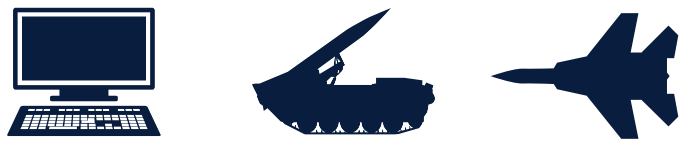
Rare earth elements (REEs), a second important group, have unique properties that make them essential for many defense products, especially high-technology ones. Currently, China dominates REE production, controlling 90 percent of global supply. This market share was achieved in part by undercutting competitors through overproduction, which drove U.S. and other mines out of business. Upon obtaining a near monopoly, Chinese producers have scaled back production to inflate prices through restricted supply. Quotas limiting the amount of raw REEs that may be exported have been used to force foreign investment in Chinese manufacturing, while exports to Japan were halted temporarily in 2010 after a diplomatic incident. Western companies scrambled to invest in REE mining to secure supplies just as the speculative bubble burst in fall 2011, sending prices downward and leaving the industry outside China in disarray. China still controls the global supply chain of REE oxides.

Production of the platinum group metals (PGMs) is dominated by South Africa. The country possesses more than 90 percent of known PGM reserves, and accounts for almost 40 percent of global palladium production and 75 percent of world platinum production. PGMs are commonly used in automotive engines and advanced electronics, and do not have viable substitutes. South Africa's dominance over PGM production threatens the integrity of defense industrial base supply chains, as political and economic instabilities within South Africa could restrict U.S. access to these metals. Recent

SPECIALTY METALS
HARNESSING THE PERIODIC TABLE

MANUFACTURING SECURITY

Specialty metals are crucial to U.S. national security and are used in a wide range of military end-items



COMPUTER CHIPS AND DEVICES | **MISSILE GUIDANCE** | **AIRCRAFT COMPONENTS**

U.S. CONSUMPTION

= 1,000

Total U.S. annual consumption of new non-fuel minerals per capita

25 THOUSAND POUNDS

RARE EARTH VULNERABILITY

China is the leading supplier of rare earth elements essential to national security

CHINA PRODUCES 90% OF THE WORLD'S **SUPPLY OF REES**

U.S. DEPENDENCY

The U.S. is wholly reliant on foreign suppliers for 19 key minerals used in specialty metals

100% IMPORT-RELIANT FOR **19 KEY MINERALS**

VALUABLE METALS

Many specialty metals are vastly more valuable than other commonly used metals

$3600 PER KILOGRAM

$1.60 PER KILOGRAM

MITIGATING RISKS

Protecting U.S. access to specialty metals

STRENGTHEN NATIONAL STOCKPILE | **DEVELOP DOMESTIC CAPACITY** | **INTERAGENCY & INTERNATIONAL COORDINATION**

MILITARY EQUIPMENT CHART

SELECTED DEFENSE USES OF SPECIALTY METALS

DEPARTMENT	WEAPON SYSTEMS	PLATFORMS	OTHER SYSTEMS
ARMY	■ Missile guidance systems (gallium, neodymium, and rhenium) ■ BGM-71 TOW Anti-Tank missile (tantalum)	■ Platforms that use Steel Armor Plate (molybdenum) ■ M1 Abrams main battle tank (tantalum)	■ Lithium-ion batteries (lithium) ■ Night Vision devices (lanthanum and gallium) ■ Laser rangefinders (neodymium)
MARINE CORPS	■ Missile guidance systems (gallium, neodymium, and rhenium) ■ Submarine-launched ballistic missiles (tungsten)	■ Platforms that use Steel Armor Plate (molybdenum)	■ Lithium-ion batteries (lithium) ■ Night vision devices (lanthanum and gallium) ■ Laser rangefinders (neodymium)
NAVY	■ Missile guidance systems (gallium, neodymium, and rhenium)	■ Platforms that use Steel Armor Plate (molybdenum)	■ Lithium-ion batteries (lithium) ■ Night vision devices (lanthanum and gallium) ■ Laser Rangefinders (neodymium)
AIR FORCE	■ Missile guidance systems (gallium, neodymium, and rhenium) ■ GBU-28 laser-guided bomb	■ Jet engines (rhenium and tungsten) ■ MQ-1B Predator drones (indium) ■ F-22 Raptor fighter (yttrium) ■ C-17 Military transport aircraft (yttrium)	■ Lithium-ion batteries (lithium) ■ Night vision devices (lanthanum and gallium) ■ Laser Rangefinders (neodymium)

reforms have increased taxes on PGM mines and introduced Chinese investment into those mines, increasing scarcity and forcing prices to rise while creating uncertainty over the future availability of the commodities.

Mitigating these risks is complex, and strategies will vary among commodities. The United States should maintain strategic reserves of those defense-critical elements that face likely shortages (REEs and PGMs) while seeking alternative sources. Congress is beginning to give this issue the necessary attention, and is shifting towards a more bottom-up approach to securing the supply chains of key materials—but more must be done. The federal government has not formulated a comprehensive and coherent policy approach to address the national security risks of inadequate access to many key minerals and metals. Strengthening efforts to identify substitutes and improve recycling will help mitigate these risks.

INTRODUCTION

This chapter will investigate "specialty metals," categories of metals that are also known as industrial, rare, or precious metals. Other common names for these types of metals include military, green, clean, critical, minor, technology, and strategic metals. It should be noted that specialty metals are *not* base metals (e.g. iron, copper, nickel, lead and zinc), or metals that oxidize, tarnish, or corrode easily. In addition, specialty metals are *not* energy metals (e.g. uranium and thorium). This chapter will examine specialty metals, comparing their properties and assessing their vulnerabilities with respect to U.S. military capabilities and U.S. economic

competitiveness associated with the extraction and production of these metals.

It is currently estimated that an average U.S. consumer's lifestyle requires roughly 25,000 pounds of non-fuel minerals per year, requiring massive efforts to either extract or import these materials.[1] Each year, the U.S. Department of Defense (DoD) acquires nearly 750,000 tons of minerals for an array of defense and military functions.[2] For example, tungsten, which is almost as hard as diamond, has the highest melting point of all non-alloyed metals, and is commonly used in turbine blades, missile nose cones, and other applications requiring exceptional heat resistance. Other minerals acquired are Rare earth elements (REEs) (some of which are used to fabricate permanent magnets), which maintain their magnetic fields even at high temperatures and are used in missile guidance and nearly every other small motor. Yet another example is palladium, which is part of the platinum metals group (PGMs), and is used in catalytic converters.

Despite possessing an estimated $6.2 trillion worth of key minerals reserves, the United States recently recorded a small surplus on the trade balance of raw mineral materials: it exported $9 billion and imported $8 billion of unprocessed minerals in 2012. However, the United States runs a deficit of $27 billion on the balance of processed mineral materials because it exported $120 billion and imported $147 billion in 2012.[3] In short, although the U.S. is self-sufficient in many minerals and has the chemical engineering know-how to process them, to some extent, it has chosen to rely on imports.

Increasingly, it is recognized that minerals are central to modern life and modern defense preparedness. Yet the federal government has not formulated a comprehensive and coherent response to the mineral/materials supply vulnerabilities, and there is no standard definition of which minerals or materials are critical and strategic and how the government should improve access to key minerals.[4]

The Defense Logistics Agency (DLA) Strategic Materials stores 28 commodities at 15 locations. In FY2012, DLA Strategic Materials sold $1.5 million of minerals and materials from its stockpile. At the end of the fiscal year, mineral materials valued at $1.4 billion remained. The stockpile is meant to help remedy the fact that the U.S. is completely import-dependent for 19 key minerals (including arsenic, asbestos, bauxite, graphite, fluorspar, indium, manganese, mica, niobium, tantalum, yttrium, and all REEs).[5] (The DLA Strategic Materials stockpile does not adequately compensate for the import dependence on a host of minerals because it emphasizes zinc, cobalt, chromium, and mercury, which are mined or recycled in the United States.) The stockpile is meant to protect against domestic and foreign supply constraints, spiking prices, and excessive speculation. However, because the U.S. government lacks a working understanding of which minerals are absolutely critical and which are strategic, the selection of metals for inclusion in the future stockpile managed by the DLA seems somewhat arbitrary.

In the past, a global abundance of minerals has been more than able to meet U.S. demand. However, as mineral-producing countries begin to consume more of their domestic production to fuel their own growing economies, the quantities available in the global marketplace have decreased. The increased demand for minerals has encouraged resource nationalism, where countries seek to exert greater control over the extraction and processing of key elements. Furthermore, many minerals are mined in only a few countries (some of which are politically unstable), exposing the United States and other importing countries to potential supply disruptions and other risks.

This situation is widely recognized as critical. In the words of one observer, "the whole periodic table is under siege… the growing demand for complex materials is leading to exploding demand for elements that are now used in only small quantities."[6]

The metals in this chapter fall into three different groups. The first group is industrial metals (e.g. antimony, manganese, tungsten, molybdenum, vanadium, and magnesium), which are usually mixed with base metals to create alloys to manufacture different kinds of steel products. Demand has risen for these alloyed metals because of their special properties that make them essential in aviation, engine turbines, green technology, and nuclear energy. Many of these metals are scarce because they are the byproduct of the other processes and because they are expensive to produce. Moreover, processing these metals involves advanced industrial chemistry and metallurgy that is more complex than extracting copper, zinc, and iron ore.

The second group consists of REEs, which are found across a surprisingly wide variety of applications and devices that enhance modern life in advanced industrialized countries. REEs are almost exclusively mined in China, which has by far the largest concentration of these elements. Mining REEs requires a more complex process than that used to mine gold or zinc, for example. From initial extraction to production, the process takes approximately 10 days. REEs are separated based on atomic weight, with actual processing duration based on the specific element. The most abundant REE is cerium. Terbium, a heavy REE, is more difficult to extract, and its extraction can take an additional 30 days.[7] Neodymium is also found with cerium, but the mine must first separate cerium and then extract the neodymium. This explains the length of production time and the costs. Importantly, companies cannot know beforehand whether valuable REEs are mixed in with the more common kinds, as each individual mine is different. Geologists and mining engineers must study each mine to find out which elements are available. The many engineering and processing challenges make REE mining among the most difficult types of mining operations.[8]

Mine operators need to know in advance how the REEs are going to be used so that they can determine the appropriate extraction and refining process. (Different processes must be used depending on the intended end-use of the REE.[9]) In fact, REEs are not inherently rare, but they are costly to mine and process because they are found in minute quantities mixed in with other ores. As Table 4 shows, REEs are used in a strikingly diverse range of products, including high-tech permanent magnets (see this report's chapter on magnets) and night vision devices (see this report's chapter on night vision devices).

The third group of specialty metals is very small and consists of the platinum group metals (PGMs), which are used in a range of applications such as vehicle production, future power sources, and many key military technologies. Palladium and platinum are used in catalytic converters. The largest concentrations of these deposits and reserves are found in South Africa.

Key themes discussed in this chapter are:

- Within the past decade, many countries rich in natural resources have taken a stance of "resource nationalism" and are attempting to control and manipulate extractive mining by threatening to impose extra taxes, reduce exports, nationalize mining operators, and restrict licensing.
- Western countries and mining operators face competition from less developed countries for access to specialty metals as well as from China, which has moved aggressively offshore to guarantee access to natural resources.
- Advanced industrialized countries, including the United States, have abandoned mining and mining exploration, even though global demand for economically and militarily significant ores and chemical elements has risen and will continue to rise.
- Many specialty metals are found in only a handful of countries, and often in regions that are politically and economically unstable.
- The risk of disruptions to the supply chains that use specialty metals is high, jeopardizing U.S. national security.

- Various U.S. agencies recognize the risks, but they provide different and divergent answers and solutions. The lack of a mechanism to coordinate policies among agencies hampers the development of a comprehensive and coherent strategy.

A NOTE ON CRITICALITY

Access to many natural resources is largely a function of geography. Although different types of specialty metals face different levels of risk (as described below), PGMs are consistently classified as facing the highest risks. Global reserves are situated almost exclusively in South Africa, which is the only country possessing significant long-term production capability. Limited global production capacity is coupled with high and increasing demand for PGMs, leading to high, unstable prices. Any number of events could create temporary or protracted shortages of PGMs, the most likely of which being internal political and economic instabilities associated with the South African government. The geographic concentration of PGM reserves, the high potential for disruption to the primary global provider, and the scarcity imposed by heightened demand indicate an *extreme* risk of these metals becoming unavailable.[10]

An insufficient supply of PGMs would have a *significant* impact on national defense capabilities. Although PGMs are most commonly known for their role in catalytic converters that reduce emissions from internal combustion engines, they also play an important role in advanced electronics used by the military (such as guided missile systems) due to their exceptional performance and ability to withstand high temperatures.

BACKGROUND

The issue for most advanced industrialized countries is that demand for rare elements has risen, while proven reserves and mining operations are increasingly

THE COST OF FAILURE TO ADDRESS POTENTIAL SPECIALTY METALS SUPPLY CHAIN DISRUPTIONS (a notional though realistic scenario)

The inauguration of the new South African president has led to a strengthening of ties between the Republic of South Africa and the People's Republic of China. In return for financial assistance in achieving its internal developmental policies and goals, South Africa has agreed to export manganese exclusively to China. Department of Defense supply chain specialists have begun to seek other sources of the metal; however, the effect on the market of this exclusive deal is expected to be pronounced. South Africa possesses one of the largest deposits of this mineral, and the removal of this source is expected to significantly increase prices for remaining sources. Reduced manganese supply means increased defense costs, as the U.S. military is a major consumer of manganese as a component of a variety of weapons systems and capabilities, including in the manufacture of steel armor plate and munitions.

concentrated in a handful of countries that have sought to exploit their geological advantages and their desire to meet their own growing domestic needs. In 2011, the British Geological Survey published a “risk list” that employed four variables (detailed below) to assess the risk factors of 52 elements or element groups with economic value.[11] The variables they used were scarcity (or the abundance of elements in the earth’s crust); production concentration (the location of current production); reserve base distribution (the location of reserves); and governance (the political stability of those locations). Using these categories, experts determined that the chemical elements or element groups with the highest supply vulnerabilities were antinomy, which is produced in China and is used in micro-capacitors; PGMs, which are produced in South Africa and used in automobile catalytic converters, fuel cells, seawater desalination equipment; mercury, which is produced in China; tungsten, which is produced in China and is a hard metal used in all cutting tools; REEs, which are produced in China; and niobium, which is produced in Brazil and used in MRI scanners, touch screens, micro capacitors, and ferroalloys.[12]

As the United States frees itself from fossil fuel dependence, it may replace it with dependence on energy sources from power-generating equipment that relies on specialty metals.

