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# Critical Minerals and U.S. Public Policy

June 28, 2019

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R45810

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SUMMARY

R45810

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President Trump and various U.S. lawmakers have expressed concerns about U.S. reliance on critical mineral imports and potential disruption of supply chains that use critical minerals for various end uses, including defense and electronics applications. Chinese export quotas on a subset of critical minerals referred to as rare earth elements (REEs) and China's 2010 curtailment of REE shipments to Japan heightened U.S. vulnerability concern.

In December 2017, Presidential Executive Order 13817, "A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals," tasked the Department of the Interior to coordinate with other executive branch agencies to publish a list of critical minerals. The Department of the Interior published a final list of 35 critical minerals in May 2018.

The concern among many in Congress has evolved from REEs and REE supply chains to include other minor minerals and metals that are used in small quantities for a variety of economically significant applications (e.g., laptops, cell phones, electric vehicles, and renewable energy technologies) and national defense applications. Also, as time passed, concerns increased about access to and the reliability of entire supply chains for rare earths and other minerals. Congressional action (e.g., National Defense Authorization Act for FY2014, P.L. 113-66) has led to the acquisition of REEs and other materials for the National Defense Stockpile. In 2017, the United States had no primary production of 22 minerals and was limited to byproduct production of 5 minerals on the critical minerals list. In contrast, the United States is a leading producer of beryllium and helium, and there is some U.S. primary production of 9 other critical minerals. China ranked as the lead global producer of 16 minerals and metals listed as critical. Although there are no single monopoly producers in China, as a nation, China is a dominant or near-monopoly producer of yttrium (99%), gallium (94%), magnesium metal (87%), tungsten (82%), bismuth (80%), and rare earth elements (80%).

The United States is 100% import reliant on 14 minerals on the critical minerals list (aside from a small amount of recycling). These minerals are difficult to substitute inputs into the U.S. economy and national security applications; they include graphite, manganese, niobium, rare earths, and tantalum, among others. The United States is more than 75% import reliant on an additional 10 critical minerals: antimony, barite, bauxite, bismuth, potash, rhenium, tellurium, tin, titanium concentrate, and uranium.

The current goal of U.S. mineral policy is to promote an adequate, stable, and reliable supply of materials for U.S. national security, economic well-being, and industrial production. U.S. mineral policy emphasizes developing domestic supplies of critical materials and encourages the domestic private sector to produce and process those materials. But some raw materials do not exist in economic quantities in the United States, and processing, manufacturing, and other downstream ventures in the United States may not be globally cost competitive. Congress and other decisionmakers have multiple legislative and administration options to weigh in deliberating on whether, and if so how, to address the U.S. role and vulnerabilities related to critical minerals.

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# Introduction

President Trump and various U.S. lawmakers have expressed concerns about U.S. reliance on critical mineral imports and the vulnerability to critical mineral disruptions of supply chains for various end uses, including defense and electronics applications. Chinese export quotas on a type of critical minerals referred to as rare earth elements (REEs) and China's curtailment of rare earth shipments to Japan over a maritime dispute in 2010 represented a wakeup call for the United States on China's near-monopoly control over global REE supply.[1] The actions of the Chinese led to record high prices for REEs and, as a result, began to shine a light on the potential supply risks and supply chain vulnerability for rare earths and other raw materials and metals needed for national defense, energy technologies, and the electronics industry, among other end uses.[2] U.S. legislators have introduced and deliberated on bills that would address the potential supply risk and vulnerability with respect to rare earth supply and bills that would promote domestic rare earth mine development.

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[1] There are 17 rare earth elements (REEs): yttrium, scandium, and 15 within the chemical group called lanthanides. The lanthanides consist of the following: lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium. Rare earths are moderately abundant in the earth's crust, some even more abundant than copper, lead, gold, and platinum. While some are more abundant than many other minerals, most REEs are not concentrated enough to make them easily exploitable economically. The lanthanides are often broken into two groups: light rare earth elements (LREEs)—lanthanum through europium (atomic numbers 57-63), and the heavier rare earth elements (HREEs)—gadolinium through lutetium (atomic numbers 64-71). Yttrium is typically classified as a heavy element.

Currently, the dominant U.S. end uses for rare earth elements are for automobile catalysts and petroleum refining catalysts; use in phosphors in color television and flat panel displays (cell phones, portable DVDs, and laptops); permanent magnets and rechargeable batteries for hybrid and electric vehicles; and numerous medical devices. There also are defense applications such as jet fighter engines, missile guidance systems, antimissile defense, and satellite and communication systems. Permanent magnets containing neodymium, gadolinium, praseodymium, dysprosium, and terbium are used in numerous electrical and electronic components and new-generation generators for wind turbines.

[2] For more information on critical mineral end uses, see **Table 5**.

After 2010, decisionmakers were faced with various policy questions, including is a domestic supply chain necessary to address potential supply risk; and would an RRE alternative supply chain outside China among allies provide reliable and less risky access to RREs? As events unfolded during the 2010s, it became clear that providing an upstream supply outside China was not enough, and that access to and the reliability of entire supply chains for rare earths and other minerals essential for the economy and national security also were vulnerable.

The concern among many in Congress has evolved from rare earths and REE supply chains, to also include other minor minerals or metals that used in small quantities for a variety of economically significant applications.[3] These minor metals are used in relatively small amounts in everyday applications such as laptops, cell phones and electric vehicles, and renewable energy technologies, in addition to national defense applications. In December 2017, the Presidential Executive Order (E.O.) 13817, "A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals," tasked the Department of the Interior (DOI) to coordinate with other executive branch agencies to publish a list of "critical minerals."[4] DOI published a final list of 35 critical minerals in May 2018.[5]

## From 2010 to Present

Initially after China's actions in 2010 contributed to prices for the various elements increasing, the focus in Congress was on rare earth supply (e.g., where in the United States new REE production could begin). Since 2010, several bills have been introduced that would use a variety of policy options and approaches—from streamlining the permitting framework for rare earth elements and other mining and processing projects on federal land, to the additions of REEs to the National Defense Stockpile.[6] Sections 1411 and 1412 of the National Defense Authorization Act for FY2014 (P.L. 113-66) contained language for Department of Defense to begin studies of rare earth materials and to require purchases of heavy REEs for the national defense stockpile.

In 2010 the sole U.S. rare earth mine located in Mountain Pass, CA, owned by Molycorp, Inc., was dormant. From the mid-1960s through the 1980s, Molycorp's Mountain Pass mine was the world's dominant source of rare earth oxides. However, by 2000, nearly all of the separated rare earth oxides were imported, primarily from China. Because of China's REE oversupply and lower-cost production, as well as a number of environmental (e.g., a pipeline spill carrying

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[3] Minor metals are primarily byproducts of base metals (e.g., copper, iron, nickel, zinc) and typically not traded on exchanges.

[4] The National Science and Technology Council Subcommittee on Critical and Strategic Mineral Supply Chains (CSMSC) and Executive Order (E.O.) 13817 define critical minerals as those that have a supply chain that is vulnerable to disruption, and that serve an essential function in the manufacture of a product, the absence of which would cause significant economic or security consequence. Strategic minerals are defined as a subset of critical minerals and are essential for national security applications. For more on E.O. 13817, see https://www.federalregister.gov/documents/2017/12/26/2017-27899/a-federal-strategy-to-ensure-secure-and-reliable-supplies-of-critical-minerals.

[5] 83 *Federal Register* 23295, May 18, 2018. The December 2018 list of critical minerals includes: aluminum, antimony, arsenic, barite, beryllium, bismuth, cesium, chromium, cobalt, fluorspar, gallium, germanium, graphite, hafnium, helium, indium, lithium, magnesium compounds, manganese, niobium, platinum group metals, rare earth elements, potash, rhenium, rubidium, scandium, strontium, tantalum, tellurium, tin, titanium, tungsten, uranium, vanadium, and zirconium. This is not a static list and is subject to change. For more on E.O. 13817, see section on "Development of the Critical Minerals List" in this report.

[6] The National Defense Stockpile (50 U.S.C. §98 et seq.) was established in 1939 to retain stocks of strategic and critical materials, thus, reducing dependence on foreign sources during times of national emergencies. The stockpile was set up for national defense purposes only and not to be used as an economic stockpile.

contaminated water) and regulatory issues at Mountain Pass, Molycorp, Inc. ceased production at its mine in 2002.

Between 2010 and 2012, there was some optimism but also criticism over Molycorp Inc.'s approach to reopen the only rare earth mine in the United States and establish a vertically integrated operation including oxide separation, production of metal alloys, and permanent magnet production.[7] A few important questions relevant to a vertically integrated approach were raised then as they are now

- How can a fully integrated supply chain be developed domestically?
- Is a domestic supply chain necessary to address potential supply risk?; and
- With China in a near-monopoly position in all aspects of the rare earth supply chain, would an alternative supply chain outside China among allies provide reliable and less risky access to needed rare earth elements?

Another immediate concern focused on the investment and skill level needed to build-out a reliable supply chain outside of China.

In 2012, Molycorp, Inc., reopened its Mountain Pass mine, and the Lynas Corporation, Ltd. began production in Australia which added more REEs to the global mix—albeit most of the production was in light rare earth elements (LREEs), not the heavy rare earth elements (HREEs) are needed for permanent magnets—the fastest growing use for rare earth elements at the time. Permanent magnets are important parts for national defense missile systems, wind turbines, and automobiles. With higher prices came lower demand as some companies began to use less REEs, try substitutes, or diversify their source of raw material supply outside of China. With China's production (including illegal production), there was more supply than demand for many of the REEs and prices declined. As a result of rapidly falling prices and Molycorp's debt, the Mountain Pass mine was not economically sustainable. Molycorp filed for Chapter 11 bankruptcy protection in June 2015. In June 2017, MP Mine Operations LLC (MPMO) purchased the Mountain Pass mine for $20.5 million. MPMO is an American-led consortium of which the Chinese-owned Leshan Shenghe Rare Earth Company has a 10% nonvoting minority share. In 2018, MMPO reportedly restarted production at Mountain Pass. See **Table 1** for Molycorp's timeline. In March 2019, the Chinese government announced a reduction in REE production quotas and suggested that the REE produced in China would be sold only in China for its domestic manufacturing activity.[8]

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[7] Permanent magnets are important parts for national defense missile systems, wind turbines, and automobiles.

[8] Tom Daly, "China Sets Lower Rare Earth Output Quotas for First Half of 2019," Reuters, March 15, 2019, https://www.reuters.com/article/us-china-rareearths-quotas.

### Table 1. Timeline of Selected Molycorp, Inc.,-Related Activities

| | |
|---|---|
| **Mid-1960s through 1990s** | Molycorp's Mountain Pass mine in the 1960s-1980s was the world's dominant source of rare earth oxides. U.S. production began to rapidly decline in the 1990s, as China's lower cost production began to accelerate. |
| **By 2000** | Nearly all of the separated rare earth oxides in the United States were imported, primarily from China. |
| **2002** | Because of China's oversupply and lower-cost production, and a number of environmental (e.g., a pipeline spill carrying contaminated water) and regulatory issues at Mountain Pass, Molycorp ceased production at its mine. Since then, the United States has lost nearly all of its capacity in the rare earth supply chain, including intellectual capacity. |
| **2008** | Under new ownership, Molycorp embarked upon a campaign to change the rare earth position in the United States with its "mine to magnet" (vertical integration) business model. |
| **2011** | Molycorp broke ground for a new separation facility at the Mountain Pass mine to facilitate a proprietary oxide separation process that it had designed to use fewer reagents and recycle the wastewater, thus eliminating the need for a disposal pond.<br>(April) Molycorp acquired the Japanese subsidiary Santoku America in Tolleson, AZ, and renamed it Molycorp Metals and Alloys (MMA). This acquisition was part of the firm's strategy to become a vertically integrated company. It produced both neodymium iron-boron (NdFeB) and samarium cobalt (SmCo) alloys used in the production of permanent magnets. Molycorp Metals and Alloys was the sole U.S. producer of the NdFeB alloy.<br>(April) Molycorp purchased a 90.023% majority interest in AS Silmet (renamed Molycorp Silmet), an Estonian-based rare earth element and rare metals processor.<br>(November) Molycorp entered a joint venture with Daido Steel and Mitsubishi Corporation of Japan to manufacture sintered permanent rare earth (NdFeB) magnets in Japan that were sold on the world market. |
| **2012** | (June) Molycorp acquired Neo Materials Technology, Inc., a Toronto-based firm (renamed Molycorp Canada) with rare earth processing and permanent magnet powder facilities in China. Molycorp restarted rare earth production. |
| **2015** | (June) Molycorp files for Chapter 11 Bankruptcy Protection. |
| **2016** | (August) Neo Performance Materials is established as a private company following the restructuring of Molycorp. Molycorp remains a separate entity as owner of Mountain Pass Mine. |
| **2017** | Neo Performance Materials completes an initial public offering (IPO) on the Toronto Stock Exchange. |
| **2017** | (June) A consortium, MP Mine Operations, LLC (MPMO)—comprised of JHL Capital Group, LLC (aka MP Materials) (65%); QVT Financial LP (25%); and Leshan Shenghe Rare Earth Company (10%)—purchase Mountain Pass Mine for $20.5 million. |
| **2018** | (January) According to MPMO, production at Mountain Pass restarted in January of 2018. Production data were not available at the time of this writing. |

**Sources:** CRS using CRS Report R41347, *Rare Earth Elements: The Global Supply Chain*, by Marc Humphries, and articles from http://www.mining.com including "Molycorp Thrown a Lifeline" (August 31, 2016), and "Mountain Pass Sells for $20.5 Million" (June 16, 2017), by Andrew Topf.

As previously noted, the vulnerability concerned expanded from RREs to critical minerals. Assessments using a criticality matrix identified minerals (such as REEs, cobalt, and tantalum, among others) that could face supply restrictions and result in vulnerabilities to the economy and national security.[9] Broad criticality assessments were prepared by the National Research Council,

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[9] A criticality matrix is a two-dimensional presentation of a mineral's importance of use and availability. This framework for analysis seeks to emphasize on a vertical axis whether minerals are easily substitutable, identify the

the Department of Energy (DOE), and the Massachusetts Institute of Technology (MIT) early in the recent discussion of mineral supply risk and potential mineral demand from the energy technology sector.[10] Many others, such as Nassar, Du, and Graedel,[11] have weighed in since 2010 on the criticality and supply risk question, providing a variety of models that examine the supply risk and vulnerabilities associated with these minerals. It is beyond the scope of this report to evaluate those models.

## Congressional Interest

Proposed Congressional findings mentioned in a number of bills introduced since the 111th Congress on critical minerals include:

- Emerging economies are increasing their demand for REEs as they industrialize and modernize;
- A variety of minerals are essential for economic growth and for infrastructure;
- The United States has vast mineral resources but at the same time is becoming more dependent on imports;
- Mineral exploration dollars in the United States are approximately 7% of the world total (compared to 19% in the early 90s);
- Heavy rare earth elements are critical to national defense;
- China has near-monopoly control over the rare earth value chain, and there has been a transfer of technology from U.S. firms and others to China in order to gain access to rare earths and downstream materials;
- Thorium regulations are a barrier to rare earth development in the United States;
- A sense of Congress that China could disrupt REE and other critical mineral supplies to the United States;
- It is important to develop the domestic industrial base for the production of strategic and critical minerals; and
- The United States must accept some risk in the form of aiding domestic investment opportunities.

The Senate Committee on Energy and Natural Resources held a hearing on S. 1317, the American Mineral Security Act, on May 14, 2019, "Examining the Path to Achieving Mineral Security."[12] Two congressional hearings were held on critical minerals in the 115th Congress: one on December 12, 2017, by the House Natural Resources Subcommittee on Energy and Mineral Resources on "Examining Consequences of America's Dependence on Foreign Minerals," and a

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impacts of potential supply restrictions, and on the horizontal axis the potential supply risks associated with geology, ecology, technology, economics, and the political environment. Many analysts have used the criticality matrix to rank the criticality of selected minerals.

[10] National Research Council, Minerals, Critical Minerals, and the U.S. Economy, National Academies Press, 2008; U.S. DOE, *Critical Materials Strategy,* December 2011; American Physical Society and The Materials Research Society, *Energy Critical Elements, Securing Materials for Emerging Technologies*, 2011.

[11] N.T. Nassar, Xiaoyue Du, and T.E. Graedel, "Criticality of the Rare Earth Elements," *Journal of Industrial Ecology*, v. 19, no. 6, 2015.

[12] For hearing details, see https://www.energy.senate.gov/public/index.cfm/hearings-and-business-meetings?ID=559FE490-CA2A-4A56-9C30-F5ED5B0C7780.

second on July 17, 2018, by the Senate Committee on Energy and Natural Resources to examine the final list of critical minerals.[13]

Public resource and minerals policy options are among the options for creating reliable supply chains of these minerals and metals. The Administration and many in Congress have combined concerns over import dependence and developing domestic supply into a number of policy proposals that would aim to streamline the permitting process for domestic critical mineral production and possibly open more public lands to mineral exploration. A 2017 U.S. Geological Survey (USGS) report, *Critical Mineral Resources of the United States*, presents its mineral assessments of 23 critical minerals for the nation as a whole, but does not break out what might be available on federal lands, where many of the legislative proposals are directed.[14] Others in Congress want to be sure that if a more efficient permitting process is put in place, all the mechanisms for environmental protection and public input are left intact, if not enhanced.[15]

## The Scope of This Report

This report examines the process by which the critical minerals list was drafted, why these minerals are being classified as critical, where production is taking place, and countries holding the largest reserves of critical minerals. There is a brief review of materials required for lithium-ion batteries and solar and wind energy systems, and a discussion of supply chains for rare earth elements and tantalum. This report also presents the statutory and regulatory framework for domestic mineral production, legislative proposals, and congressional and executive branch initiatives (and actions), as well as an overview of U.S. critical mineral policy.

There are a number of policy issues related to U.S. critical minerals, such as trade policy (particularly with China) and conflict minerals,[16] just to name two. Treatment of these issues is beyond the scope of this report.

# Brief History of U.S. Critical Minerals and Materials Policy

Minerals for national security have long been a concern in the United States. For example, there were concerns over shortages of lead for bullets during the early 1800s. There were material shortages during WWII and the Korean War that contributed to the formation of the National Defense Stockpile. The current stockpile of strategic and critical minerals and materials was developed to address national emergencies related to national security and defense issues; it was not established as an economic stockpile.

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[13] For hearing details, see House Natural Resources Subcommittee on Energy and Mineral Resources hearing, https://docs.house.gov/committee/calendar/byevent.aspx?eventID=106736 (December 21, 2017); and Senate Energy and Natural Resources hearing, https://www.energy.senate.gov/public/index.cfm/2018/7/full-committee-hearing-to-examine-the-department-of-the-interior-s-final-list-of-critical-minerals (July 17, 2018).