The German government also has expressed concern, as the country’s large manufacturing base requires substantial amounts of REEs. As demand from emerging economies has risen, the German government has been aggressive in securing access to REEs in regions or countries other than China. The German government entered into multiple agreements with Kazakhstan to give German companies better access to REEs.[13]

Last but not least, the European Union has pushed the governments of its member states to agree to a “critical metals” list, and to approve new policies to ensure continuous access to gallium, indium, tantalum, and tungsten, in addition to REEs. One of the measures on the agenda is to establish a critical metals stockpile, which would include gallium, indium, tantalum, and tungsten.[14]

It is not surprising that the U.S. Geological Survey (USGS), DoD, the Department of Energy (DoE), and the Congressional Research Service have joined the chorus of concerned voices by publishing numerous reports and presenting long lists of critical minerals. Critical minerals are indispensable to modern life and security, yet they may be at risk because of their geographic availability, the costs of extraction and processing, the dearth of (manmade) substitutes, and limited potential for recycling. USGS puts REEs highest on their list,[15] followed by cobalt, indium, and tellurium, which are needed for many important applications including magnets for motors and super alloys common in turbine blades and other aeronautical functions. In light of the rapid growth in demand for advanced batteries, most of which require minute amounts of lithium, USGS also has raised concerns about the possibility of depleting all known reserves of the element (see this report’s chapter on lithium-ion batteries).

Tables 1 and 2 demonstrate the trend of the last 10 years during this relatively short period of time, U.S. import dependence has radically increased across the board.

A wide variety of metals are plagued by the same issues that account for this current state of affairs. For one, political leaders of advanced industrialized countries have abandoned mining in light of the substantial negative externalities and pollution of waterways, soil, and air. Take the example of REEs. In reality, they are abundant in the earth's crust, but they tend to be found in small concentrations and deposits. They rarely exist in pure form and must be extracted from other oxides, which increases the costs of processing. More importantly than the expense of extraction, RE mining also creates radioactive environmental pollutants.[16] In every mining operation, the extraction process results in tailings (ground rock, processing agents, and chemicals), which cannot be fully reclaimed or reused or recycled. Frequently, the unrecoverable and uneconomic metals, minerals, chemicals, and process water are discharged, normally as slurry, to a final storage area. RE mining, however, produces tailings that contain radioactive uranium and thorium, which pose additional environmental threats beyond the risks associated with normal mining waste. In Western countries, governments and the public essentially have decided that it is easier to offshore this process to localities with less vocal and organized citizens or less democratic and transparent regimes. China, for example, has witnessed extreme degradation of its soil, water, and air quality to a degree that would not be tolerated in advanced industrialized countries.[17]

Another issue is that global demand is being driven higher by new discoveries of these metals' special properties, and by new technological innovations in how to design, fabricate, and incorporate them into consumer and military products. For example, neodymium (an REE) combined with iron and boron was discovered to possess strong magnetic properties, and it became the foundation of the high-tech permanent magnet sector (discussed in this report's chapter on high-tech magnets). Other examples include: gallium and tellurium, which are used in completing types of solar panels; rhenium, used in the super alloys employed in jet turbines; indium, which is used in flat panel displays; and graphite, used in lithium-ion (Li-ion) batteries. Green technology (such as hybrid cars, wind turbines, electric motors, and lightweight metals) relies heavily on specialty metals and REEs.

Many technological devices consume tiny amounts of specialty metals, without which the product would not operate or would need to be much larger and heavier. For example, every guided missile requires modest amounts of oxides, the form in which REEs occur in the mineral ore. While the amount of REEs used in a guided missile is genuinely small in quantity, without them the missiles would be heavier, less precise, and less advanced. In a similar vein, some metals must be able to withstand high temperatures, which are primarily achieved by adding minor elements to steel.

Additionally, more than two billion people (notably, the populations of China and India) are moving towards higher standards of living more closely resembling those in advanced industrial nations such as the United States and those in Europe. This development means that demand for electronic devices, green technology, and other advanced applications will continue to rise and in spite of economic crises in Europe, the United States, and Japan.

Table 1: U.S. Net Import Reliance for Selected Nonfuel Mineral Materials in 2000

Material		Percent
ARSENIC (TRIOXIDE)	China, Chile, Mexico	100%
ASBESTOS	Canada	100%
COLUMBIUM (NIOBIUM)	Australia, Guinea, Jamaica, Brazil	100%
BAUXITE & ALUMINA	Brazil, Canada, Germany, Russia	100%
FLUORSPAR	China, South Africa, Mexico	100%
GRAPHITE (NATURAL)	China, Mexico, Canada	100%
MANGANESE	South Africa, Gabon, Australia, France	100%
MICA, SHEET (NATURAL)	India, Belgium, Germany, China	100%
QUARTZ CRYSTAL	Brazil, Germany, Madagascar	100%
STRONTIUM	Mexico, Germany	100%
THALLIUM	Belgium, Canada, Germany, United Kingdom	100%
THORIUM	France	100%
YTTRIUM	China, Hong Kong, France, United Kingdom	100%
GEMSTONES	Israel, India, Belgium	100%
BISMUTH	Belgium, Mexio, United Kingdom, China	95%
ANTIMONY	China, Mexico, South Africa, Bolivia	94%
TIN	China,Brazil, Peru, Bolivia	86%
PLATINUM	South Africa, United Kingdom, Russia, Germany	83%
STONE	Italy, Croatia, Spain, India	80%
TANTALUM	Australia, China, Thailand, Japan	80%
CHROMIUM	South Africa, Kazakhstan, Russia, Zimbabwe	78%
TITANIUM CONCENTRATES	South Africa, Australia, Canada, India	76%
COBALT	Norway, Finland, Zambia, Canada	74%
RARE EARTHS	China, France, Japan, United Kingdom	72%
BARITE	China, India, Mexico, Morocco	71%

Source: U.S. Geological Survey, Mineral Commodity Summaries 2000 (Washington DC: U.S. Geological Survey).

Table 2: U.S. Net Import Reliance for Selected Non-fuel Mineral Materials in 2011

Material	Major import sources	Percent
ARSENIC (TRIOXIDE)	Morocco, China, Belgium	100%
ASBESTOS	Canada, Zimbabwe	100%
BAUXITE & ALUMINA	Jamaica, Brazil, Guinea, Australia	100%
CESIUM	Canada	100%
FLUORSPAR	Mexico, China, South Africa, Mongolia	100%
GRAPHITE (NATURAL)	China, Mexico, Canada, Brazil	100%
INDIUM	China, Canada, Japan, Belgium	100%
MANGANESE	South Africa, Gabon, China, Australia	100%
MICA, SHEET (NATURAL)	China, Brazil, Belgium, India	100%
NIOBIUM (COLUMBIUM)	Brazil, Canada, Germany, Russia	100%
QUARTZ CRYSTAL (INDUSTRIAL)	China, Japan, Russia	100%
RARE EARTHS	China, France, Estonia, Japan	100%
RUBIDIUM	Canada	100%
SCANDIUM	China	100%
STRONTIUM	Mexico, Germany	100%
TANTALUM	China, Germany, Kazakhstan, Australia	100%
THALLIUM	Russia, Germany, Kazakhstan	100%
THORIUM	France, India, Canada, United Kingdom	100%
YTTRIUM	China, Japan, France, United Kingdom	100%
GALLIUM	Germany, Canada, United Kingdom, China	99%
IODINE	Chile, Japan	99%
GEMSTONES	Israel, India, Belgium, South Africa	98%
GERMANIUM	China, Belgium, Russia, Germany	90%
BISMUTH	China, Belgium, United Kingdom	89%
DIAMOND (DUST, GRIT, & POWDER)	China, Ireland, Republic of Korea, Russia	89%

Source: U.S. Geological Survey, Mineral Commodity Summaries 2012 (Washington D.C.: U.S. Geological Survey).

Finally, metal and mineral suppliers have witnessed booming mining sectors due to rising prices. Thanks to the rising value of natural resources, producing countries have pursued a policy of resource nationalism. Many of the most sought-after elements are found in developing countries that face multiple economic and political challenges. To finance development projects or to extract rents, governments of these countries might be tempted to push for a greater share of the profits made by mining companies. Examples of this trend are ubiquitous. Ghana has been reviewing mining contracts, and may renegotiate existing arrangements to increase governmental revenue. Zambia doubled its copper royalty to six percent. Guinea, which controls the largest known reserves of both bauxite and iron ore, has taken a 15 percent stake in mining operations. In Namibia, a state-owned company controls all new mining and exploration. Foreign mining operations in Zimbabwe must cede a 51 percent stake to local owners.[18]

To ensure the country benefits from its mineral wealth, South Africa may impose a 50 percent windfall tax on mining profits and a 50 percent capital gains tax on prospecting rights. The ruling African National Congress wants to collect a larger share of the resource boom. Even Australia, an advanced industrialized country, plans to impose a new, $8 billion tax on mining.[19]

This state of affairs has not gone unnoticed. Since the mid to late 2000s, increased scrutiny and heightened alarm surround the fact that the U.S. economy and national security depend on specialty metals—many of which are vulnerable to supply threats resulting from sovereign risk and resource nationalism, geological scarcity, lack of viable substitutes, byproduct sourcing, and inadequate post-consumer recycling and recovery programs.[20]

In 2008, the National Research Council Committee on Critical Mineral Impacts on the U.S. Economy (Committee on Earth Resources) compiled a statistical approximation to assess supply restrictions impact on the entire U.S. economy and defense capabilities. The report also took into consideration the technical substitution potential of a mineral.[21]

The National Research Council report presented a criticality matrix that juxtaposed the probability of a supply disruption with the overall economic impact of that supply disruption. Supply disruptions can be caused by the physical unavailability of a commodity or by increasingly restrictive prices as a result of scarcity or of artificial means. The study considered five factors that contribute to availability: geological; technical; social and environmental; economic; and political. Economic impact was assessed by the availability of a close substitute, the costs associated with that substitution, and the consequences of the supply restriction. The committee examined 11 metals or metal groups: copper, gallium, indium, lithium, manganese, niobium, PGMs (including iridium, osmium, palladium, platinum, rhodium, ruthenium), REEs, tantalum, titanium, and vanadium to determine their criticality. The study's conclusions are presented in Figure 1.

Indium, manganese, niobium, PGMs, and REEs fall in the "critical" zone of the matrix.[22] They are considered critical because of the importance of their applications in catalytic converters, industrial chemical production, electronics, batteries, liquid crystal displays, and hardeners or strengtheners in steel and iron alloys. In addition, if a physical disruption or sudden price surge jeopardizes supplies, there are no readily available mineral substitutes for these applications.

Figure 1: Specialty Metals Criticality Matrix

IMPACT OF SUPPLY RESTRICTION (low → high) \ SUPPLY RISK (low → high)	1	2	3	4
4			• Manganese	• Rhodium
3	• Copper	• Tantalum	• Indium • Niobium	• Palladium • Platinum • Rare Earth Elements
2		• Vanadium • Lithium • Titanium	• Gallium	
1				

Source: National Research Council, Minerals, Critical Minerals, and the U.S. Economy (Washington, D.C.: National Academies Press, 2008). p. 165.

However, the study concludes that essentially any mineral could be considered critical, because both economic importance as well as factors influencing availability could change. Additionally, the report stresses that import dependence alone is not means for alarm; however, the concentration of supplies in a small number of countries plagued by political instability could be disastrous. Alternatively, rapid growth in the internal demand of exporting countries could limit the quantities available on the global market, resulting in rising prices and restricted supply.

INDUSTRIAL METALS

Industrial metals (also called minor metals) are in vogue because new uses for these metals are discovered frequently. They are classified as minor metals because until recently they were largely ignored by industry. They are not readily available or mined in the United States. Often, the elements are in fact rare and are not abundant in the earth's crust, with only a few parts per million of recoverable ore, even in the geologically significant deposits. As many of these elements are only found in a few dense concentrations globally, extraction may be dominated by a handful of countries. Subsequently, the price and supply of the element may be subject to export controls, price manipulation, and sudden disruptions. In some cases, elements are in fact a byproduct of a primary ore and are uneconomical to extract independent of the refining process for those other ores. These metals are therefore relatively costly and challenging to produce. Finally, the time required to adapt to new production and utilization processes is long, making planning and investment difficult.

The United States (along with almost all Organization for Economic Co-operation and Development [OECD] countries) relies heavily on imports for these materials, while the main producers are often countries with rapidly expanding economies (such as China, Russia, Chile, and South Africa) with sizeable and increasing domestic demand for these metals. Because certain metals are only commercially produced in a few countries, they can claim near monopolies over global reserves and influence pricing and availability.

The evolution of computing circuitry over the past three decades clearly illustrates the critical importance of industrial metals. The number of elements used in computer circuitry has expanded from 12 in the 1980s, to 16 during the 1990s, to over 60 today.[23] These circuits are found in nearly every piece of modern technology, and especially in highly specialized, high-tech defense applications.

The summary of the industrial metals sector below includes an overview of the different metal groups, selected elements, their most significant uses, and some of the concerns surrounding these commodities. The next section presents a more general discussion of the dominant risks facing this sector. The critical importance of these metals should be readily apparent. At the most basic level, many of them are used in heat-resistant, hard metal alloys that are used in aircraft, ships, submarines, and countless other defense-related applications. Other metals are at the core of solar energy, which is necessary for defense satellites and has a growing importance for civilian energy. Others still are used in electronic components such as rechargeable batteries, which are essential to consumer electronics, communication, and hybrid engines.