[14] USGS, Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply, Professional Paper 1802, 2017, http://doi.org/10.3133/pp1802.

[15] U.S. House of Representatives, Committee on Natural Resources, H.Rept. 112-583, *Report Together with Dissenting Views on H.R. 4402: National Strategic and Critical Minerals Production Act of 2012*.

[16] Conflict minerals are defined as ores that when sold or traded have played key roles in helping to fuel conflict and extensive human rights abuses in far eastern Democratic Republic of the Congo (DRC). The main conflict minerals are tantalum, tin, tungsten, and gold (also known as "3TGs").

In 1939, after Germany invaded Poland, the Strategic Materials Act of 1939 (50 U.S.C. §98, P.L. 76-117) provided the authority for the United States to establish a strategic materials stockpile. Then in 1946, the Strategic and Critical Materials Stockpiling Act was enacted so that the United States would be prepared for national military emergencies and to prevent material shortages. The 1946 Act (P.L. 79-520) set a target of $2.1 billion of materials to be spent for the stockpile.[17] Congress increased funding for supplying the stockpile to $4 billion over four years (1950-1953). The Defense Production Act of 1950 (50 U.S.C. §4501, P.L.81-774) added $8.4 billion to expand supplies of strategic and critical materials.[18]

In 1951, President Truman formed the Materials Policy Commission (also known as the Paley Commission) which recommended a stockpile for strategic materials and the use of lower cost foreign sources of supply. President Eisenhower established long term stockpile goals during a national emergency as a way to prevent the shortages that occurred during World War II and the Korean War.

The initial time frame for the duration of the emergency the stockpile was intended to cover was three years, but later reduced to one year. However, with the passage of the 1979 Strategic and Critical Minerals Stockpiling Revision Act (P.L. 96-41), a three-year military contingency was reestablished as a criterion for stockpile goals. Funding for the stockpile was subsequently increased to $20 billion.

During the Cold-War era, the National Defense Stockpile (NDS) had an inventory of large quantities of strategic and critical materials. In the early 1990s, after the Cold War with the Soviet Union, the U.S. Congress supported an upgrade and modernization of the strategic materials stockpile. By FY1993, the National Defense Authorization Act (NDAA) for Fiscal Year 1993 (P.L. 102-484) authorized a major sell-off of 44 obsolete and excess materials in the stockpile such as aluminum metal, ferrochromium, ferromanganese, cobalt, nickel, silver, tin, and zinc.[19] The majority of these materials were sold to the private sector. Proceeds of these sales were transferred to other federal or Department of Defense (DOD) programs.

## The Modern Day Stockpile

In 1988, the Secretary of Defense delegated the management of the stockpile to the Undersecretary of Defense for Acquisition, Technology, and Logistics and operational activities of the NDS to the Director of the Defense Logistics Agency (DLA). Among other duties, the DLA manages the day-to-day operations of the stockpile program.

The current stockpile contains 37 materials valued at $1.152 billion.[20] Much of the materials are processed metals or other downstream products such as, columbium (niobium) metal ingots, germanium metal, tantalum metal, metal scrap, beryllium rods, quartz crystals, and titanium metal.

Congressional action starting in 2014 led to the acquisition of REEs and other materials for the NDS. The DLA is acquiring six materials based on the NDAA for FY2014: Ferro-niobium;

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[17] The stockpile consisted of many base metals and minerals such as copper, lead, zinc, aluminum, chromite, tin, and quartz among others.

[18] CRS Report 95-5, *The National Defense Stockpile: A Historical Perspective*, by Alfred R. Greenwood, December 14, 1994, p. 2 (out of print; available to congressional clients upon request).

[19] GAO, NSIAD-93-60, p. 12. Also, see pp. 37-38 for list of proposed disposals.

[20] U.S. Department of Defense, Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Strategic and Critical Materials Operations Report to Congress*, January 2017, pp. 7-8.

dysprosium metal; yttrium oxide; cadmium-zinc-telluride substrates; lithium-ion precursors; and triamino-trinitrobezene.[21]

In FY2016, the DLA made progress on its FY2014 goals for high-purity yttrium and dysprosium metal. The NDS initiated a program to develop economical methods to recycle REEs from scrap and waste. The goal was to investigate technologies to determine whether recycling is feasible in the United States.[22] Work on this project goal is ongoing.

In addition to acquisitions and upgrades, Congress approved a DOD proposal to sell materials determined to be in excess of program needs as part of the FY2017 NDAA (P.L. 114-328).

# Initiatives and Actions on Critical Minerals

## Development of the Critical Minerals List

E.O. 13817, "A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals," published on December 20, 2017, tasked the Department of the Interior (DOI) to coordinate with other executive branch agencies in establishing a draft list of critical minerals published in the *Federal Register* 60 days from the initial order. On December 17, 2017, the Secretary of the Interior issued Secretarial Order (No. 3359, "Critical Mineral Independence and Security") directing the U.S. Geological Survey (USGS) and Bureau of Land Management (BLM) to develop the list.[23] DOI agencies, with cooperation from others (e.g., DOD, DOE, and members of the National Science and Technology Council Subcommittee on Critical and Strategic Mineral Supply Chains [CSMSC]), developed using specific criteria an unranked list of 35 minerals. The Secretary of the Interior issued the final list of critical minerals in May 2018.[24]

The USGS used the critical mineral early warning methodology developed by the CSMSC as its starting point for the draft list.[25] One of the metrics used was the Herfindahl-Hirschman Index which measures the concentration of production by country or company. Another metric used was the Worldwide Governance Index, which was used to ascertain the political volatility of a country and is based on six indicators.[26] The early warning methodology is a two-stage process. The first stage uses the geometric mean of three indicators to determine if the mineral is potentially critical: supply risk (production concentration), production growth (change in market size and geological resources), and market dynamics (price changes). The second stage uses the results of the first stage to determine which of the potentially critical minerals require an in-depth analysis.

In developing the list, the USGS also relied on its net import reliance data;[27] its Professional Paper 1802, (referenced in footnote 14 of this report); NDAA FY2018 (P.L. 115-91) from DOD; U.S. Energy Information Administration (EIA) data on uranium; and the input of several subject

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[21] Ibid, p. 9.

[22] Ibid, p. 6.

[23] Secretary's Order 3359, "Critical Mineral Independence and Security" (December 21, 2017), https://www.doi.gov/sites/doi.gov/files/uploads/so_criticalminerals.pdf.

[24] 83 *Federal Register* 23295, May 18, 2018.

[25] Draft Critical Mineral List—Summary of Methodology and Background Information—U.S. Geological Survey Technical Input Document in Response to Secretarial Order No. 3359, Open File Report 2018-102, DOI/USGS.

[26] Those six indicators are accountability, political stability and absence of violence, government effectiveness, regulatory quality, rule of law, and control of corruption.

[27] "Net import reliance" refers to the percentage of a mineral commodity used by the United States that must be imported from another country.

matter experts. The USGS established a threshold above which the minerals were deemed to be critical. Some minerals below the threshold that had critical applications were also included on the list. The USGS used a supply chain analysis to include some metals, such as aluminum, because the United States is 100% import reliant on bauxite, the primary source mineral for aluminum production.

The unranked list of 35 minerals does not indicate the levels of criticality for some versus others. This is of note because some earlier studies had shown that the supplies of platinum group metals, REEs, niobium, and manganese are potentially far more vulnerable than lithium, titanium, and vanadium.[28] Further, the REEs are not broken out by element. Some of the heavy rare earth elements have been shown to be more critical and vulnerable to supply shortages than some of the lighter elements.

## Other Federal Critical Minerals Actions

In addition to developing a critical minerals list, Congress and various executive branch entities have invested in other actions related to critical minerals. Investment in research and development (R&D) is considered by many experts (e.g., DOE, MIT, and elsewhere)[29] to play a critical role in the support for and development of new technologies that would address three primary areas: greater efficiencies in materials use; substitutes or alternatives for critical minerals; and recycling of critical minerals. Below is a summary of selected current federal R&D, and information and analysis activities on critical minerals at federal agencies.

### Department of Energy[30]

#### *Critical Materials Hub*

DOE's FY2019 budget request included funding for R&D on rare earth and other critical materials. DOE's "Critical Materials Hub" is conducting R&D on a number of critical material challenges, including "end of life" recycling to help mitigate any possible supply chain disruptions of REEs. Funding for the program was at $25 million, each year, for the past three fiscal years (FY2017-FY2019), as FY2019 is the third year of its second five-year research phase.[31] Congress approved this level of support despite the Trump Administration's proposal to eliminate the program in FY2019 and FY2020. The Critical Materials Hub is funded under the Advanced Manufacturing R&D Consortia within DOE's Energy Efficiency and Renewable Energy Program.

#### *REEs from Coal*

Additionally, in FY2019 DOE proposed to launch its Critical Materials Initiative within the Fossil Energy R&D program under the Advanced Coal Energy Systems program to examine new technologies to recover REEs from coal and coal byproducts. Congress had appropriated funding

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[28] National Research Council, *Minerals, Critical Minerals, and the U.S. Economy*, National Academies Press, 2008.

The list is fluid; mineral with low measure of criticality today may have a higher measure of criticality in months or a few years depending on many variables.

[29] See footnote 10 of this report for reports by DOE, MIT, and the National Research Council weighing in on critical minerals.

[30] Budget information on DOE programs obtained from DOE Budget Highlights, FY2010-FY2019 Congressional Budget Request.