THE UNIVERSE OF INDUSTRIAL METALS

Most of the elements in industrial metals are used in alloys in order to improve heat resistance, reduce the weight of a metal item, or harden steel. (Table 3 provides an overview of the different metals and their defense applications and describes the particular risks or vulnerabilities associated with each industrial metal.) Many industrial metals are in demand in consumer electronics, high-energy rechargeable batteries, and the computer industry. They also are indispensable in numerous and wide-ranging military defense applications. Radar systems, airframes and engines, optical equipment, armor plating, coatings, electronic display screens, solar cells, and military batteries rely on small but vital quantities of industrial metals.

The universe of industrial metals can be divided into different chemical classifications. Each chemical group possesses different properties and advantages, which are further discussed below.

ALKALI AND ALKALI EARTH METALS

Alkali and alkali earth metals are located in the first two columns of the periodic table (excluding hydrogen). They are highly reactive elements, and as such, are not found in their elemental form, but instead as compounds in the earth's crust. Alkali metals (such as lithium) are relatively soft with low melting points, and form weak bonds with other elements because they have only one electron available for bonding. Alkali earth metals (such as beryllium) are harder and denser than the alkali metals, though not to the same extent as the transition metals.

LITHIUM

Lithium (Li) is a light and highly reactive metal, and is a key component of the rechargeable, high-energy lithium-ion (Li-ion) batteries that are widely used in the military and have a bright future as the main power source for electric or hybrid vehicles. Chile, Australia, Argentina, and China are the leading producers of lithium; almost the entirety of the U.S. import market comes from Argentina and Chile. Chile possesses over half of the world's known lithium reserves and is the main producer, extracting lithium from the Atacama Desert.[24] U.S. production of lithium is insignificant.[25] Because lithium is highly reactive and reacts with water, producing the pure form of lithium is very complex and requires a dry environment.[26]

Increase in demand for lithium, especially from China, have caused a recent expansion of production in many countries. Production of lithium was reported to have increased 20 percent in both Australia and Chile in 2011, while Chinese production was reported to have increased 30 percent. [27] This expansion corresponds to the growing demand for high-purity lithium for use in Li-ion batteries.

Analysts in the advanced battery sector and green technology community express considerable concern about the world's reliance on lithium, because most of the reserves are concentrated in two countries (Chile and Argentina) and may outstrip global demand as soon as 2017. Currently, there is no substitute for lithium, which is the ideal material to create rechargeable batteries and energy network stations to store surplus power from solar and wind power (see this report's chapter on lithium-ion batteries).[28] Unlike with other specialty metals, the main concern about lithium is not price or the potentially monopolistic behavior by foreign governments but rather that the world may face supply restrictions as reliance on technologies that require lithium increases and the world's known reserves of lithium are depleted.[29]

BERYLLIUM

Beryllium (Be) currently is considered a material critical to U.S. national defense, and is retained in the DLA Strategic Materials stockpile. Beryllium is critical to many military systems, including the airborne Forward-Looking-Infrared (FLIR) system, missile guidance systems, and surveillance satellites. There are no

Table 3: Industrial Metals
Properties, Uses, and Defense Applications

Element	Atomic Symbol	Atomic Number	Uses and Applications	Significant Producers
Lithium	(Li)	3	Batteries	Chile, Australia, China, Argentina
Beryllium	(Be)	4	Lightweight alloys, radiation windows, nuclear reactors	U.S., China
Gallium	(Ga)	31	Low melting-point alloys, high-power high-frequency electronics semiconductors, light emitting diodes (LEDs), solar cells	China, Germany, Kazakhstan, Ukraine
Indium	(In)	49	Liquid crystal displays (LCDs), low melting-point alloys, bearing alloys, transistors, thermistors, photoconductors, rectifiers, mirrors	China, South Korea, Canada
Germanium	(Ge)	32	Fiber optics, infrared optics, solar photovoltaic cells, semiconductors, alloys	China
Antimony	(Sb)	51	Flame retardant, semiconductors, bearing alloys, batteries	China
Tellurium	(Te)	52	Thin-film photovoltaic panels, semiconductors, steel alloys, vulcanizing agent, synthetic fibers	China, Canada, Philippines
Vanadium	(V)	23	Nuclear reactors, springs, carbide stabilizer (alloys), batteries	China, South Africa, Russia
Molybdenum	(Mo)	42	Tempered steel, gun barrels, boiler plates, armor plating, nuclear energy, missile components	China, U.S., Chile
Tantalum	(Ta)	73	Tantalum carbide (hard-metal), Tantalum capacitors	Brazil, Australia, Mozambique, Rwanda
Tungsten	(W)	74	Tungsten carbide (hard-metal), drilling and cutting tools, specialty steels, heat sinks, turbine blades	China
Rhenium	(Re)	75	High-temperature alloys and coatings, jet engines	Chile, U.S., Peru, Poland, Kazakhstan
Palladium	(Pd)	46	Catalytic converters, multi-layer ceramic capacitors (chips), hybrid integrated circuits	South Africa, Russia, Canada, Zimbabwe
Platinum	(Pt)	78	Catalytic converters (diesel)	South Africa, Russia, Canada, U.S.

substitutes for beryllium, and in previous years there was a shortage of high-purity beryllium due to high production costs and health and safety issues. Foreign-sourced beryllium is not of sufficient purity for defense applications.

In 2005, under Title III of the Defense Production Act (P.L. 81-774), DoD invested roughly $90 million in a private-public partnership with domestic beryllium producer Brush Wellman, Inc. (now called Materion Brush Beryllium and Composites) to produce a primary beryllium plant in Ohio.[30] That plant became operational in early 2011, dropping the reported U.S. import dependence from 61 percent in 2010 to 21 percent in 2011. Twelve percent of the annual U.S. beryllium consumption is attributed to defense applications. The USGS reports that the U.S. currently possesses about 65 percent of the world's beryllium reserves and, with the opening of the Materion Brush plant in 2011, accounts for almost 90 percent of world production.[31]

TRANSITION METALS

The group of transition metals contains 38 elements that are grouped together due to their common electron configuration, and are generally hard, malleable, and possess high melting points. They are good electric conductors and are often magnetic. The uses of transition metals are vast, making their use common.

RHENIUM

Rhenium (Re) is a rare metallic element that is important to the defense community because of its contribution to the properties of high-temperature alloys and coatings. The USGS reports that nearly 70 percent of rhenium is used for high-temperature engine turbines common to jet engines, while an additional 20 percent is a key catalyst in refining oil.[32] Rhenium is also used as a promoter in catalysts in gas-to-liquid operations, which may become more important in the future in light of the rapid expansion of shale gas output in the United States and elsewhere.

Rhenium is obtained almost exclusively as a byproduct of the processing of a special type of copper deposit known as a porphyry copper deposit. Specifically, rhenium is obtained from the processing of the mineral molybdenite (a molybdenum ore), which in itself is a copper byproduct. Therefore, rhenium is among the most expensive and volatile metals in the world, and its price fluctuated from $10,000/kg in 2008 to $3,500/kg in March 2013.[33] Currently, the United States is the world's second leading producer of rhenium (after Chile), with about a 12 percent market share. However, because rhenium is a byproduct of a byproduct, its production is limited by the production of molybdenum, which is in turn limited by copper production. In 2012, the U.S. imported nearly seven times its domestic production of rhenium, mainly from Chile and Kazakhstan.[34] Rhenium is part of the DLA Strategic Materials stockpile.

MOLYBDENUM

Molybdenum (Mo) is an important alloying agent that contributes to the hardening and toughness of tempered steels, and is used in steel armor plate, gun barrels, and boiler plates. Almost all ultra-high strength steels contain up to eight percent molybdenum. Molybdenum is used in nuclear energy applications and for missile and aircraft parts. Molybdenum is both mined as a primary ore and recovered as a byproduct of copper. The United States is the second largest producer of molybdenum with about one quarter of the global share, and currently exports about half of its annual output.[35]

VANADIUM

Vanadium (V) is used predominantly as an additive in steel that is then used in nuclear energy applications and in rust-resistant springs and high-speed tools. Ferrovanadium, an alloy of steel, accounts for 95 percent of the vanadium used in the United States. Vanadium is a non-substitutable component of aerospace titanium alloys; however, for many other applications, other metals such as molybdenum, tungsten, manganese, niobium, or titanium may be substituted for vanadium.[36] Small amounts of vanadium are added to iron alloys to improve corrosion resistance; ferrovanadium is mostly used in gears for cars, jet engines, and springs. The type of vanadium used in steel does not face immediate supply constraints. Due to increasing demand for steel in expanding economies, the demand for vanadium is expected to increase.

Three countries —China, South Africa, and Russia—dominate the vanadium market, and together account for more than 96 percent of current global production. The United States depends on imports for 80 percent of its domestic consumption of ferrovanadium; its main import sources are South Korea, Austria, Canada, and the Czech Republic.[37]

Twenty percent of the vanadium market consists of vanadium pentoxide, which is more valuable than ferrovanadium. In 2012, the major exporters of vanadium to the United States were Russia (47 percent), South Africa (32 percent), and China (19 percent). Vanadium pentoxide is used as a catalyst in petroleum refineries, in ceramics, and in super-conductive magnets. Currently, however, vanadium pentoxide is considered suitable for vanadium redox batteries, a new type of advanced rechargeable battery that is able to store renewable energy coming from wind or solar generation. This new type of battery can store more energy more efficiently than Li-ion batteries, with a faster recharge time and a longer lifecycle (see this report's chapter on Li-ion batteries).[38]

Demand for vanadium pentoxide is expected to expand 30 percent in the next three years while supply is tight; 90 percent of the vanadium on the market is not suitable for processing into vanadium pentoxide, and is only appropriate for strengthening steel.[39] Vanadium pentoxide (used in large format batteries) is a byproduct of combusting fossil fuels containing vanadium. The byproducts containing vanadium pentoxide can be in the forms of dust, soot, boiler scale, and fly ash.

TANTALUM

Tantalum (Ta) is used in several alloys due to its thermal and corrosion resistances, ductility, and strength. Many types of tantalum minerals are mined in different parts of the world and possess slightly different properties. In many applications, it cannot be substituted without lessening quality. For example, tantalum carbide is among the most durable materials currently known.[40] The United States has no identified reserves of tantalum and depends on imports for all its tantalum consumption.

Tantalum is found in selected geological regions of the world, namely in the eastern areas of the Democratic Republic of Congo as well as in Australia, Brazil, Canada, and Mozambique. Furthermore, a related mineral, coltan, the industrial name for a columbite–tantalite mineral from which columbium (also known as niobium) and tantalum are extracted,[41] is widely used to manufacture capacitors found in consumer electronics, computers, and automobiles.[42] In the last 10 years, demand for coltan-extracted tantalum has surged, stirring armed conflicts in central Africa as paramilitary groups mine and smuggle the chemical elements in order to finance their own activities. Coltan is the mineral equivalent of “blood diamonds,” which received large amounts of publicity and incited a human rights campaign in the late 1990s and early 2000s. Coltan-related conflicts also have destroyed the habitat of lowland gorillas and the livelihood of numerous indigenous communities.

In spite of tantalum’s importance to the U.S. economy and national security, the DLA Strategic Materials sold off most of its tantalum mineral, tantalum metal powder, metal ingots, and metal oxides in the 2000s. In 2013, it still holds small quantities of tantalum carbide powder. The latter is extremely hard and brittle, and is commonly used in tool bits for cutting applications or sometimes added to tungsten to create a metal alloy. The United States consumes 120,000 metric tons annually, with no reserves; the United States imports all tantalum from China, Germany, Australia, and Kazakhstan.

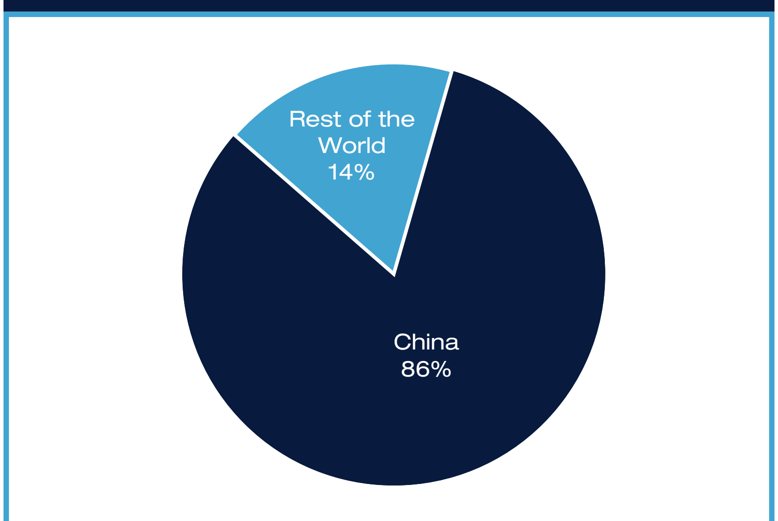
Although USGS forecasts that supplies of tantalum are sufficient for projected demand, and significant untapped reserves exist in Brazil and Australia, a third of the current tantalum production originates from politically unstable sub-Saharan African countries.[43]

TUNGSTEN

Tungsten (W) possesses the highest melting point of all metals (3,400 degrees Celsius or 6,150 degrees Fahrenheit) and is nearly as strong as diamond. Additionally, it is an excellent electrical conductor. The most common use is as tungsten carbide, a “hard metal” known for industrial drilling and other cutting tools.[44] Additionally, tungsten carbide and tungsten alloys are used for armaments, heat sinks, turbine blades, and rocket nozzles.[45]

China is the largest producer of tungsten is, accounting for about 80 percent of global production and possessing roughly two-thirds of world tungsten reserves. China is also the world’s top consumer of tungsten, and using a majority of the tungsten it produces. The Chinese government actively intervenes in the tungsten industry to limit supply: foreign investment is forbidden; exports are controlled by licenses, taxes, and quotas; overall

Figure 2: Global Production of Tungsten in 2010



Source: International Tungsten Industry Association, 2011. http://ormondemining.com/uf/Company%20Presentations/Ormonde%20Mining%20Website%20Presentation%20January%202012.pdf production is limited; and exploration and new operations are tightly controlled. In the immediate future, China is expected to be even more protective of its domestic supply, and is likely to attempt to further reduce exports as well as increase tungsten imports.[46]

Accordingly, tungsten prices are expected to increase in light of increasing demand and constricted supply. Historically, the United States and Russia have stockpiled tungsten, although both countries have been disposing of their stockpiles over recent years. The Russian stockpile is thought to be depleted, while the entire U.S. government holding of tungsten has been authorized for disposal.[47]

Although the United States imports a fair amount of tungsten, thanks to improved recycling of scrap consumed by processors and end-users, import reliance dropped from 63 percent in 2010 to 36 percent in 2011.[48] Nevertheless, there is only one domestic source of tungsten concentrates in the United States. The U.S. military cannot function without tungsten, and there are no substitutes for most applications. World demand slackened due to the global financial crisis, but scarcity will push up tungsten prices, especially since strategic manufacturing sectors would be willing to pay inflated prices.[49]

POST-TRANSITION METALS

Post-transition metals are softer than transition metals, with lower melting points, but they have high electronegativity, meaning that they are better at attracting electrons than the transition metals and more readily form polar bonds. They are malleable, ductile, and generally good conductors.