[31] The first phase, funded at about $125 million, ran from FY2012 to FY2016.

for this project under the National Energy Technology Lab (NETL) R&D program during the Obama Administration, despite no request for funding. For FY2019, the Trump Administration requested $30 million in funding for the Critical Materials Initiative; Congress elected to support the initiative at $18 million.

### *Critical Minerals Report*

In December 2010 and December 2011, DOE issued *Critical Materials Strategy* reports. These reports examine and provide demand forecasts for rare earths and other elements required for numerous energy and electronic applications.[32] An update on this research is forthcoming, according to DOE.[33]

## Department of the Interior

The National Minerals Information Center housed within the USGS provides an annual summary of critical mineral activity in its Mineral Commodities Summaries report and Minerals Yearbook.[34] The USGS also provides mineral resource assessments and has in 2017 published a study on 23 mineral commodities, all of which have been listed as critical by the Administration.[35] In 2010, the USGS released a report on the rare earth potential in the United States.[36] A 2017 collaboration between the USGS and the State of Alaska issued a report on critical and precious minerals in Alaska[37] and conducted a geospatial analysis identifying critical mineral potential in Alaska.[38] The results of the analysis provided new information on areas of Alaska that might contain deposits of critical minerals.

## Department of Defense

In a DOD-led assessment of the U.S. manufacturing and defense industrial base and supply chain resiliency, there are sections on critical minerals and impacts on national security.[39] The DOD continues to fulfill its stockpile goals for various critical materials and has funded small R&D projects related to rare earths.[40]

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[32] U.S. Department of Energy, *Critical Materials Report*, December 2011.

[33] Personal communication with Diana Bauer, Director of Energy Systems Analysis and Integration, Office of Energy Policy and Systems Analysis, May 16, 2019.

[34] Department of the Interior, USGS, Mineral Commodity Summaries, https://minerals.usgs.gov/minerals/pubs/mcs/; USGS, *Minerals Yearbook*, https://minerals.usgs.gov/minerals/pubs/myb.html.

[35] U.S. Department of the Interior, USGS, *Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply*, Professional Paper 1802, 2017.

[36] U.S. Department of the Interior, USGS, *The Principal Rare Earth Elements Deposits of the United States—A Summary of Deposits and a Global Perspective*. USGS Scientific Investigations Report 2010-5220.

[37] U.S. Department of the Interior, USGS, *Geospatial Analysis Identifies Critical Mineral-Resource Potential in Alaska*, fact sheet, March 2017.

[38] USGS, Geospatial Analysis Identifies Critical Mineral-Resource Potential in Alaska, Fact Sheet 2017-3012, March 2017.

[39] U.S. Department of Defense, *Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency of the United States*, Report to Donald J. Trump by the Interagency Task Force in Fulfillment of Executive Order 13806, September 2018.

[40] For stockpile goals, see footnote 20 of this report. For small grant programs, see ASM International, "Army Research Lab project to develop U.S. supply chain for rare earth elements," June 10, 2014, http://www.asminternational.org/home, and Texas Rare Earth Resources, "U.S. Defense Logistics Agency Awards Texas Rare Earth Resources Strategic Materials Research Contract," September 25, 2015, http://www.marketwired.com/press-release.

In 2009, the Office of Industrial Policy reviewed the rare earth mineral supply chain. The Office of the Secretary of Defense reviewed its National Defense Stockpile and issued a report titled: *Reconfiguration of the National Defense Stockpile Report to Congress*.[41]

As part of the Ike Skelton National Defense Authorization Act for FY2011 (Section 843 of P.L. 111-383), the DOD was required by Congress to prepare an "Assessment and Plan for Critical Rare Earth Materials in Defense Applications" and report to a number of congressional committees by July 6, 2011.[42] A DOD assessment and congressional appropriations supported new stockpile goals for HREEs.

In an April 2012 interview with *Bloomberg News*, the DOD head of industrial policy stated that DOD uses less than 5% of the rare earths used in the United States, and that DOD was closely monitoring the rare earth materials market for any projected shortfalls or failures to meet mission requirements.[43]

## White House Office of Science and Technology Policy

In 2010, the White House Office of Science and Technology Policy (OSTP) formed an Interagency Working Group on Critical and Strategic Minerals Supply Chains.[44] The group's focus is to establish critical mineral prioritization and to serve as an early warning mechanism for shortfalls, to establish federal R&D priorities, to review domestic and global policies related to critical and strategic minerals (e.g., stockpiling, recycling, trade, etc.), and to ensure the transparency of information.

The White House National Science and Technology Council Subcommittee on Critical and Strategic Mineral Supply Chains produced a report describing a screening methodology for assessing critical minerals.[45] The "early warning screening" approach for material supply problems was first included as a U.S. policy goal in the National Materials and Minerals Policy, Research and Development Act of 1980 (30 U.S.C. §1601) (P.L. 96-479).[46]

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[41] Department of Defense, Reconfiguration of the National Defense Stockpile Report to Congress, April 2009. https://www.dla.mil/Portals/104/Documents/StrategicMaterials/Reports/Operations%20Report/FY16%20Operations%20Report_FINAL_Website%20Version.pdf.

[42] Letter from the Congress of the United States, directed to The Honorable Leon E. Panetta, U.S. Department of Defense, August 5, 2011.

[43] Ratnam, Gopal, "Rare Earth Shortage Would Spur Pentagon to Action," *Bloomberg News*, April 9, 2012, http://www.bloomberg.com/news/2012-04-09/rare-earths-shortage-would-spur-pentagon-to-action.html.

[44] The group's participants include representatives from the Department of Energy, the Department of Defense, the Department of the Interior, the Department of Commerce, the Environmental Protection Agency, the Department of State, the Department of Justice, and the Office of the U.S. Trade Representative.

[45] National Science and Technology Council, Committee on Environment Natural Resources, and Sustainability, Subcommittee on Critical and Strategic Mineral Supply Chains, *Assessment of Critical Minerals: Screening Methodology and Initial Applications*, March 2016, https://www.whitehouse.gov/sites/whitehouse.gov/files/images/CSMSC%20Assessment%20of%20Critical%20Minerals%20Report%202016-03-16%20FINAL.pdf.

[46] U.S. Governmental Accountability Office, *Advanced Technologies: Strengthened Federal Approach Needed to Help Identify and Mitigate Supply Risks for Critical Raw Materials*, GAO-16-699, September 2016, p. 9.

# Supply: Critical Minerals Production and Resources

## Production/Supply

According to the 2019 USGS Mineral Commodity Summaries report,[47] China ranked as the number one producer of 16 minerals and metals listed as critical. While there are no single monopoly producers in China, as a nation China is a near-monopoly producer of yttrium (99%), gallium (94%), magnesium metal (87%), tungsten (82%), bismuth (80%), and rare earth elements (80%). China also produces roughly 60% or more of the world's graphite, germanium, tellurium, and fluorspar. In 2017, the United States had no primary production of 22 minerals and byproduct production of five minerals on the critical minerals list. There is some U.S. primary production of nine minerals, and the United States is a leading producer of beryllium and helium (see **Table 2**, **Figure 1**).

China had gains in production that far outpaced the rest of the world. By 2003, China had already dominated in the production of graphite, indium, magnesium compounds, magnesium metal, REEs, tungsten, vanadium, and yttrium; it solidified its number one producing status of these minerals about a decade later. Chinese producers are seeking not only to expand their production capacity at home but to continue to negotiate long-term supply agreements or create equity partnerships around the world, particularly in Africa (cobalt and tantalum), Australia (lithium), and South America (lithium).[48]

The dominant producing region for chromium, manganese, platinum group metals, tantalum, and cobalt is southern Africa. Brazil produces 88% of the world's niobium, and Australia accounts for 58% of the world's lithium production, according to USGS data. According to USGS data, critical minerals dominated by a single producing country include: niobium from Brazil, cobalt from the Democratic Republic of the Congo (DRC), platinum group metals from South Africa, REEs (including yttrium), and tungsten from China.

### Production of Minerals and Mineral Resource Potential on Federal Land

Current mineral production information on federal land is not available from the DOI. The Government Accountability Office (GAO) noted in a 2008, report that the DOI does not have the authority to collect information from mine operators on the amount of minerals produced or the amount of mineral reserves on public lands, and there is no requirement for operators to report production information to the federal government.[49]

However, previous DOI[50] and GAO[51] reports completed in the early 1990s reported that gold, copper, silver, molybdenum, and lead were the five dominant minerals produced on federal lands under the General Mining Law of 1872 (30 U.S.C. §§21-54). Currently, the vast majority of

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[47] USGS, *Mineral Commodity Summaries 2019*, February 2019, https://minerals.usgs.gov/minerals/pubs/mcs/2019/mcs2019.pdf. The annual report used 2017 data; 2018 is estimated.

[48] Elizabeth C. Economy and Michael Levi, *By All Means Necessary, How China's Resource Quest Is Changing the World*, Council of Foreign Relations, 2014; The Society for Mining, Metallurgy, and Exploration (SMME), "Annual Mining Review," *Mining Engineering*, vol. 60, no. 5, May 2018, p. 47, http://www.miningengineeringmagazine.com.

[49] GAO, *Hardrock Mining: Information on State Royalties and Trends in Mineral Imports and Exports*, GAO-08-849R, July 21, 2008.

[50] U.S. Department of the Interior, Task Force on Mining Royalties, *Economic Implications of a Royalty System for Hardrock Minerals*, August 16, 1993.