GALLIUM

Gallium (Ga) is not produced in the United States even though it is a critical component of optoelectronic devices, solar cells, light-emitting diode (LED) lights, and photo-detectors. Gallium is essential for creating high-brightness LEDs, and many governments in Asia are committed to introducing widespread LED lighting.[50] Therefore, demand for gallium likely will increase. Moreover, gallium is also a key component for thin film photovoltaic technology, a sector expected to grow by a factor of 9 by 2018; however, falling prices of silicon-based solar cells are limiting the current demand for more expensive gallium-based cells.[51] The primary military application of gallium is in high-power, high-frequency communications, such as those used in missile guidance systems. Gallium semiconductors can function at much higher temperatures than silicon, allowing them to function at a much higher capacity and reliability than more common silicon-based chips.[52] While silicon-based alternatives may be viable for commercial uses, they are not suitable replacements for defense-related applications.

The leading producers of gallium are China, Kazakhstan, and Ukraine. The United States is roughly 99 percent import-dependent on gallium, which is produced as a byproduct of bauxite (aluminum ore) and zinc ores, making it very difficult to accurately calculate gallium reserves. United States bauxite resources generally are not economical to extract, because their high silica content makes domestic production uneconomic and very unlikely.[53] Because gallium is primarily a byproduct of bauxite, and only a small portion of gallium in bauxite is recoverable (approximately 50 parts per million [ppm]), it is uneconomical to recover gallium independently of aluminum. The demand for aluminum will likely continue to dictate the world's supply of gallium.

INDIUM

Indium (In) is used in liquid crystal displays (LCDs) as the compound indium tin oxide, and is a byproduct of zinc ores. Indium is unevenly distributed in the earth's crust, causing the United States to be completely reliant on imports (although lower-grade imported indium is refined domestically). Due to its low abundance in most ores (less than 100 ppm in most zinc ores), recovering indium separately is uneconomical except as the byproduct of refining other ores. Currently, over half the world's indium is produced in China, with another 16 percent coming from South Korea. While there are techniques for reclaiming indium from discarded LCD screens, this option is only economically viable when indium prices are already high.[54]

Indium is used in transistors, thermistors, photoconductors, and low melting point alloys. It can also be used to create corrosion-resistant mirrors.[55] Indium is used in short-wave infrared (SWIR) imaging, including advanced night vision applications. Its advantage over traditional night vision systems is that a single SWIR device can function in both daylight and night, and does not require the extreme cooling that alternative technologies require. Such indium devices are used in Unmanned Aerial Vehicles, such as the Spectre-Finder and Predator. Because this technology does not rely on detecting heat but rather reflected light, it provides crisp images in starlight conditions, allowing for much greater accuracy in identifying targets than the alternative imaging technologies.[56]

METALLOIDS

Metalloids are elements that possess properties of both metals and non-metals. They are generally metallic in appearance, but are often brittle rather than malleable. They often possess good semiconductor qualities, and can serve as good insulators. Chemically, they behave as both metals and non-metals depending on the substance with which they react.

GERMANIUM

Germanium (Ge) is constrained in its availability because it is not found in concentrated deposits. It is relatively rare in the earth's crust (approximately 1.6 ppm), and while certain minerals do contain high levels of germanium, those minerals do not exist in any mineable deposits. Instead, germanium is most often produced as a byproduct of zinc extraction. Significant quantities of germanium are also recoverable from ash that comes from the burning of certain coals in energy production. China is the main producer of germanium, with a 68 percent market share, although significant reserves do exist within the United States. In 2011, the price of germanium nearly doubled as a result of increased Chinese export taxes and the closing of one germanium plant in China due to "environmental concerns."[57] However, germanium recycling has become increasingly common, with roughly 30 percent of consumed germanium coming from recovered scrap (recycled optical devices and window blanks in decommissioned tanks and other military vehicles).[58]

Germanium is used in fiber and infrared optics and in solar photovoltaic cells. Silicon shares many similar semiconducting properties with germanium, and may be a suitable substitute (at the expense of performance).

The estimated value of U.S. germanium consumption in 2012 was only about $55 million. Germanium sales represent an extremely small market. Yet germanium has been considered a critical material, and DLA Strategic Materials holds a small stockpiled inventory in case of sudden shortages. None was released in 2012.[59] The United States has known reserves of germanium though it has not mined them. Certain military applications will not work without germanium, and the metal's price fluctuates wildly because of the policy decisions by the most important mining regions.

The Chinese government restricts supplies by imposing new export controls or closing down germanium mines. These export restrictions are aimed at encouraging more finished production in China and stimulating the growth of an industry that relies on raw germanium such as optical lenses, fiber optics, LEDs, and solar cells. Chinese authorities have also identified germanium as a strategic resource and included it in their stockpile.[60]

ANTIMONY

Antimony (Sb) is used in a variety of applications, including semiconductors and batteries. It is most widely used as a flame-retardant, which accounts for about 36 percent of its use, and for which there is no effective substitute. While antimony sometimes occurs in pure form, it is more common as stibnite (Sb2S3, a sulfite), with other heavy metals, and as oxides.

China accounts for about 88 percent of annual antimony production, and over 60 percent of the global antimony reserves. Government officials in the Hunan region (where nearly 60 percent of China's antimony is produced) recently closed many antimony plants, citing health and safety concerns. As a result, the price of antimony increased by 20 percent between January and September 2011. Additionally, at current production levels, the Chinese supply is projected to be depleted within five years.[61] The U.S. previously stockpiled antimony; however, these stocks were disposed of by 2003.

TELLURIUM

Tellurium (Te) is a relatively uncommon element, and acts as a semiconductor. Tellurium's major use is as an alloying additive in steel to improve machining characteristics. It is also used as a vulcanizing agent for rubber and as a catalyst for synthetic fiber and is important for photovoltaic (solar) cells, which will likely become a major source of solar electricity in the future. These cells are incredibly thin—usually only 1 to 10 micrometers (µm) thick—and can be flexible and highly adaptable to various designs in different applications. Tellurium is also used in creating fiber-optics capable of functioning in harsh environments, which are likely to become increasingly prevalent in military aircraft.

Tellurium is most often produced as a byproduct of copper processing. Tellurium is extremely rare, with its presence in copper concentrates often below 100 ppm.[62] Most imported tellurium comes from China, although tellurium is also produced in the United States, which possesses sizeable reserves (about 15 percent of known global reserves).[63] The metal is commercially profitable to recover only when it is concentrated in residues collected from copper refineries.

EXTRACTION RISK FACTORS

Many of these metals or metal-type elements are in fact byproduct metals of a carrier metal such as zinc, copper, or bauxite. Consequently, many of these metals are uneconomical to produce independent of the production of the carrier metal. Demand for the carrier metal therefore drives the production of these industrial metals, creating the potential for undesirable market conditions including price spikes and shortages. Germanium, gallium, and indium, for example, are all extracted from zinc ores; gallium is also obtainable from the processing of bauxite (aluminum) ore; tellurium, gallium, and molybdenum are recovered as byproducts of copper ores. Rhenium is a special case, as it is produced as a byproduct from molybdenum, which in itself is a byproduct of copper, making it among the most expensive metals in the world.[64]

Many of these elements simply are not found in concentrations high enough to warrant extraction as a primary product and are produced only as the byproduct of other metals. This fact raises problems with both increasing supply and supply availability. For example, it is uneconomical to increase the mining of copper in order to extract more tellurium. In 2009, copper production approached $80 billion, while the production value of tellurium was only about $30 million.[65] Because tellurium's abundance in copper ores is very low (less than 100 ppm), there would have to be a massive increase in copper production to have any impact on the tellurium supply. Given the values of the two markets, and the resultant drop in copper prices if such an expansion were to occur, producers would lose money overall if they attempted to expand the supply of tellurium. Expanding tellurium production does not appear economically viable despite the fact that tellurium's role in photovoltaic panels that could dramatically reduce the costs of solar energy.

Another example is gallium, which is experiencing a surge in demand due to increased interest in LED lighting. Gallium arsenide (GaAs) is commonly used in high-efficiency, high-brightness LEDs because it has the ability to convert electricity directly into laser light. Many governments, including that of South Korea, are encouraging the adoption of LED lighting in the private sector and mandating it in the public sector, resulting in a rapid increase in gallium demand. According to the USGS, gallium consumption more than doubled between 2009 and 2011, resulting in a price increase of more than 50 percent.[66] However, gallium is mostly extracted as a byproduct of bauxite (aluminum). If demand for bauxite ore declines, then there would also be a reduced supply of gallium, even though the demand for gallium appears to be rapidly increasing.

GEOPOLITICAL RISKS

The United States relies on imports for many of the industrial metals (see Tables 1 and 2), a trend that has grown over the last decade. According to data collected by the USGS, the United States now imports more than 50 percent of 43 key minerals (compared to 29 in 1995). The United States is now totally reliant on importing 19 minerals, compared to 10 in 1995. Thus, import reliance or dependence has increased as the importance of certain minerals has grown.

The concentration of an important commodity among only a small number of sources creates significant potential for supply disruptions. For example, cobalt and tantalum are produced in the Democratic Republic of the Congo. The extraction of these elements has fed political instability, poverty, and human rights violations. In other situations, the presence of raw materials encourages monopolistic practices and price manipulation. For example, South Africa nearly has a monopoly over PGMs; citing concerns over shrinking reserves, China, the dominant producer of antimony, has tightened its production restrictions. As countries become dependent on the extraction and global production of often-scarce elements, they may be tempted to impose extra fees, taxes, and prices in order to exploit their unique position in the global market. They also may be tempted to restrict exports in order to build up a domestic processing and fabricating industry, as China did with the REs market. Even in the best of cases, the United States faces risks if it depends on a few suppliers of critical elements, since a major earthquake, accident, industrial strife, or lack of investments may disrupt supplies.

RARE EARTH ELEMENTS

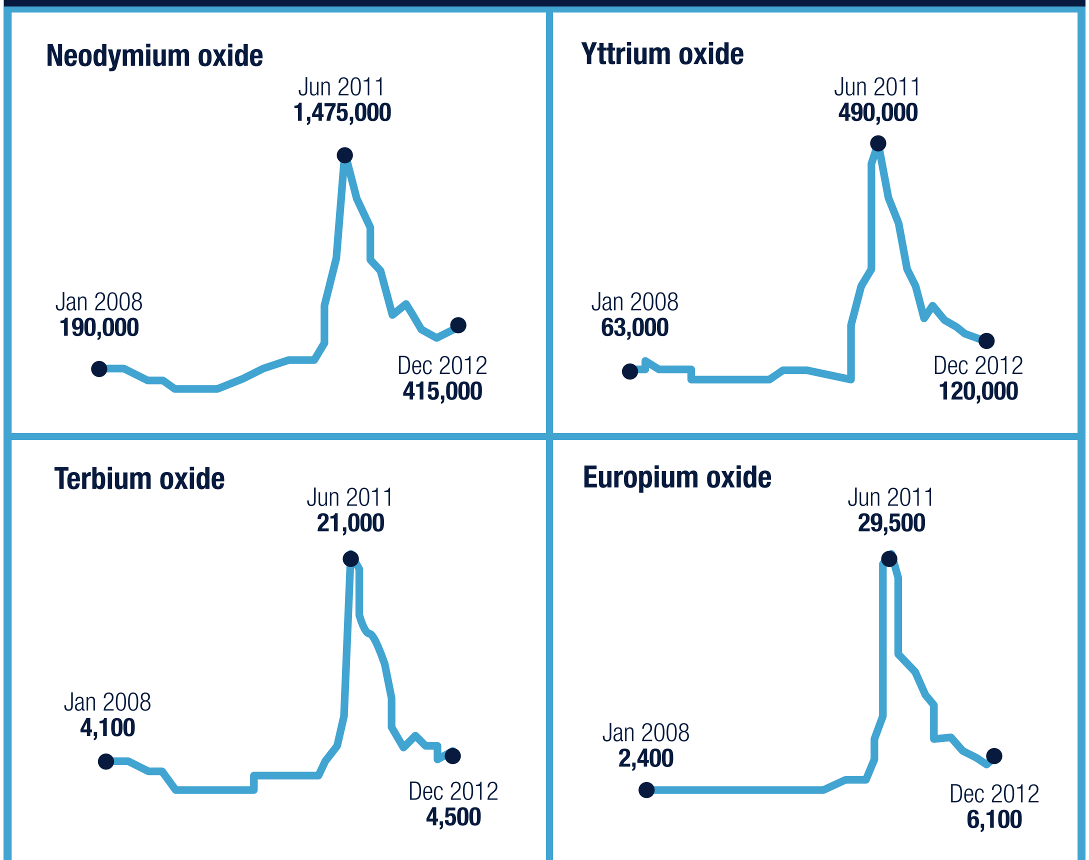
REEs are necessary for many of the modern world's most advanced technologies: missile guidance systems, flat-screen TVs, cellphones, generators in windmills, and motors in hybrid cars, to name just a few. During the last decade, China has cornered the market on REEs—a group of 17 elements including scandium, yttrium, and 15 lanthanide elements at the bottom of the periodic table (see Table 4). Demand for REEs is expected to continue to increase.

In the short term, REE demand has fluctuated, because the state of the global economy strongly determines the need for REEs. Demand rose again in 2009, after the immediate impact of the global economic crisis had passed. As demand increased, the Chinese authorities cut export quotas, artificially reducing the supply of REEs. This fueled fears of possible shortages and caused stockpiling, driving prices to historically high levels by 2011. In 2012, prices plunged by as much as 90 percent in international markets (see Figure 3).

During the two years of surging prices for REEs, many mining companies and investors decided to go into the business of extracting REE oxides. When prices fell suddenly, mining companies suffered financial setbacks. In fact, the collapse of prices has been devastating for Western mining companies, which were trying to bring online new operations to take advantage of the high prices and reduce the West's dependence on Chinese oxides. Molycorp of the U.S. and Lynas of Australia suffered financial difficulties and ran into operational problems. Both companies have seen their share prices drop by more than half.[67] Many smaller players have also suffered calamitous financial setbacks, and their fate hinges on being able to mine so-called heavy REEs. Not all 17 rare earth elements are equally rare; DoE has identified five of them as "critical." Neodymium, a light REE, and dysprosium, a heavy REE, are used in permanent magnets for wind turbines or electric vehicles. Europium, terbium, and yttrium are heavy REEs, and are used in flat-screen electronics and energy-saving lightbulbs. Demand growth for these REEs will be strong, while mining them will be challenging.

REE mining is unlike any other type of mining. Unlike other metals used in many consumer and defense items, REEs are

Figure 3: Price Trends for Four Rare Earth Elements 2008-2012 (Renminbi per ton)



Source: Adapted from: Helen Thomas, "Miners ready to take punt on rare earths," The Financial Times, December 30, 2012.

to some extent abundant though they are hardly ever found in high enough concentrations to make mining them economical. Rather, REEs are mingled with other metals and must be carefully extracted and refined. REEs are often found together; mine operators must identify and isolate the individual oxides. Moreover, each REE oxide possesses different and distinct properties; mine operators must take the customer of their oxides into consideration. Thus, a mine that has a contract to sell neodymium must first refine the oxides and then extract the neodymium elements. The length of this process makes REE mining costly and complex. First the miner must extract the ore, and then the mine operator must separate the REEs according to atomic weight. The various separation processes differ in complexity because some REEs (such as cerium) are common, while others (such as terbium) require a month of separation before ample oxides can been extracted.[68] Accordingly, mine operators cannot ramp up production quickly in response to changing global demand. Not only is it time-consuming to extract and refine the

Table 4: Rare Earth Elements, their Applications and Uses

Element	Atomic Symbol	Atomic Number	Applications and Uses
Scandium	(Sc)	21	Lightweight alloys
Yttrium	(Y)	39	Lasers, high-temperature superconductors, microwave filters, metal alloys
Lanthanum	(La)	57	High refractive glass, battery-electrodes, fluid-catalytic cracking, hybrid engines, metal alloys
Cerium	(Ce)	58	Chemical oxidizing agent, fluid catalytic cracking, metal alloys
Praseodymium	(Pr)	59	Magnets, lasers, ceramic capacitors
Neodymium	(Nd)	60	Magnets, lasers, neutron capture, hybrid engines, computer components
Promethium	(Pm)	61	Nuclear batteries
Samarium	(Sm)	62	Magnets, lasers, neutron capture, masers
Europium	(Eu)	63	Phosphors, lasers, nuclear magnetic resonance
Gadolinium	(Gd)	64	Magnets, high refractive glass, lasers, x-ray tubes, computer components, neutron capture, magnetic resonance
Terbium	(Tb)	65	Phosphors, magnets
Dysprosium	(Dy)	66	Magnets, lasers, hybrid engines
Holmium	(Ho)	67	Lasers
Erbium	(Er)	68	Lasers, vanadium steel
Thulium	(Tm)	69	Portable x-ray machines
Ytterbium	(Yb)	70	Lasers, chemical reduction
Lutetium	(Lu)	71	PET scanners, high refractive glass, chemical catalyst

Leslie Hook, "Chinese rare earth metals prices soar," The Financial Times, May 26, 2011. http://www.ft.com/intl/cms/s/0/751cab5a-87b8-11e0-a6de-00144feabdc0.html#axzz25SIRqVhy; and Department of Energy, Critical Materials Strategy (December 2010). http://energy.gov/sites/prod/files/edg/news/documents/criticalmaterialsstrategy.pdf

REE oxides, but deposits vary by mine and each separation plant must be tailored to the specific local situation of that particular mine. For this reason, REEs represent some of the most technically challenging mining operations.[69]

Nevertheless, it is worth remembering that REEs are important to many renewable energy technologies. To a large extent, green energy technologies rely on an abundance of REEs. Electric vehicles use large amounts of neodymium and dysprosium (magnets) and lanthanum. Wind

Table 5: Selected Defense Uses of Rare Earth Elements

REE	Defense Use
Lanthanum	Night vision goggles
Neodymium	Laser rangefinders, guidance systems, communications, magnets
Europium	Fluorescents and phosphors in lamps and monitors
Erbium	Amplifiers in fiberoptic data transmission
Samarium	Permanent magnets that are stable at high temperatures, precision-guided munitions, and "white noise" production in stealth technology

Source: Hobart King REE - Rare Earth Elements and their Uses
http://geology.com/articles/rare-earth-elements/

turbines need large quantities of neodymium and praseodymium for their powerful magnets. Energy-efficient lighting, such as LEDs and compact fluorescent bulbs, use RE phosphor powders made from yttrium, europium, and terbium.[70]

In short, the appeal of REEs lies in their ability to perform highly specialized tasks effectively (see Table 4). Europium is needed to create the red phosphor for television and computer monitors; cerium is needed to polish glass. Because they are light-weight and have high magnetic strength, REEs have reduced the size of many electronic components dramatically, and are common in consumer electronics, cars, and many military platforms. Common devices such as flash memory sticks depend on rare earth magnets (REMs), which can contain dysprosium, gadolinium, neodymium, praseodymium, and samarium. These elements are used in nuclear control rods, smart missiles, carbon-arc lamps, miniature magnets, high-strength ceramics and glass, and countless other applications.[71]

In spite of their importance to the overall economy and national security, for most of the past decade, the United States did not have a secure supply of REEs. (The Mountain Pass mine closed in 2002 and re-opened in 2012.) By 2010, Chinese producers moved into the global market for REEs and ended up controlling about 97 percent of world production and refining of REEs (see Chart 2).[72] The situation has changed somewhat since 2012 because U.S. and Australian mining companies, drawn by the high prices, opened or re-opened REE mines. Currently China is estimated to control 90% of global supply of REEs.[73] Since the 1990s, Chinese authorities pursued an explicit policy of controlling a resource they considered “strategic and critical.”[74] In the 1990s, Chinese operators (both legal and illegal) flooded international markets with low-priced oxides, ores, and raw materials. Many mining companies in the United States and Australia (a country with a wealth of natural recourses) could not compete against these prices, causing many non-Chinese mining companies to shut down. Subsequently, Chinese

Table 6: United States Usage of Rare Earth Elements (2008)	
Usage of Rare Earth Elements	**Percent of Usage**
Metallurgy & alloys	29 %
Electronics	18 %
Chemical catalysts	14 %
Phosphors for monitors, television, lighting	12 %
Catalytic converters	9 %
Glass polishing	6 %
Permanent magnets	5 %
Petroleum refining	4 %
Other	3 %

Source: Hobart King REE - Rare Earth Elements and their Uses
http://geology.com/articles/rare-earth-elements/

operators have gained control over many different mineral resources while driving out production in advanced economies. In Australia, dozens of mines closed in the early 2000s due to a collapse of prices for many metals. In the United States, the Mountain Pass Mine in California, which is owned by Colorado-based Molycorp, closed in 2002 as production became uneconomical due in large part to Chinese mercantilist practices.

In the 2000s, Chinese authorities decided that, rather than exporting raw materials, it would be preferable if the processing, refining, and fabrication of final product applications would take place in China itself so that Chinese companies could reap the benefits of the added value. In 2007, Beijing instituted a 25 percent export tax on europium, terbium, and dysprosium. In 2010, Chinese authorities implemented further export restrictions on REEs by tightening export quotas.[75] The impact of a series of new measures to restrict the export of REEs meant that foreign REE consumers were paying a third more for REEs than Chinese fabricators. According to the World Trade Organization, Chinese manufacturers of REEs have a distinct price advantage over foreign firms.[76]
In response, many foreign refiners and producers of final products that use REEs relocated to China to gain access to REEs and to avoid the export quotas and taxes. Japanese and U.S. companies established

a foothold in China and moved production and manufacturing offshore. (In another chapter of this report, we examine permanent magnets and present an extreme case of outsourcing and offshoring that has led to a situation wherein the defense industrial base wholly depends on Chinese processing of REEs and the U.S. economy and defense industrial base must import virtually all of their high-tech magnets.)

China's near monopoly in this strategic sector raised concerns in Washington, D.C., and Tokyo, particularly when China suspended REs shipments to Japan during a diplomatic dispute in 2010. That incident, combined with broader concerns about the reliability of Chinese supply, triggered a surge of investment in RE mines outside China and brought down prices and speculative hoarding of REE oxides. Subsequently, the small REE global market has been depressed. In response, China cut production of REEs at its mines, in an effort to bolster global prices; this production cut has had a huge impact on prices. Current market dynamics do not support high RE prices. Supply is up and demand is down.

Supply is up because non-Chinese companies have aggressively invested in REE mining. Japanese companies have opened rare earths mines and processing in Kazakhstan, India, and Vietnam. The production of elements outside China is predicted to grow tenfold over five years, from 6,000 tons in 2011 to 60,000 tons in 2015.[77] According to industry analysts, as of March 2013, 50 rare earth mineral resources are active, associated with 46 advanced rare earth projects and 43 different companies, located in 31 different regions within 14 different countries. The large and sudden investments in REE mining and processing have brought prices down, especially as global demand has softened.

However, China may ultimately retain its dominant position. The price squeeze is making it unprofitable to continue operations in advanced industrialized countries. Molycorp reopened Mountain Pass Mine when prices skyrocketed. But the mine mostly produces light REs, which are relatively abundant and the least valuable. Australia's Lynas Corp. opened a mine called Mt. Weld, which also produces light rare earth oxides. Both companies have promised to find more valuable heavy REEs. These oxides are more difficult to locate; China possesses them in abundant quantities. Even if mines outside China can locate heavy REs, the issue remains that China is an extremely low-cost producer. It will be difficult for companies in the United States or Australia to compete with Chinese mines when Chinese authorities are lax in enforcing health, safety, and environmental rules. REE mining is notorious for generating massive amounts of toxic waste. Occupational safety rules as well as environmental controls make mining in the United States (and other OECD countries) more expensive than in China. However, the cost differentials between countries may be especially striking when the extraction is accompanied by a comparatively high amount of radioactive tailings, as is the case with REEs

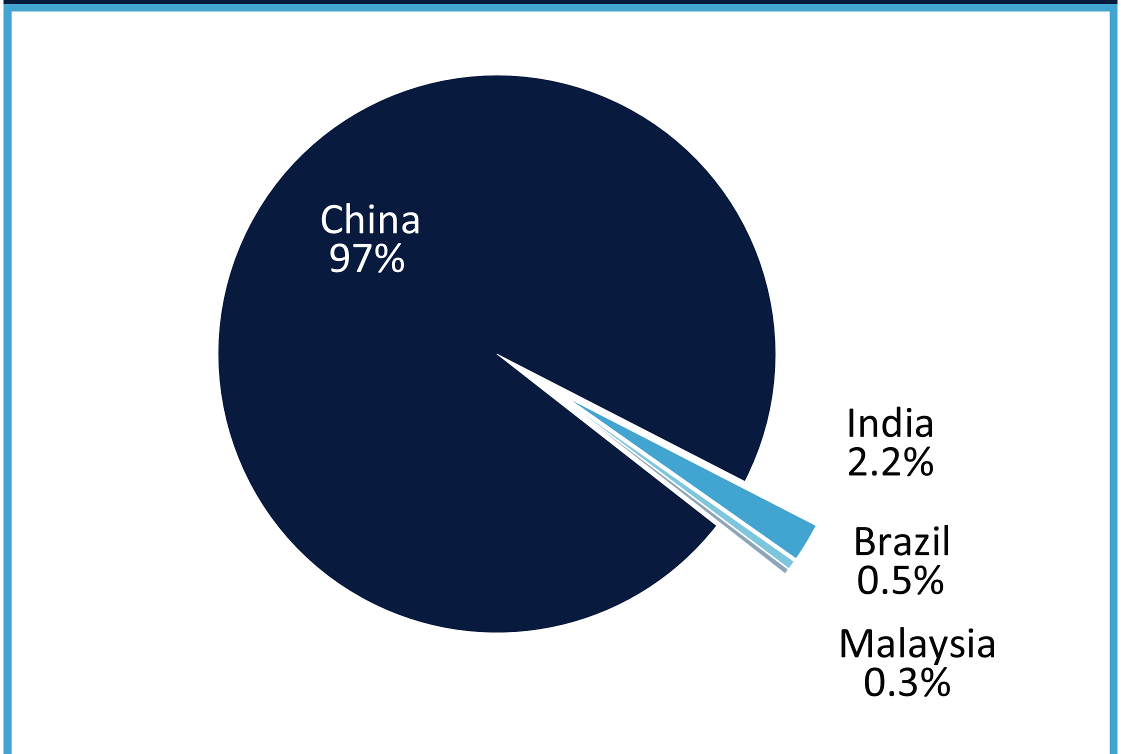
Ultimately, the real issue is not the oxides. Mining and separating the oxides is the first step in using REEs for commercial and defense applications. The real trick lies in converting the oxides into powders, metals, alloys, and magnets. Mining is costly, but the real technological skill involves processing the RE oxides into usable items. That technology has shifted to China, which has sought to build up a "mine-to-magnet" vertical integration. The supply chain starts with oxides and then moves to refining, purification, manufacturing metal alloys, and finally to fabrication of magnets.