[51] GAO, *Mineral Resources: Value of Hardrock Minerals Extracted From and Remaining on Federal Lands*, GAO/rced-92-192, August 1992.

mining activity on federal lands is for gold in Nevada, based on past DOI information. The DOI report also showed that federal lands mineral production represented about 6% of the value of all minerals produced in the United States. There is uncertainty over how much production of minerals occur on federal lands. Most minerals listed as critical are locatable on U.S. federal lands under the General Mining Law of 1872; comprehensive information on which minerals are located and produced on federal land remains incomplete. An unanswered question is the extent that critical mineral resource potential exists on federal land. Until more is known through mineral resource assessments of federal land, it will be hard to determine the impact of opening federal land to development that is now withdrawn from mineral development.

Some mining advocates support developing domestic supply chains in critical minerals. Other stakeholders support a diversified portfolio of reliable suppliers, particularly if foreign sources are more economic or if domestic production (or manufacturing) is uneconomic, not technically feasible, or environmentally unacceptable.

## Byproduct Supply

There are six critical minerals that are classified as byproducts: indium, tellurium, gallium, germanium, cobalt, and rhenium.[52] There are important differences between main product and byproduct supply. Byproduct supply is limited by the output of the main product. For example, the amount of indium recoverable in zinc cannot be more than the quantity of indium in the zinc ore. As production of the main product continues, the byproduct supply may be constrained because a higher price of the byproduct does not increase its supply in the immediate term. Even in the long run, the amount of byproduct that can be economically extracted from the ore is limited. That is, byproduct supply is relatively inelastic (i.e., not particularly responsive to price increases of the byproduct). For byproducts, it is the price of the main product, not the byproduct that stimulates efforts to increase supply. But a high enough byproduct price may encourage new technologies that allow for greater byproduct recovery from the main product. There may be occasions when the main product supply contains more byproduct than is needed to meet demand. If this were the case, byproduct processing facilities would need to be expanded so that byproduct processing capacity would not be a limiting factor in byproduct supply.

Another important difference between byproduct and main product is that only costs associated with byproduct production affect byproduct supply. Joint costs (costs associated with production of both products) are borne by the main product and do not influence byproduct supply. Byproducts are typically available at lower costs then the same product produced elsewhere as a main product, (e.g., REEs produced as a byproduct of iron ore in China would have lower production costs than would REEs produced elsewhere in the world as a main product).

Byproducts, typically, are not free goods, meaning that there are costs associated with their production. Byproducts could be without cost if two conditions are met: (1) production of main product must require the separation of the byproduct, and (2) no further processing of the byproduct is required after separation.

## Global Mineral Production

**Table 2** provides data on the global production of critical minerals and the leading producing countries. The data shows that production for nearly all of the critical minerals has increased

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[52] A byproduct is a secondary or additional product associated with production of the main/primary ore and is limited by the output of the main/primary product. Co-products share joint production costs as no single co-product can support mine development costs alone.

since 2000, many of which have doubled (e.g., chromium, indium, lithium, manganese, niobium, and tantalum) or tripled (e.g., cobalt, gallium, and tellurium) in the amount produced.

### Table 2. Critical Minerals: Global Production and Leading Producers, Selected Years

(data in metric tons (mt) or million metric tons (m mt) unless otherwise noted)

| | Global Production | | | | |
|---|---|---|---|---|---|
| **Mineral** | **2000** | **2010** | **2017** | **Leading Producers in 2017** | **Comments** |
| **Aluminum (bauxite)** | 135.0 m mt | 209.0 m mt | 309 m mt | Australia (28.5%),<br>China (22.6),<br>Brazil (12.5%),<br>Guinea (15%),<br>Others (21.4%) | No bauxite produced in the United States |
| **Antimony** | 118,000 mt | 167,000 mt | 137,000 mt | China (72%),<br>Others (28%) | Relatively little U.S. production; none reported in 2017 |
| **Arsenic** | 33,900 mt | 52,800 mt | 34,600 mt | China (69%),<br>Others (31%) | No U.S. production |
| **Barite** | 6.2 m mt | 7.85 m mt | 8.7 m mt | China (37%),<br>India (18%),<br>Others (45%) | No U.S. production |
| **Beryllium** | 280 mt | 205 mt | 210 mt | U.S. (71%),<br>Others (29%) | U.S. is a net exporter |
| **Bismuth** | 5,880 mt | 8,900 mt | 17,100 mt | China (73%),<br>Others (27%) | No U.S. production |
| **Cesium** | NA | NA | NA | NA | No U.S. production |
| **Chromium** | 14.4 m mt | 23.7 m mt | 30.2 m mt | South Africa (46.2%),<br>Kazakhstan (12.9%),<br>Others (40.9%) | No U.S. production |
| **Cobalt** | 33,300 mt | 89,500 mt | 120 m mt | DRC (61%),<br>Others (39%) | Some U.S. production as byproduct of copper |
| **Fluorspar** | 4.5 m mt | 6.0 m mt | 5.7 m mt | China (61%),<br>Mexico (18%),<br>Others (21%) | No U.S. production |
| **Gallium** | 100,000 kg | 182,000 kg | 320,000 kg | China (94%),<br>Others (6%) | Small amount of low-grade gallium as a U.S. byproduct |
| **Germanium** | 71,000 kg | 118,000 kg | 106,000 kg | China (57%),<br>Others (43%) | Small amount of U.S. production as byproduct of zinc ore |
| **Graphite (Natural)** | 571,000 mt | 925,000 mt | 897,000 mt | China (75%),<br>Brazil (10%),<br>Others (15%) | No U.S. production |
| **Hafnium** | NA | NA | NA | NA | See zirconium |
| **Helium** | 98 million cubic meters (mcm) | 75 mcm | 160 mcm | U.S. (57%),<br>Qatar (28%),<br>Algeria (8.7%),<br>Others (6.3%) | U.S. is a leading producer |

| Mineral | Global Production 2000 | Global Production 2010 | Global Production 2017 | Leading Producers in 2017 | Comments |
|---|---|---|---|---|---|
| **Indium** | 335 mt | 609 mt | 714 mt | China (40%),<br>South Korea (31.5%),<br>Others (27.5%) | Data is for refinery production |
| **Lithium** | 14,000 mt | 28,100 mt | 38,000 mt | Australia (58%),<br>Chile (21%),<br>China (9.8%),<br>Argentina (8.3%),<br>Others (2.9%) | Some U.S. production |
| **Magnesium Metal** | 368,000 mt | 757,000 mt | 1.1 m mt | China (89%),<br>Others (11%) | Some U.S. production |
| **Manganese** | 7.28 m mt | 13.9 m mt | 17.3 m mt | South Africa (31%),<br>Australia (16%),<br>Gabon (12.7%),<br>China (9.8%),<br>Others (30.5%) | No U.S. production |
| **Niobium** | 32,600 mt | 62,900 mt | 69,100 mt | Brazil (88%),<br>Others (12%) | No U.S. production |
| **Platinum** | 155,000 kg | 192,000 kg | 199,000 kg | South Africa (72%),<br>Russia (11%) | The data in this row represents platinum only. Palladium production of 225,000 kg is split between two major producers – South Africa (39%) and Russia (38%). Small amount of U.S. production |
| **Potash** | 25.3 m mt | 33.7 m mt | 41.4 m mt | Canada (29%),<br>Russia (17.6%),<br>China (13%),<br>Others (40.4%) | Relatively little U.S. production (roughly 1%) |
| **Rare Earth Elements** | 83,500 mt | 133,000 mt | 132,000 mt | China (80%),<br>Australia (14%),<br>Others (6%) | No production in 2017. The USGS estimates U.S. production to be around 15,000 mt in 2018. |
| **Rhenium** | 28,400 kg | 47,200 kg | 51,600 kg | China (55%),<br>Poland (19%),<br>U.S. (17%),<br>Others (9%) | Relatively small amount of U.S. production as byproduct of copper recovery |
| **Rubidium** | NA | NA | NA | NA | No U.S. production |
| **Scandium** | NA | NA | NA | NA | No U.S. production |
| **Strontium** | 520,000 mt | 405,000 mt | 255,000 mt | Spain (35.3%),<br>Mexico (28%),<br>China (19.6%),<br>Iran (15.7%) | No U.S. production |

| | Global Production | | | | |
|---|---|---|---|---|---|
| **Mineral** | **2000** | **2010** | **2017** | **Leading Producers in 2017** | **Comments** |
| **Tantalum** | 836 mt | 681 mt | 1,810 mt | DRC (42%),<br>Rwanda (24%),<br>Nigeria (8.5%),<br>Others (25.5%) | No U.S. production |
| **Tellurium** | 125 mt | NA | 470 mt | China (68%),<br>Japan and Russia about 12% each,<br>Others (9.2%) | Some U.S. production as byproduct of copper and lead recovery |
| **Tin** | 238,000 mt | 256,000 mt | 313,000 mt | China (29.7%),<br>Indonesia (26.5%),<br>Burma (15%),<br>Others (28.8%) | No U.S. production |
| **Titanium** | 4.3 m mt | 6.4 m mt | 5.5 m mt | South Africa (18%),<br>China (15%),<br>Canada (16%),<br>Australia (13%) | Relatively small amount of U.S. production |
| **Tungsten** | 37,400 mt | 68,800 mt | 82,100 mt | China (82%),<br>Others (18%) | No U.S. production |
| **Uranium** | NA | 1,506 mt | 1,021 mt | Kazakhstan (39%,<br>Canada (22.5%),<br>Australia (10%) | Some U.S. production |
| **Vanadium** | 43,000 mt | 57,600 mt | 71,200 mt | China (56%),<br>Russia (25%),<br>South Africa (11.2%) | No U.S. production |
| **Zirconium** | 1.04 m mt | 1.25 m mt | 1.55 m mt | Australia (32.5%),<br>South Africa (24.3%),<br>China (9%),<br>Others (34.2%) | Some U.S. production |

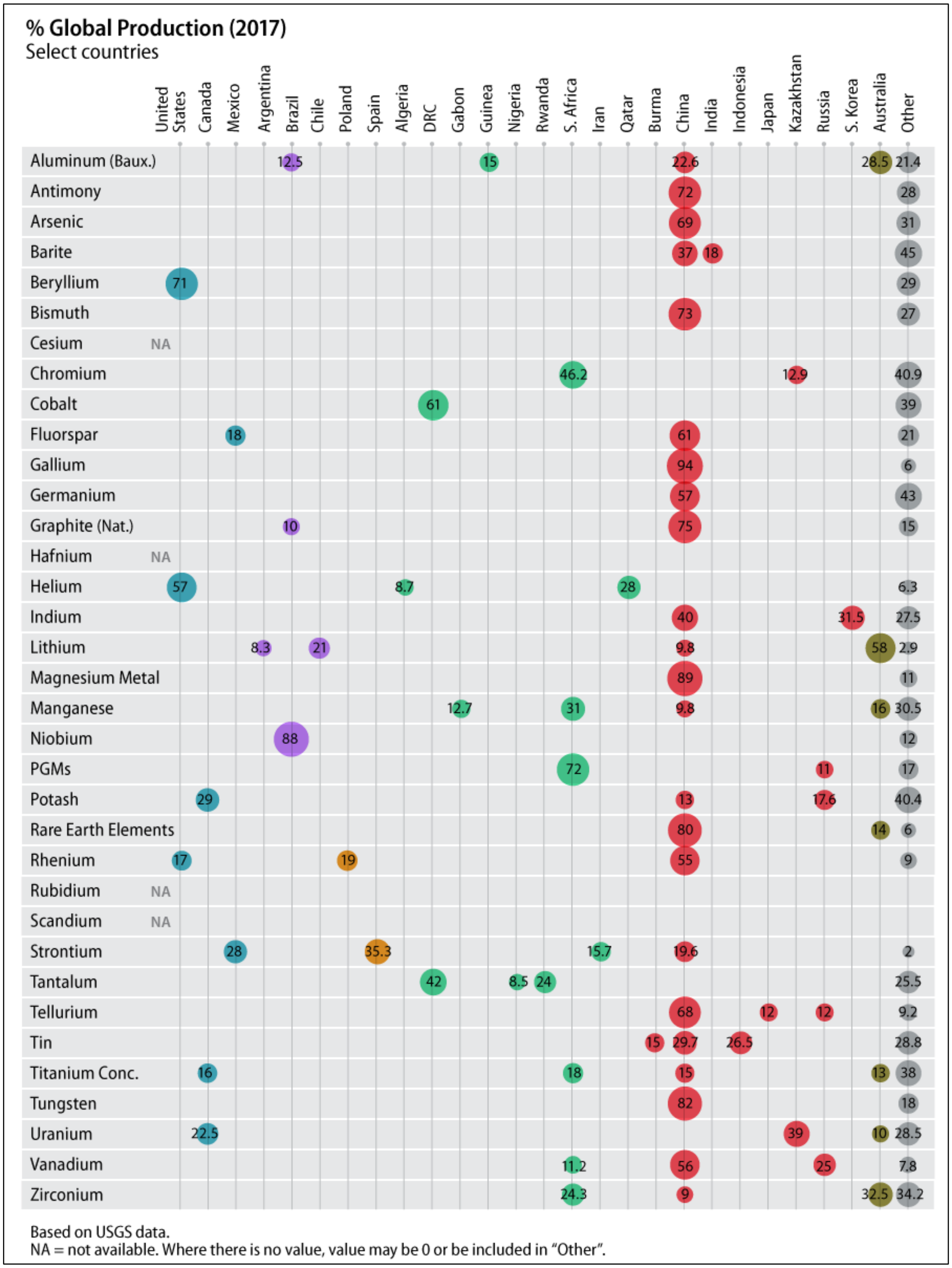
**Source:** USGS, Mineral Commodity Summaries, 2019. Data on uranium from the Energy Information Administration.

**Notes:** kg = kilograms; NA = not available. DRC = Democratic Republic of Congo; U.S. = United States.

The table is using 2017 data from the USGS Mineral Commodity Summaries, 2019 report because the report provides actual data for 2017 and only estimated data for 2018.

Some countries may be listed as leading producers but not listed as leading reserve holders of the same mineral listed in **Table 4**.

## Figure 1. Critical Minerals: Global Production (2017)



% Global Production (2017)
Select countries

| | United States | Canada | Mexico | Argentina | Brazil | Chile | Poland | Spain | Algeria | DRC | Gabon | Guinea | Nigeria | Rwanda | S. Africa | Iran | Qatar | Burma | China | India | Indonesia | Japan | Kazakhstan | Russia | S. Korea | Australia | Other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aluminum (Baux.) | | | | | 12.5 | | | | | | | 15 | | | | | | | 22.6 | | | | | | | 28.5 | 21.4 |
| Antimony | | | | | | | | | | | | | | | | | | | 72 | | | | | | | | 28 |
| Arsenic | | | | | | | | | | | | | | | | | | | 69 | | | | | | | | 31 |
| Barite | | | | | | | | | | | | | | | | | | | 37 | 18 | | | | | | | 45 |
| Beryllium | 71 | | | | | | | | | | | | | | | | | | | | | | | | | | 29 |
| Bismuth | | | | | | | | | | | | | | | | | | | 73 | | | | | | | | 27 |
| Cesium | NA | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Chromium | | | | | | | | | | | | | | | 46.2 | | | | | | | | 12.9 | | | | 40.9 |
| Cobalt | | | | | | | | | | 61 | | | | | | | | | | | | | | | | | 39 |
| Fluorspar | | | 18 | | | | | | | | | | | | | | | | 61 | | | | | | | | 21 |
| Gallium | | | | | | | | | | | | | | | | | | | 94 | | | | | | | | 6 |
| Germanium | | | | | | | | | | | | | | | | | | | 57 | | | | | | | | 43 |
| Graphite (Nat.) | | | | | 10 | | | | | | | | | | | | | | 75 | | | | | | | | 15 |
| Hafnium | NA | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Helium | 57 | | | | | | | | 8.7 | | | | | | | | 28 | | | | | | | | | | 6.3 |
| Indium | | | | | | | | | | | | | | | | | | | 40 | | | | | | 31.5 | | 27.5 |
| Lithium | | | | 8.3 | | 21 | | | | | | | | | | | | | 9.8 | | | | | | | 58 | 2.9 |
| Magnesium Metal | | | | | | | | | | | | | | | | | | | 89 | | | | | | | | 11 |
| Manganese | | | | | | | | | | | 12.7 | | | | 31 | | | | 9.8 | | | | | | | 16 | 30.5 |
| Niobium | | | | | 88 | | | | | | | | | | | | | | | | | | | | | | 12 |
| PGMs | | | | | | | | | | | | | | | 72 | | | | | | | | | 11 | | | 17 |
| Potash | | 29 | | | | | | | | | | | | | | | | | 13 | | | | | 17.6 | | | 40.4 |
| Rare Earth Elements | | | | | | | | | | | | | | | | | | | 80 | | | | | | | 14 | 6 |
| Rhenium | 17 | | | | | | 19 | | | | | | | | | | | | 55 | | | | | | | | 9 |
| Rubidium | NA | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Scandium | NA | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Strontium | | | 28 | | | | | 35.3 | | | | | | | | 15.7 | | | 19.6 | | | | | | | | 2 |
| Tantalum | | | | | | | | | | 42 | | | 8.5 | 24 | | | | | | | | | | | | | 25.5 |
| Tellurium | | | | | | | | | | | | | | | | | | | 68 | | | 12 | | 12 | | | 9.2 |
| Tin | | | | | | | | | | | | | | | | | | 15 | 29.7 | | 26.5 | | | | | | 28.8 |
| Titanium Conc. | | 16 | | | | | | | | | | | | | 18 | | | | 15 | | | | | | | 13 | 38 |
| Tungsten | | | | | | | | | | | | | | | | | | | 82 | | | | | | | | 18 |
| Uranium | | 22.5 | | | | | | | | | | | | | | | | | | | | | 39 | | | 10 | 28.5 |
| Vanadium | | | | | | | | | | | | | | | 11.2 | | | | 56 | | | | | 25 | | | 7.8 |
| Zirconium | | | | | | | | | | | | | | | 24.3 | | | | 9 | | | | | | | 32.5 | 34.2 |

Based on USGS data.
NA = not available. Where there is no value, value may be 0 or be included in "Other".

**Source:** Figure created by CRS based on USGS Mineral Commodity Summaries, 2019.

Notes: Color codes: Blue = North America; Purple = South America; Orange = Europe; Green = Africa &Middle East; Red = Asia and Russia; Dark Green = Australia; and Gray = Other countries that are not specifically mentioned in the previous columns.

## Secondary Recovery of Critical Minerals in the United States

Secondary recovery can occur from waste products during the metal refining and manufacturing process or from discarded end use products. As indicated in **Table 3**, in the United States, there is little to no production or reserves and little to no secondary recovery currently for many (but not all) of the critical minerals of high net import reliance.