The critical technology for manufacturing these magnets is overseas—mostly in China. China captured the market gradually by transferring U.S. technology to China and flooding the market with cheap magnets in the early 2000s. Since then, China has continued to improve its manufacturing expertise and now possesses a depth of engineering skills.

This explains why Molycorp bought a Canada-based REE company, Neo Material Technology, which runs major manufacturing facilities in China. Molycorp cannot process the oxides into fabricated and finished products in the United States. The U.S. mine ships RE material to China, where REEs such as dysprosium and neodymium are transformed into military-grade magnets.[78]

In the FY2007 National Defense Authorization Act (NDAA), Congress passed reforms to the specialty metals restrictions and created the Strategic Materials Protection Board (SMPB). The SMPB was meant to determine what protections were necessary to ensure the supply of materials for national defense purposes; assess potential risk associated with the non-availability of those materials; and advise policymakers on how to ensure

Figure 4: Global REE Production, 2010
(133,000 Metric Tons)



Source: Marc Humphries, Rare Earth Elements: The Global Supply Chain (Washington, D.C. CRS, June 8, 2012). http://www.fas.org/sgp/crs/natsec/R41347 that supply. The SMPB is required to meet at least once every two years, publish recommendations regarding materials critical to national security, and vet the list of specialty metals.

The SMPB met twice in 2008 and issued its report and recommendations in December 2008 and February 2009.[79] The boards concluded that specialty metals were *not* "materials critical to national security," but instead "strategic materials" that warranted monitoring but not domestic source restrictions.[80] Alternatively, the Board recommended relaxing or removing domestic source requirements in an effort to reduce costs and more readily access specialty metals produced abroad.

The FY2010 NDAA required the Government Accountability Office (GAO) to assess the domestic and global availability of REMs, their importance to defense programs, and the potential for the supply of these metals to be restricted. As a result in the April 2010, GAO issued the report "Rare Earth Materials in the Defense Supply Chain" (GAO 10-617R).[81] The report stated that dependence on Chinese suppliers puts future availability of REMs—especially neodymium—at risk. The report also stated that projected domestic supply options would take seven to 15 years before becoming fully operational, primarily due to state and federal regulations. At the time of the GAO report, DoD was still in the process of evaluating defense vulnerabilities, and was scheduled to complete its analysis by September 2010. That report has never been released to the public.

The FY2012 NDAA calls for DLA to submit a plan to DoD to establish a stockpile of REMs, as well as to provide a broader assessment of source reliability. The DLA report, which was scheduled for completion in July 2012, would require a DoD decision on the plan within 90 days of submission. At present, the DLA maintains a stockpile of 28 materials with a value of about $1.4 billion, but does not currently stockpile any REs.[82] In a significant change that increases the authority of the U.S. government to address stockpile deficiencies, Sec 901(a) of the FY2013 NDAA says that the Deputy Assistant Secretary of Defense for Manufacturing and Industrial Base Policy is now responsible for "[e]nsuring reliable sources of materials critical to national security, such as specialty metals, armor plate, and rare earth elements." DoD issued its *Strategic and Critical Materials 2013 Report on Stockpile Requirements* in March 2013 and identified 23 strategic and critical materials. The report calls for a fund of $1.2 billion to mitigate the shortfall of key materials.

Separate from the NDAA, the 112th Congress introduced at least 13 bills (nine in the House of Representatives, four in the Senate)[83] relating to REs; however, none has yet passed out of the relevant committee. Additionally, the Congressional Research Service has conducted at least three studies focused on REs and specialty metals, while GAO has released one. Broadly speaking, these reports indicate that Congress should demand renewed assessment by DoD of the "strategic materials" categorization in light of recent global supply chain concerns, and suggest policies including stockpiling REs and reinvesting in domestic research and production. These suggestions appear to be conditional on a new assessment of the SMPB/DoD, which appears reluctant to take any further action without an additional mandate from Congress. It does not appear that DoD is likely to alter its opinion expressed in the FY2011 Industrial Capability Report to Congress, which stated that, although securing a non-Chinese source of REs is essential, only minimal provisions (such as prioritizing defense applications over commercial applications) are required.[84]

To some extent, DoD's position dovetails with the interests of large defense contractors who prefer to source the small amount of magnets they need from cheap Chinese suppliers rather than to deal with U.S.-based producers.

In conclusion, although prices have dropped and shortages have disappeared in the short term, the Chinese authorities continue to meddle and intervene in the global market for RE oxides, mostly because they control the global mining of these oxides and seek to take advantage of that position. The long-term Chinese goal is to foster a high-tech RE industry in China while preserving RE reserves.[85]

PLATINUM GROUP METALS

The PGMs (also sometimes called platinum group elements, or PGEs) include iridium (Ir), osmium (Os), palladium (Pd), platinum (Pt), rhodium (Rh), and ruthenium (Ru). PGMs have excellent resistance to heat and serve as catalysts for chemical reactions, contributing to their uniqueness and importance in a variety of applications.

The most prominent application of PGMs is in catalytic converters, which dramatically reduce the pollution from automobiles. Many PGMs, especially palladium, are used as catalysts in fuel cells that find wide applications in the auto industry. Since the global car industry is projected to expand in the next decades (Chinese and Indian consumers), demand for palladium will continue to grow.[86] In addition, palladium is also used in fuel cells in hybrid cars. Thus, the switch to cars emitting fewer pollutants will not necessarily sharply reduce the demand for palladium.

In addition, platinum and palladium are extremely common in most electronic devices, including military hardware. Although the actual per-unit metal content is minute, a huge quantity of palladium is needed to meet the growing demand for electronic goods. Multi-layer ceramic capacitors (MLCC), which regulate the flow of electricity through a circuit, represent the largest demand for palladium from the electronics industry. While the automotive industry mostly consumes palladium as components of catalytic converters, automobiles also contain a large number of hybrid integrated circuits (HIC), which make use of silver-palladium tracks to connect different components of the circuit.[87]

Platinum is reportedly used in some capacity during the fabrication process of more than 20 percent of all manufactured goods.[88] It is malleable, ductile, resistant to corrosion, and possesses a high melting point around 1,770 degrees Celsius (3,215 degrees Fahrenheit). Its uses include electronics and chemical catalysts, in addition to many other applications. Platinum is up to 30 times as rare as gold (another precious metal).

Platinum and palladium supplies are potentially at risk due to their geographic concentration in areas that face political instability. In 2011, global production of platinum was dominated by South Africa (72 percent) and Russia (14 percent). The material is found in large commercial concentration in only a few regions of the world, yet the future of energy, transportation, and the environment relies on platinum. Platinum's catalytic property aids emissions control in transportation and combats pollution. Demand is bound to increase, not only in advanced industrialized countries, but also in emerging markets as governments seek to control emissions and smog. U.S. federal agencies' reports identify platinum as subject to supply risks with enormous consequences for the U.S. defense and the economy at large.[89]

In 2011, South Africa accounted for about 38 percent of palladium production, and Russia 41 percent. In all, South Africa controls more than 95 percent of known PGM reserves.[90] Two North American mines extract palladium, but their share of global new production amounts to only 14 percent.[91] Since the 1980s, the Russian government has held a stockpile of palladium. The actual size of the Russian stockpile has long been a closely guarded secret. But when prices were exorbitantly high in the early 2000s, they sold a large portion of the stockpile, bringing down the price of palladium.

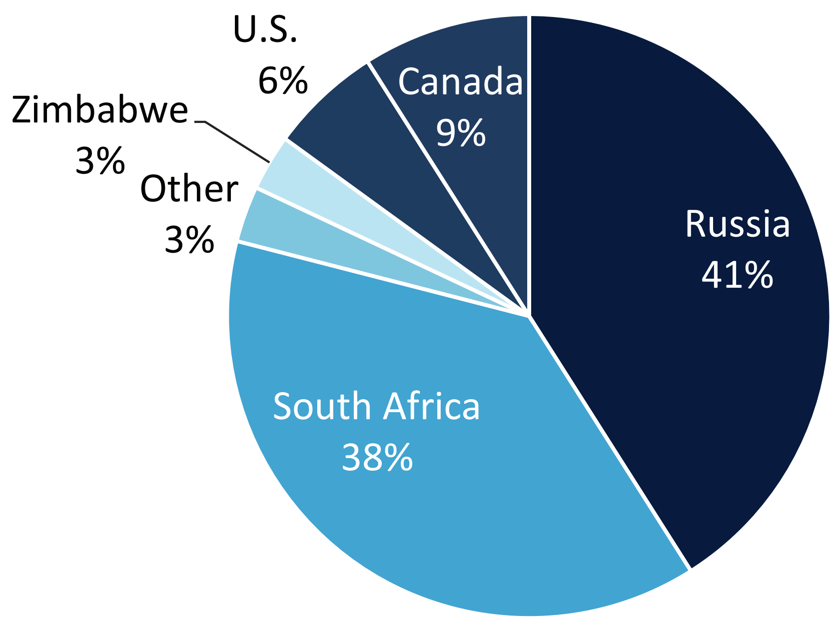
South Africa traditionally has been aligned with the West; its business environment is open to Western foreign direct investments and capital flows. Yet many observers are extremely concerned about the political situation in South Africa and the possibility that its political instability may place future supplies at risk. South Africa copes with many internal tensions and conflicts. For example, different factions within the ruling African National Congress are pressing for a more aggressive policy towards the natural resource sector in order to extract greater revenues to accelerate economic development and foster wider redistribution.

Additionally, the South African government has failed to invest in society's infrastructure; as a result, many public sectors are starved of capital. Also, the current vulnerabilities in the mining sector may create a window of opportunity for more determined outside forces to gain control over a slice of the South African mineral wealth. The South African Mining Charter requires mining companies to be at least 26 percent owned by historically disadvantaged South Africans.[92] After two decades, the black empowerment objectives have not fundamentally changed the ownership structure of the mining industry, except for some smaller junior mines. These mines are scrambling for capital infusions, which may come from Chinese investors, which means that Chinese companies are moving into the PGM sector by propping up junior mining companies in South Africa. Another issue is that labor relations in some of the largest mines are fraught with conflict and tension. In the summer of 2012, a standoff between management and miners resulted in the deaths of dozens of miners and a shutdown of platinum mines. Strikes and labor unrest subsequently spread to other mines, pushing up prices of platinum and gold.[93]

As industrial strife and stoppages reduced the supply of platinum to its lowest level in a decade, the sluggish global economy and a rebound in scrap supply have kept prices within its historic range. Platinum sales from South Africa dropped by 12.5 percent in 2012, yet platinum's price fell from a high of $2,290/oz in 2008 to $1,605/oz in March 2013.

The risk is that the depressed prices will deter investments in ailing South African mines and therefore generate future supply constraints. Low prices for platinum and other PGMs have exacerbated the plight of the South African mining industry, which needs to make enormous investments to upgrade existing facilities and improve productivity.[94]

Figure 5: Global Palladium Production, 2011



Source: Luke Burgess, "Investing in Palladium Investment U Research," Investment U Research, February 24, 2012. http://www.investmentu.com/2012/February/investing-in-palladium.html

While major South African mining companies face an uncertain and difficult future, Chinese investors have entered the market to assist junior mines in South Africa—a move that matches its larger strategy in sub-Saharan Africa. Concerned about supply risks to its the Chinese economy and determined to build up its military capabilities, Chinese authorities identify access to raw materials as one of their major foreign policy goals. To prevent any supply disruptions, China has been very active in sub-Saharan Africa, which is one of the regions of largely untapped metals and minerals. In turn, China's investments and presence is welcomed in some African countries. Chinese authorities also do not exert pressure on African governments about human rights, transparency, political freedom, internal politics, environmental standards, or ethical trading practices.[95] The entry by Chinese investors or state holdings into the South African PGM sector should be a source of concern, especially as the established mining sector struggles with low productivity and underinvestment.

For these reasons, most OECD countries perceive PGMs as one of the groups of specialty metals with the single highest

risk factor. First, there are no obvious substitutes for palladium and platinum, yet they are indispensable for the global production of vehicles, engines, and computer storage devices. Moreover, supply risks are high because of the political conditions in South Africa, which pull the South African government in conflicting directions, resulting in disappointing mining performance. Labor disputes add another layer of uncertainty, as discontent among workers about working conditions and pay creates a volatile atmosphere. The financial situation in some smaller start-up mines is often delicate, and provides Chinese operators with the means to gain control over sectors of the mining operations. Finally, many mines require major upgrades, and the overall transportation, power, and public service infrastructures in South Africa are in steady decline.[96]
The other country with substantial deposits of PGMs is Russia. Mining in Russia is a risky business and many mines have failed to attract private sector capital. With the fall of communism, state-owned mines were privatized and distributed to a handful of individuals. Because commodity prices were low, capital was sent overseas rather than reinvested in the mines, resulting in the decline of the Russian mining sector.[97]

Today, while greater attention is devoted to the mining sector, Russia is perceived as an unpredictable place for investments. Its economic and political environment is stable, but the mining sector is subject to arbitrary non-transparent decisions and immense bureaucratic hurdles. Obtaining a permit to explore a region is daunting because of the many technical and administrative rules. Once a company has secured an exploration license and identified a resource, it must apply for a mining license, which requires extensive paperwork as well as approvals from different levels of governments and authorities. The whole process may take years and discourages investment and expansion. Foreigners are also dissuaded by various laws that privilege domestic operators over foreign investors. The Russian state has issued laws protecting “strategic” assets, including raw materials.[98]

MITIGATING THE RISKS

The metals and chemical elements discussed in this chapter are a diverse group and require a differentiated approach, but the following recommendations will mitigate risks for most of them.

Increase the exploration of alternative sources for the elements and thereby secure a diversification of the supply chain. Deposits of specialty metals are found in smaller concentrations in various parts of the United States. For example, northeast Minnesota is thought to possess deposits of underground copper, nickel, platinum, palladium, and gold. While it seems unlikely that this region can meet all U.S. needs, mining these deposits would lessen the reliance on imports from unstable parts of the world and also reduce the impact of any future supply restrictions.

The United States should continue the search for substitute and synthetic materials to replace REEs and REMs. Even if mining companies find more geological concentrations of exotic elements, in reality at some point the United States will run out of easily accessible resources. Manmade composites would be the long-term solution to increased dependence on the scarcer elements of the periodic table.

Recycling must be improved, strengthened, and increased. Manufacturers and producers should use extracted materials in ways that facilitate recycling and re-use. The more that is recycled, the less the economy will be dependent on imports.

A new system of stockpiling or inventory should be designed to mitigate the impact of possible supply disruptions. The DLA currently stores 28 commodities valued at over $1.4 billion. Although the stockpile contains quantities of PGMs, it does not hold REEs, and it does not appear to be properly coordinated with other agencies. To operate more efficiently, DLA Strategic Materials should adopt a sensible and proactive plan to acquire materials when prices are weak and coordinate with downstream users. Congress has recently taken steps that will enable U.S. stockpiling efforts to be more proactive; however, sustained, high-level attention will be necessary.

The United States should continue to adequately fund the USGS, which collects and analyzes data, without which it would be very difficult to pursue a mitigation strategy in the first place. USGS is a critical agency in gathering and disseminating information on the state of affairs of our natural resources. Past budget cuts have caused the USGS to struggle to meet one of its principal objectives: to inform the nation of the status of its geological resources and warn of the potential for emerging supply constraints.

Enforce greater interagency coordination, which is critical to mapping out a proper long-term strategy for managing our specialty metals supply chain. DoE, DoD, and the White House Office of Science and Technology Policy all have issued reports on how to address the critical materials agenda. There should be greater coordination and collaboration in establishing a common approach to addressing the risks of supply constraints of critical and strategic materials. In addition, since other advanced industrialized countries face very similar challenges, it would also be helpful to foster greater international cooperation and coordination among the European Union, Japan, Australia, and Canada, including possible collaboration on topics such as resource mapping, substitutes, and recycling.

U.S. foreign and security policy has paid limited attention to sub-Saharan Africa, which possesses some of the world's richest concentrations of key minerals. China has been very active in Africa to ensure that it has a presence in countries with large concentrations of strategic minerals. Because the continent supplies many of the most strategic minerals, U.S. foreign, trade, and security policy should focus on ensuring continued access to African mineral deposits.

CONCLUSION

Many minerals already were labeled as critical and strategic in the early 1980s. Advanced technologies upon which our economy and national security depend are themselves heavily dependent on specialty metals and minerals. Nevertheless, over time the United States has become more dependent on imports of key minerals from countries with unstable political systems, corrupt leadership, or opaque business environments. Moreover, the countries themselves (notably, China) have taken a more aggressive posture towards mineral resources and now compete with Western mining operators for extraction control.

The United States is not the only Western country that has increasingly ignored the economics of mineral extraction. Many electronic devices, green technology, and advanced weapon systems rely on a host of exotic chemical elements. An overarching strategy linking DoD with other government and industry stakeholders is imperative to address potential shortages before they impact U.S. national security.

ENDNOTES

1 National Research Council, Committee on Critical Mineral Impacts of the U.S. Economy, Committee on Earth Resources, *Minerals, Critical Minerals, and the U.S. Economy* (Washington, D.C.: National Academies Press, 2008), 39.

2 U.S. Department of Defense, Office of Manufacturing and Industrial Base Policy, *Reconfiguration of the National Defense Stockpile Report to Congress* (April 2009). http://www.acq.osd.mil/mibp/docs/nds_reconfiguration_report_to_congress.pdf.

3 U.S. Geological Survey, *Mineral Commodities Summary 2013* (Reston, Virginia: 2013), 5. http://minerals.usgs.gov/minerals/pubs/mcs/2013/mcs2013.pdf.

4 According to the American Resources Policy Network, the absence of a working understanding of why a mineral may be critical or strategic has greatly contributed to the delay in securing access to key minerals. Daniel McGroarty and Sandra Wirtz, "Reviewing Risk: Critical Metals & National Security," *American Resources Policy Network* (June 6, 2012). http://americanresources.org/wp-content/uploads/2012/09/ARPN_Fall_Quarterly_Report_WEB.pdf.

5 "Minerals Make National Security," National Mining Association. http://mineralsmakelife.org/assets /images/content/resources/MineralsMakeNationalSecurityFactSheet.pdf.

6 Roderick G. Eggert, Mineral and Energy Economics Program at Colorado School of Mines, quoted in David J. Hanson, "Critical Materials Problem Continues Debate over Use of and Substitutions for Rare Earth Elements Points out a Need for Much More Research," *Chemical & Engineering News* 89 (October 24, 2011), 28.

7 Rare earth elements (REEs) are a group of 17 chemical elements that occur together in the periodic table. These metals have many similar properties, which explains why they often are found together in geologic deposits. However, the group is divided into two categories according to their atomic weight on the periodic table: light and heavy REEs. Many light REEs are in fact abundant and of less value than the heavy ones; heavy REEs are of higher value in spite of a smaller market for them. See Chapter 3 on Magnets for a further discussion of light and heavy REEs.

8 U.S. Geological Survey (UGS), *Principal Rare Earth Elements Deposits of the United States: A Summary of Domestic Deposits and a Global Perspective* Keith R. Long et al., (Reston, VA: USGS & U.S. Department of the Interior, Scientific Investigations Report 2010-5220). http://pubs.usgs.gov/sir/2010/5220/downloads/SIR10-5220.pdf.

9 Brian Sylvester. "Rare Earth Metals—Not Your Father's Mining Biz: Byron King," *The Gold Report*, January 13, 2012. http://www.theaureport.com/pub/na/12440.

10 Elisa Alonso, Frank R. Field, and Randolph E. Kirchain, "Platinum Availability for Future Automotive Technologies," *Environmental Science & Technology* 46, no. 12 (2012), 986-1012.

11 British Geological Survey (BGS), *Risk List 2011*. http://www.bgs.ac.uk/downloads/start.cfm?id=2063. See also, BGS, *Critical Raw Materials*. http://www.bgs.ac.uk/mineralsuk/statistics/criticalRawMaterials.html.

12 Other elements with substantial supply risks are bismuth (China), carbon graphite (China), germanium (China), indium (China), iodine (Chile), rhenium (Chile), strontium (China), and thorium (India). British Geological Survey, *Risk List 2011*. http://www.bgs.ac.uk/downloads/start.cfm?id=2063.

13 Gerrit Wiesmann, "Merkel Strikes Kazakh Rare Earth Accord," *The Financial Times*, February 8, 2012.

14 "European Union Critical Raw Materials Analysis the European Commission Raw Materials Supply Group," *Executive Summary by Swiss Metal Assets* (October 1, 2011). http://www.swissmetalassets.com/wp-content/uploads/2011/10/EU-Critical-Metals-Summary-Oct-3-2011.pdf.

15 U.S. Geological Survey, *Rare Earths Statistics and Information 2012* (Reston, VA: USGS, 2012). http://minerals.usgs.gov/minerals/pubs/commodity/rare_earths/.

16 The Mountain Pass Mine in California was one of the largest producers of REE until it closed in 2002 as a result of falling RE prices as China stepped up production and heightened U.S. environmental regulations and concerns regarding pollution from the extraction and refining processes. A series of environmental disasters between 1984 and 1998 released thousands of gallons of toxic sludge into the California desert, prompting a major lawsuit. The mine reopened in 2012. Russell McLendon, "What Are Rare Earth Metals?" *Mother Nature Network*, June 22, 2011. http://www.mnn.com/earth-matters/translating-uncle-sam/stories/what-are-rare-earth-metals.

17 Bryan Tilt, *The Struggle for Sustainability in Rural China: Environmental Values and Civil Society (*New York, NY: Columbia University Press, 2010).

Shunsuke Managi and Shinji Kaneko, *Chinese Economic Development and the Environment*, (Northampton, MA: Edward Elgar, 2008).

18 "Wish You Were Mine," *The Economist*, February 11, 2012. http://www.economist.com/node/21547285.

19 "Wish You Were Mine," *The Economist*, February 11, 2012. http://www.economist.com/node/21547285.

Alex MacDonald, "Australia Gives Africa a Lesson in Resource Nationalism," *The Wall Street Journal,* February 13, 2012. http://blogs.wsj.com/dealjournalaustralia/2012/02/13/australia-gives-africa-a-lesson-in-resource-nationalism/.

Andrew England, "Zuma Seeks to Allay Fears over Nationalization," *The Financial Times*, February 10, 2012. http://www.ft.com/intl/cms/s/0/cfc3f05a-5403-11e1-bacb-00144feabdc0.html.

20 Brian Sylvester, "Richard Karn: 50 Specialty Metals Under Supply Threat," *The Critical Metals Report*, June 14, 2011. http://www.theaureport.com/pub/na/9867.

21 National Research Council, *Minerals, Critical Minerals, and the U.S. Economy* (Washington, D.C.: National Academies Press, 2008).

22 National Research Council, *Minerals, Critical Minerals, and the U.S. Economy* (Washington, D.C.: National Academies Press, 2008), 165.

23 National Research Council, *Minerals, Critical Minerals, and the U.S. Economy* (Washington, D.C.: National Academies Press, 2008), 58.

24 U.S. Geological Survey, *Mineral Commodity Summaries, Lithium* (Reston, VA: January 2012). http://minerals.usgs.gov/minerals/pubs/commodity/lithium/mcs-2012-lithi.pdf.

25 There is one active lithium mine in Nevada. The mine's production capacity was expanded in 2012, and there is a small amount of recycled lithium. Nevertheless, the U.S. imports more than 70 percent of its lithium. U.S. Geological Survey, *Mineral Commodities Summaries 2013* (Reston, VA: January 2013). http://minerals.usgs.gov/minerals/pubs/mcs/2013/mcs2013.pdf.

The American Physical Society and Materials Research Society, *The Energy Critical Elements: Securing Materials for Emerging Technologies* (Washington, D.C.: February 18, 2011). http://www.aps.org/policy/reports/popa-reports/loader.cfm?csModule=security/getfile&PageID=236337.

26 David J. Hanson, "Critical Materials Problem Continues Debate over Use of and Substitutions for Rare Earth Elements Points out a Need for Much More Research," *Chemical & Engineering News* 89 (October 24, 2011), 29.

27 U.S. Geological Survey, *Mineral Commodity Summaries, Lithium* (Reston, VA: January 2012). http://minerals.usgs.gov/minerals/pubs/commodity/lithium/mcs-2012-lithi.pdf.

28 Thomas Cherico Wanger, "The Lithium Future—Resources, Recycling, and the Environment," *Conservation Letters* 4 (2011), 202-206.

29 Thomas Goonan, "Lithium Use in Batteries," *U.S. Geological Survey Circular* 1371 (Reston, VA: USGS, 2012). http://pubs.usgs.gov/circ/1371/.

30 U.S. Department of Defense, Office of Manufacturing and Industrial Base Policy, *Annual Industrial Capabilities Report to Congress* (2011). http://www.acq.osd.mil/mibp/docs/annual_ind_cap_rpt_to_congress-2011.pdf.

31 U.S. Geological Survey, *Mineral Commodity Summaries, Beryllium* (Reston, VA: January 2012). http://minerals.usgs.gov/ minerals/pubs/commodity/beryllium/mcs-2012-beryl.pdf.

32 U.S. Geological Survey, *Mineral Commodity Summaries, Rhenium* (Reston, VA: January 2012). http://minerals.usgs.gov/ minerals/pubs/commodity/rhenium/mcs-2012-rheni.pdf.

33 Live price of Rhenium Price accessed on March 10, 2013. http://www.taxfreegold.co.uk/rheniumpricesusdollars.html.

34 U.S. Geological Survey, *Mineral Commodity Summaries, Rhenium* (Reston, VA: January 2012). http://minerals.usgs.gov/minerals/pubs/commodity/rhenium/mcs-2012-rheni.pdf.

35 U.S. Geological Survey, *Mineral Commodity Summaries, Molybdenum* (Reston, VA: January 2012). http://minerals.usgs.gov/minerals/pubs/commodity/molybdenum/mcs-2012-molyb.pdf.

36 U.S. Geological Survey, *Mineral Commodity Summaries, Vanadium* (Reston, VA: January 2012). http://minerals.usgs.gov/minerals/pubs/commodity/vanadium/mcs-2012-vanad.pdf.

37 U.S. Geological Survey, *Mineral Commodity Summaries 2013* (Reston, VA: January 2013).

38 Brian Sylvester, "Solving Critical Rare Earth Metal Shortages: Dr. Michael Berry and Chris Berry," *The Critical Metals Report*, January 10, 2012. http://www.theaureport.com/pub/na/12217.

39 Steve Gagnon, "Vanadium," *Jefferson Lab*. http://education.jlab.org/itselemental/ele023.html.

Nick Hodge, "Vanadium: The Best Thing Since Lithium," *Energy & Capital*, May 25, 2011. http://www.energyandcapital.com/articles/the-best-thing-since-lithium/1531.

40 "Tantalum Facts: Chemical and Physical Properties," Anne Marie Helmenstine for About.com. http://chemistry.about.com/od/elementfacts/a/tantalum.htm.

41 Columbite is an older name, no longer in use except in the context of columbite-tantalite. Columbite comes from columbium, which was renamed niobium in the 1950s.

42 U.S. Geological Survey, *Mineral Commodity Summaries, Tantalum* (Reston, VA: January 2012). http://minerals.usgs.gov/minerals/pubs/commodity/niobium/mcs-2012-tanta.pdf.