There is a significant amount of secondary recovery in the United States of nine critical minerals according to the USGS Mineral Commodity Summaries: aluminum, chromium, cobalt, gallium, indium, magnesium metal, platinum group metals, tin, and titanium. While U.S. capacity for secondary recovery of metals and other materials has not grown much between 1997 and 2016, rates of recovery have fluctuated annually. Steel is the most recycled material in the United States. There are well established infrastructures, for old and new scrap, for selected metals such as steel, copper, aluminum, cobalt, and chromium.[53] For many other metals, such as manganese, REEs, and niobium, little-to-no recycling takes place in the United States because it is either economically or technically not viable.[54] Countries in the European Union, Japan, and South Korea are strengthening their efforts in secondary recovery as emerging markets (e.g., China and India) seek to secure greater access to primary materials.

The quantity of most metal and materials available for recycling will likely continue to meet a fraction of demand, particularly if demand is rising. The rate of availability (i.e., based on the useful life of the product) puts a limit on how much can be recycled. According to the National Research Council, the primary impediment facing secondary recovery in the United States is the lack of clear policies and programs at all levels of government to embrace the recovery of materials.[55] Without a national mandate, the National Research Council report indicates that state and local governments are likely to continue a "patchwork" of programs and policies.[56]

**Table 3** illustrates the point that there is very little secondary recovery of critical minerals and metals in the United States.[57] The data could indicate that there is a lack of infrastructure for secondary recovery of critical minerals and metals. Economic and technological factors must also be evaluated as to whether the benefits outweigh the costs for recovering certain materials, particularly the small amounts of critical minerals that may be available for secondary recovery (from manufacturing waste or end use products). Additional R&D may be needed to determine whether secondary recovery of the most import-dependent minerals could be increased to reduce U.S. import reliance.

In 2018, the USGS reports that for base metals and precious metals the recycling rate is much different. For example, the recycling rates were 28% for aluminum, 35% for copper, 52% for nickel, 18% for silver, and 25% for zinc. In 2014, steel in the auto industry was recycled at 106%—more steel than was used for domestic manufacturing. The recycling rate of steel is 90% for appliances containing steel and 67% for steel cans.

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[53] Old scrap is material in discarded or obsolete products that have reached the end of their life. New scrap is material generated from processing primary materials. Almost all new scrap is recycled, and thus, it is not always considered a substitute for primary material.

[54] Manganese used in making steel is typically recycled as part of ferrous and nonferrous steel scrap.

[55] National Research Council, *Minerals, Critical Minerals, and the U.S. Economy*, Washington, DC, 2008.

[56] Ibid.

[57] Base metals are any of the nonprecious metals. Precious metals include gold, silver, and platinum.

### Table 3. U.S. Secondary Recovery of Critical Minerals, 2017

| Mineral | Secondary Recovery as % of U.S. Apparent Consumption (unless otherwise noted) | Comments |
|---|---|---|
| **Aluminum** | 28% | |
| **Antimony** | Unknown | Majority of U.S. supply is from secondary sources |
| **Arsenic** | None reported | |
| **Barite** | None reported | |
| **Beryllium** | 20%-25% | |
| **Bismuth** | <5% | Both old and new scrap |
| **Cesium** | Unknown | Some formate brines reprocessed |
| **Chromium** | 29% | |
| **Cobalt** | 29% | No primary production; secondary recovery of purchased scrap |
| **Fluorspar** | Unknown | Very little |
| **Gallium** | Unknown | No old scrap, significant new scrap recovered |
| **Germanium** | NA | About 30% worldwide |
| **Graphite** | Unknown | Not much because of raw material abundance |
| **Hafnium** | Negligible | |
| **Helium** | NA | Very little |
| **Indium** | Significant domestic recycling but amount not known | On a global scale, secondary production greater than primary production |
| **Lithium** | Very little | DOE grant was awarded in 2009 for a recycling facility. A U.S. recycling facility for lithium-ion vehicle batteries opened in 2015. |
| **Magnesium metal** | 120,000 tons | Old and new scrap |
| **Manganese** | Negligible | |
| **Niobium** | none reported | May be as high as 20% according to USGS. |
| **Platinum** | Known for platinum only | 120,000 kilograms of platinum group metals recovered globally from old and new scrap |
| **Potash** | None | |
| **REEs** | Very little | |
| **Rhenium** | Some | |
| **Rubidium** | None | |
| **Scandium** | None | |
| **Strontium** | None | |

| Mineral | Secondary Recovery as % of U.S. Apparent Consumption (unless otherwise noted) | Comments |
|---|---|---|
| **Tantalum** | New scrap recovered but amount unknown | May be as much as 10% according to USGS. |
| **Tellurium** | Very little | |
| **Tin** | 25% | 12,300 tons, mostly old scrap |
| **Titanium** | 69,600 tons scrap metal | |
| **Tungsten** | NA | Old and new scrap |
| **Uranium** | NA | |
| **Vanadium** | NA | Significant amount from spent chemical process catalysts |
| **Zirconium** | Some | |

**Source:** USGS Mineral Commodity Summaries, 2019.

**Notes:** NA = not available. Unknown = no data reported by the USGS. The table is using 2017 data from the USGS Mineral Commodity Summaries, 2019 report because the USGS 2019 summaries provides actual data for 2017 and only estimated data for 2018.

## Reserves and Resources

There is a distinction between what is described when using the terms *reserves* and *resources* in the context of minerals. Reserves are quantities of mineral resources anticipated to be recovered from known deposits from a given date forward. All reserve estimates involve some degree of uncertainty. Proved reserves are the quantities of minerals estimated with reasonable certainty to be commercially recoverable from known deposits under current economic conditions, operating methods, and government regulations. Current economic conditions include prices and costs prevailing at the time of the estimate. Estimates of proved reserves do not include reserves appreciation.

Resources are concentrations in the earth's crust of naturally occurring minerals that can conceivably be discovered and recovered. Undiscovered technically recoverable resources are minerals that may be produced as a consequence of natural means, or other secondary recovery methods, but without any consideration of economic viability. They are primarily located outside of known deposits.

### U.S. Critical Mineral Reserves and Resources

Regarding reserves, the USGS lists little to no reserves in all 35 of the critical minerals except for helium and beryllium and significant resource potential in only tungsten, lithium, vanadium, uranium,[58] and REEs. Of the 14 critical minerals listed as 100% import dependent, the USGS lists some reserves for two: REEs and vanadium (see **Table 4** and **Figure 2**).[59]

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[58] Uranium data obtained from the Energy Information Administration.

[59] For example, note the following minerals with some reserves and or production: arsenic—small reserves; asbestos—small reserves; bauxite—small production and reserves; fluorspar—byproduct of lime; thorium ore—some reserves, no U.S. production; yttrium—some reserves, little production; rare earths—some production, large reserves; rubidium and

Regarding resources, USGS identifies some resource potential for cesium, manganese, and niobium. There are byproduct resources of cobalt, germanium, tellurium, and rhenium that are associated with main products such as copper, zinc, and bauxite (see **Table 4**). The USGS is uncertain about U.S. and global reserves of several critical minerals as not enough data are available according to the USGS.[60]

## Global Critical Mineral Reserves and Resources

According to the USGS, at the global level, there are significant or abundant resource potential for the critical minerals for which the agency has data, which is some but not all of the critical minerals. Global resource potential is either unknown or uncertain for bismuth, cesium, germanium, indium, and tellurium. Most of the germanium, indium, and tellurium are obtained as byproducts of base metal production.

China leads the world in reserves in seven critical minerals, including antimony, REEs, strontium, tellurium, tin, tungsten, and vanadium (see **Table 4**). China is among the top three reserve holders in barite, fluorspar, graphite, magnesium compounds, and titanium.

**Table 4** provides available information on global resources of critical minerals, as well as information on the size of the reserves. **Figure 2** provides information on the regional distribution of the reserves.

### Table 4. Critical Minerals: Global Resources and Reserves, 2017

(data in metric tons unless otherwise noted)

| Mineral | Resources | Reserves | Leading Reserve Holders by Country | Comments |
|---|---|---|---|---|
| **Aluminum (Bauxite)** | Abundant global resources; U.S. resources not significant | 30 b mt | Guinea (24.6%), Australia (20.6%), Vietnam (12.3%), Brazil (8.6%), Jamaica (6.6%) | China has 3% of reserves but produces almost 23% of bauxite. |
| **Antimony** | Some resource potential in Alaska, Montana and Idaho. Principal global resources in Australia, Bolivia, China and Mexico | 1.5 b mt | China (32%), Russia (23%), Bolivia (21%) | The United States has about 4% of global reserves |
| **Arsenic** | Unknown | NA | NA | No U.S. reserves; world reserves unavailable but estimated at about 20x current global production. |
| **Barite** | 2 billion tons worldwide; significant U.S. resources | 320 m mt | Kazakhstan (26.5%), India (16%), China (11%), Turkey (11%), Others (35.5%) | No U.S. reserves |

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thallium—no production, small reserves. China produces 99% of the world's yttrium. There is no planned or current production of bauxite or fluorspar on public lands. The USGS indicates U.S. mineral reserves of beryllium, helium, lithium, platinum group metals, REEs, tungsten, and uranium.