43 Both the Securities Exchange Commision and OECD are contemplating new rules to force corporations to conduct business ethically in central Africa. The Dodd-Frank Act has banned the export of minerals from regions where mining appears to be intertwined with ongoing civil strife. U.S. Geological Survey, *Mineral Commodity Summaries, Tantalum* (Reston, VA: January 2012). http://minerals.usgs.gov/minerals/pubs/commodity/niobium/mcs-2012-tanta.pdf.

Michael Nest, *Coltan* (New York: Polity Press 2011).

44 "About Tungsten," Ormonde Mining, PLC. . http://www.ormondemining.com/en/investors/about_tungsten/about_tungsten_details.

45 "Tungsten: Statistics and Information," last modified March 11, 2013, U.S. Geological Survey.

http://minerals.usgs.gov/minerals/pubs/commodity/tungsten/index.html.

46 U.S. Geological Survey, *Mineral Commodity Summaries, Tungsten* (Reston, VA: January 2012). http://minerals.usgs.gov/minerals/pubs/commodity/tungsten/mcs-2012-tungs.pdf.

47 U.S. Under Secretary of Defense for Acquisition, Technology, and Logistics, *Strategic and Critical Materials Operations Report to Congress*, January 2011. https://www.dnsc.dla.mil/Uploads/Materials/dladnsc2_9-13-2011_15-9-40_FY10%20Ops%20Report%20-%2005-06-2011.pdf.

48 U.S. Geological Survey, *Mineral Commodity Summaries, Tungsten* (Reston, VA: January 2012). http://minerals.usgs.gov/minerals/pubs/commodity/tungsten/mcs-2012-tungs.pdf.

49 Jonathan Marshall, "Opium, Tungsten, and the Search for National Security, 1940–52," *Journal of Policy History*, 3 (October 1991), 89-116.

Mildred Gwen Andrews, *Tungsten: The Story of an Indispensable Metal*, (Washington, D.C.: Tungsten Institute, 1955).

50 For example, South Korea plans to convert 100 percent of public sector lighting to LED by 2020, and aims to reach 60 percent LED lighting nationwide.

51 U.S. Geological Survey, *Mineral Commodity Summaries, Gallium* (Reston, VA: January 2012). http://minerals.usgs.gov/minerals/pubs/commodity/gallium/mcs-2012-galli.pdf.

52 Keith Gurnett and Tom Adams, "Taming the Gallium Arsenic Dicing Process," *Military & Aerospace Electronics*, December 1, 2006. http://www.militaryaerospace.com/articles/print/volume-17/issue-12/news/taming-the-gallium-arsenide-dicing-process.html.

53 U.S. Geological Survey, *Mineral Commodity Summaries, Gallium* (Reston, VA: January 2012). http://minerals.usgs.gov/minerals/pubs/commodity/gallium/mcs-2012-galli.pdf.

54 U.S. Geological Survey, *Mineral Commodity Summaries, Indium* (Reston, VA: January 2012). http://minerals.usgs.gov/minerals/pubs/commodity/indium/mcs-2012-indiu.pdf.

55 "Indium." Chemicool Periodic Table. *Chemicool.com*, November 9, 2012. http://www.chemicool.com/elements/indium.html.

56 "Technology: Why SWIR? What is The Value of Shortwave Infrared?" Sensors Unlimited, Inc., Goodrich Corporation. http://www.sensorsinc.com/whyswir.html.

57 U.S. Geological Survey, *Mineral Commodity Summaries, Germanium* (Reston, VA: January 2012). http://minerals.usgs.gov/minerals/pubs/commodity/germanium/mcs-2012-germa.pdf.

58 U.S. Geological Survey, *Mineral Commodity Summaries, 2013* (Reston, VA: January 2013). http://minerals.usgs.gov/minerals/pubs/commodity/germanium/mcs-2012-germa.pdf.

59 For example, the 2012 DLA made only 3000 kg available for purchase of a 16000 kg total holding. See Defense Logistics Agency, *Strategic Materials, Annual Material Plan (FY2012)* (2012). https://www.dnsc.dla.mil/Uploads/NewsRelease/bberuete_10-6-2011_11-9-18_3028%20FY12%20AMP.pdf.

60 U.S. Geological Survey, *Mineral Commodity Summaries, Germanium* (Reston, VA: January 2012).

61 U.S. Geological Survey, *Material Commodity Summaries, Antimony* (Reston, VA: January 2012). http://minerals.usgs.gov/minerals/pubs/commodity/antimony/mcs-2012-antim.pdf.

62 U.S. Geological Survey, *Byproduct Mineral Commodities used for the Production of Photovoltaic Cells*, by Donald Bleiwasy. (Reston, VA: 2010). http://pubs.usgs.gov/circ/1365/Circ1365.pdf.

63 U.S. Geological Survey, *Material Commodity Summaries, Tellurium* (Reston, VA: January 2012). http://minerals.usgs.gov/minerals/pubs/commodity/selenium/mcs-2012-tellu.pdf.

64 Live price of rhenium, Tax Free Gold, accessed February 17, 2012. http://www.taxfreegold.co.uk/rheniumpricesusdollars.html.

65 American Physical Society. *Energy Critical Elements: Securing Materials for Emerging Technologies*. http://www.aps.org/policy/reports/popa-reports/loader.cfm?csModule=security/getfile&PageID=236337.

66 U.S. Geological Survey, *Mineral Commodity Summaries, Gallium* (Reston, VA: January 2012). http://minerals.usgs.gov/minerals/pubs/commodity/gallium/mcs-2012-galli.pdf.

67 Molycorp's share price dropped below its IPO price of $14/share. It rose to $76/share on April 28, 2011, and then dropped as low as $5.75/share in November 2012. It traded at $6.50/share in March 2013.

68 Kia Ghorashi, Lucinda Gibbs, Polly Hand, and Amber Luong, *Rare Earth Elements: Strategies to Ensure Domestic Supply*. (Stanford, CA: Bay Area Council and the Breakthrough Institute, March 10, 2011). http://publicpolicy.stanford.edu/system/files/RareEarthElements.pdf.

69 Kia Ghorashi, Lucinda Gibbs, Polly Hand, and Amber Luong, *Rare Earth Elements: Strategies to Ensure Domestic Supply*. (Stanford, CA: Bay Area Council and the Breakthrough Institute, March 10, 2011). http://publicpolicy.stanford.edu/system/files/RareEarthElements.pdf.

70 United States Department of Energy, *Critical Materials Strategy* (Washington, D.C.: DOE/PI-0009, December 2011). http://energy.gov/sites/prod/files/DOE_CMS2011_FINAL_Full.pdf.

71 Russell McLendon. "What Are Rare Earth Metals?" *Mother Nature Network*, June 22, 2011. http://www.mnn.com/earth-matters/translating-uncle-sam/stories/what-are-rare-earth-metals.

72 Marc Humphries, *Rare Earth Elements: The Global Supply Chain* (Washington, D.C.: Congressional Research Service 7-5700, September 6, 2011).

73 ResearchInChina, China Rare Earth Industry Report, 2012-2015 (Beijing: ResearchInChina, April 2013).

74 John Tkacik, Jr., Magnequench: CFIUS and China's Thirst for U.S. Defense Technology (Washington, D.C.: The Heritage Foundation, May 2, 2008). http://www.heritage.org/research/reports/2008/05/magnequench-cfius-and-chinas-thirst-for-us-defense-technology. See also Chapter 3 on Magnets.

75 Patti Waldmeir, "China Ups Rare Earth Reserve," *The Financial Times*, February 12, 2010. http://www.ft.com/intl/cms/s/0/fe51dd3c-1775-11df-87f6-00144feab49a.html.

76 Michael Martina, "China Says Ready to Defend its Rare Earth Policies," *Reuters*, February 1, 2012. http://www.reuters.com/article/2012/02/01/us-china-rare-earths-idUSTRE8101OT20120201.

77 Leslie Hook, "China to Subsidise Rare Earths Producers," *The Financial Times*, November 22, 2012. http://www.ft.com/intl/cms/s/0/b3332e0a-348c-11e2-8986-00144feabdc0.html#axzz2NBcKoeAw.

78 Lou Kilze, "Pentagon 'naive' on rare earth outlook, several experts say," *Pittsburgh Tribune-Review* April 10, 2012. http://triblive.com/x/pittsburghtrib/news/s_7905799.html#axzz2NCMazsVs.

79 U.S. Department of Defense, "Report of Meeting, Department of Defense, Strategic Materials Protection Board, December 12, 2008" (December 2008). http://www.acq.osd.mil/mibp/docs/report_from_2nd_mtg_of_smpb_12-2008.pdf.

"Analysis of National Security Issues Associated With Specialty Metals," *Federal Register* 4, no. 34 (February 23, 2009), 8061-64. http://edocket.access.gpo.gov/2009/pdf/E9-3708.pdf.

80 U.S. Department of Defense, "Report of Meeting, Department of Defense, Strategic Materials Protection Board, December 12, 2008" (December 2008). http://www.acq.osd.mil/mibp/docs/report_from_2nd_mtg_of_smpb_12-2008.pdf.

81 The GAO report is available online at http://www.gao.gov/new.items/d10617r.pdf.

82 However, in March 2013, DoD suggested adding heavy rare earth elements to the stockpile in the amount of $120.43 million. DoD would have to buy these elements from China, because there is no domestic producer of heavy REEs. Dorothy Kosich, "U.S. DoD, Congress Worry on Rare Earths Stockpiles, Supplies," *MineWeb*, March 25 2013. http://www.mineweb.com/mineweb/content/en/mineweb-industrial-metals-minerals-old?oid=183283&sn=Detail.

U.S. Department of Defense, Under Secretary of Defense for Acquisition, Technology, and Logistics, "Strategic and Critical Materials Operations Report to Congress" (Washington, D.C.: January 2011). https://www.dnsc.dla.mil/Uploads/Materials/dladnsc2_9-13-2011_15-9-40_FY10%20Ops%20Report%20-%2005-06-2011.pdf.

83 H.R. 618, H.R.952, H.R.1314, H.R.1367, H.R.1388, H.R.1875, H.R.2011, H.R.2184, H.R.22847, S. 734, S. 1113, S. 1270, S. 1351.

84 U.S. Department of Defense, Office of Under Secretary of Defense for Acquisition, Technology, and Logistics, "Annual Industrial Capabilities Report to Congress" (Washington, D.C.: September 2011), 10-12. http://www.acq.osd.mil/mibp/docs/annual_ind_cap_rpt_to_congress-2011.pdf.

85 Rebecca Keenan, "China May Double Rare Earth Exports as Demand Rebounds," *Bloomberg News*, February 27, 2012. http://www.bloomberg.com/news/2012-02-26/china-may-double-rare-earth-exports-as-overseas-demand-rebounds-on-price.html.

86 Daniel Sperling and Deborah Gordon, *Two Billion Cars: Driving Toward Sustainability* (New York, NY: Oxford University Press, 2009).

87 "Electronic Uses of Palladium," Stillwater Palladium, http://www.stillwaterpalladium.com/electronics.html.

88 "Gold Depository," WHYY, http://www.whyy.org/tv12/secrets/gold.html.

89 Elisa Alonso, Frank R. Field, and Randolph E. Kirchain, "Platinum Availability for Future Automotive Technologies;" *Environmental Science & Technology* 46, no. 12 (2012), 986-1012.

Daniel McGroarty and Sandra Wirtz, "Reviewing Risk: Critical Metals & National Security," *American Resources Policy Network* (June 6, 2012). http://americanresources.org/wp-content/uploads/2012/09/ARPN_Fall_Quarterly_Report_WEB.pdf.

90 U.S. Geological Survey, *Material Commodity Summaries, Platinum Group Metals* (Reston, VA: January 2012). http://minerals.usgs.gov/minerals/pubs/commodity/platinum/mcs-2012-plati.pdf.

91 The two mines are Stillwater Complex in Montana and North American Palladium in the Thunder Bay District of Ontario. Luke Burgess, "Investing in Palladium," *Investment U Research,* February 24, 2012. http://www.investmentu.com/2012/February/investing-in-palladium.html.

Luke Burgess, "The Definitive Guide to Palladium Investing in 2012," *Investment U Research*, February 28, 2012.

http://www.investmentu.com/2012/February/palladium-investing.html.

92 Peter Leon, "Business Should Be Driving Empowerment of Workers," *The Financial Times*, February 8, 2012. http://www.ft.com/intl/cms/s/0/dfe79f60-4ce0-11e1-8741-00144feabdc0.html#axzz25SIRqVhy.

93 Andrew England, "Marikana Mine Bus Crews Face Threats," *The Financial Times* (August 27, 2012). http://www.ft.com/intl/cms/s/0/d405cd72-f058-11e1-b7b2-00144feabdc0.html#axzz25SIRqVhy.

Andrew England, "S Africa Gold Miners Strike as Strife Spreads," *The Financial Times* (August 31, 2012). http://www.ft.com/intl/cms/s/0/1b0f6d3c-f378-11e1-9c6c-00144feabdc0.html#axzz25SIRqVhy.

94 Jack Farchy, "Platinum Shortfall Largest in Decade," *The Financial Times*, November 13, 2012. http://www.ft.com/intl/cms/s/0/99c85de0-2cf9-11e2-beb2-00144feabdc0.html#axzz2NBcKoeAw.

95 Masuma Farooki, "China's structural demand and commodity prices," edited by Christopher M. Dented, *Implications for Africa China and Africa development relations* (New York, NY: Routledge, 2011), 121-142.

Deborah Brautigam, *The Dragon's Gift: The Real Story of China in Africa* (New York, NY: Oxford University Press, 2010).

96 Hein Marais, *South Africa Pushed to the Limit: The Political Economy of Change* (London: Zed Books, 2011).

Bill Freund and Harald Witt, eds., *Development dilemmas in post-apartheid South Africa* (Cottsville, South Africa: University of Kwazulu-Natal Press, 2010).

Janine Aron, Brian Kahn, and Geeta Kingdon, *South African Economic Policy under Democracy* (New York, NY: Oxford University Press, 2009).

97 Global Business Reports, "Mining in Russia: Braving the Bear," *Engineering & Mining Journal*, February 2012, 50-54. http://www.gbreports.com/admin/reports/EMJ-Russia-2012.pdf.

98 Ibid.