[60] See the USGS 1802 Study and Mineral Commodity Studies.

| Mineral | Resources | Reserves | Leading Reserve Holders by Country | Comments |
|---|---|---|---|---|
| **Beryllium** | 60% of world's estimated100,000 mt of resources in the U.S. | NA | NA | |
| **Bismuth** | NA | NA | NA | No U.S. reserves |
| **Cesium** | Some U.S. resource potential, world resources unknown | 90,000 mt | Zimbabwe (67%), Namibia (33%) | No U.S. reserves |
| **Chromium** | Small U.S. resources<br>Significant world resources | 560 m mt | Kazakhstan (41%), South Africa (35.7%), India (17.8%), Others (5.5%) | |
| **Cobalt** | Small U.S. resources<br>25 m mt terrestrial; 120 m mt seabed nodules | 6.9 b mt | DRC (49%), Australia (17.4%), Cuba (7.2%), Others (26.4%) | |
| **Fluorspar** | 500 million tons worldwide; significant resources in phosphate rock in the United States | 310 m mt | Mexico (21.9%), China (13.5%), South Africa (13.2%), Others (51.4%) | No stand-alone U.S. reserves, but significant amounts contained in phosphate rock |
| **Gallium** | Significant resources worldwide in bauxite and zinc but only 10% recovered; sub-economic resources in the U.S. contained in bauxite | NA | Unknown | |
| **Germanium** | Uncertain | NA | Unknown | |
| **Graphite** | >800 m mt inferred resources. Small U.S. resources | 300 m mt | Turkey (30%), China (24.3%), Brazil (24%), Others (21.7%) | |
| **Hafnium** | NA | NA | NA | |
| **Helium** | 20,600 million cubic meters in the United States | NA | U.S., Algeria, Russia | U.S. is a world leader in reserves with 3,900 million cubic meters |
| **Indium** | NA | NA | NA | NA |
| **Lithium** | 47 m mt globally;<br>6.9 m mt in the United States | 14 m mt | Chile (57%), Australia (19.3%), Argentina (14.3%) China (7%), Others (2.4%) | Small U.S. reserves but significant resources |
| **Magnesium compounds** | Billions of tons worldwide | 8.5 b mt | Russia (27%), North Korea (27%), China (11.8%), Others (34.2%) | |

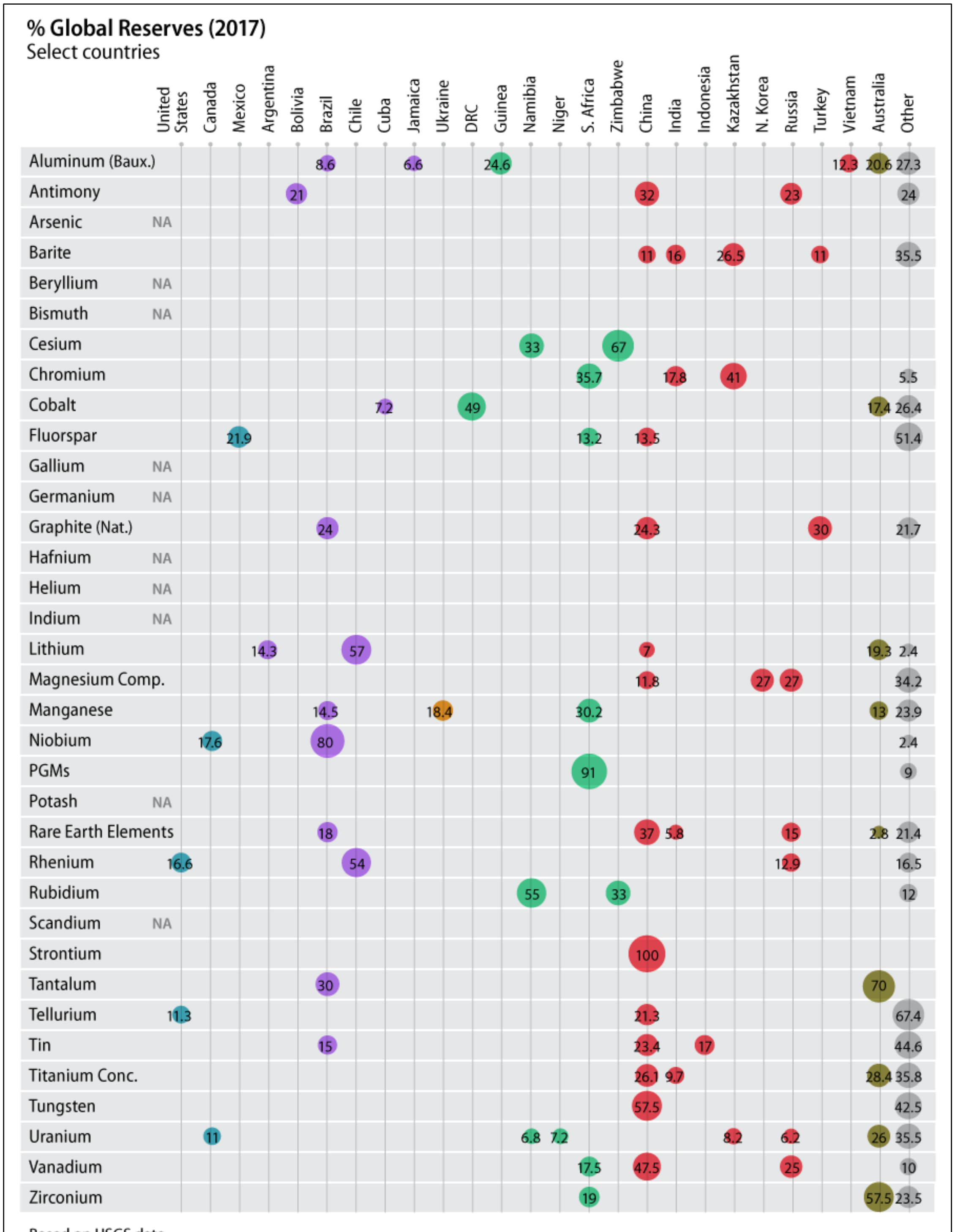
| Mineral | Resources | Reserves | Leading Reserve Holders by Country | Comments |
|---|---|---|---|---|
| **Manganese** | Low grade resources in the United States;<br>78% of global resources in South Africa | 760 m mt | South Africa (30.2%), Ukraine (18.4%), Brazil (14.5%), Australia (13%), Others (23.9%) | |
| **Niobium** | Resources more than adequate supply to meet global demand;<br>Low grade resources in the U.S. | 9.1 m mt | Brazil (80%), Canada (17.6%), Others (2.4%) | |
| **Platinum Group Metals** | 100 million kilograms | 69,000 mt | South Africa (91%) | Some U.S. reserves. Most of the world's resources are in South Africa |
| **Potash** | 7 billion tons in the United States, 250 b mt worldwide | NA | Canada, Belarus, Russia | USGS did not report total world reserves |
| **Rare Earth Elements** | Abundant but not always in minable concentrations; significant resources in the United States | 120 m mt | China (37%), Brazil (18%), Russia (15%), India (5.8%), Australia (2.8%) | Some U.S. reserves |
| **Rhenium** | Significant U.S. and world resources | 2,400 mt | Chile (54%), United States (16.6%), Russia (12.9%), Others (16.5%) | |
| **Rubidium** | Significant world resources | 90,000 mt | Namibia (55%), Zimbabwe (33%), Others (12%) | |
| **Scandium** | Abundant world resources | | Unknown | |
| **Strontium** | About 1 billion tons | 6.8 b mt | China (percent of total unknown) | USGS did not report reserve data for other countries |
| **Tantalum** | Some resources in the U.S. | >110,000 mt | Australia (70%), Brazil (30%) | Data unavailable for other countries, even though 80% of production is in Africa |
| **Tellurium** | NA | 31,000 mt | China (21.3%), United States (11.3%), Others (67.4%) | Some U.S. reserves contained in copper and lead ores |
| **Tin** | Abundant worldwide; some resources in the U.S., mostly in Alaska | 4.7 m mt | China (23.4%), Indonesia 17%), Brazil (15%), Others (44.6%) | No U.S. reserves reported |

| Mineral | Resources | Reserves | Leading Reserve Holders by Country | Comments |
|---|---|---|---|---|
| **Titanium** | 2 billion mt of titanium mineral concentrate worldwide | 880 m mt | Australia (28.4%), China (26.1%), India 9.7%), Others (35.8%) | Data in this row does not include rutile (a related mineral). Small amount of U.S. reserves |
| **Tungsten** | Abundant global resources; the United States has significant tungsten resources | 3.2 m mt | China (57.5%), Others(42.5%) | |
| **Uranium** | 7,641,600 tons worldwide | 4.4 m mt | Australia (26%), Canada (11%) Kazakhstan (8.2%), Niger (7.2%), Namibia (6.8%), Russia (6.2%) | |
| **Vanadium** | 63 million tons worldwide; significant resources in the United States | 20 m mt | China (47.5%), Russia (25%), South Africa (17.5%), Others (10%) | Small U.S. reserves |
| **Zirconium** | Substantial zirconium resources as part of titanium and phosphate rock | 73 m mt | Australia (57.5%), South Africa (19%), Others (23.5%) | |

**Source:** USGS, Mineral Commodity Summaries, 2019. Data on uranium from the Energy Information Administration, 2018 Domestic Uranium Production Report, May 2019.

**Notes:** mt = metric tons; m mt = million metric tons; kg = kilograms; b mt = billion metric tons; NA = not available.

**Figure 2. Critical Minerals: Global Reserves (2017)**



Based on USGS data.
NA = not available. Where there is no value, value may be 0 or be included in "Other".

**Source:** Figure created by CRS based on USGS data, Mineral Commodity Summaries, 2019.

Note: Color codes: Blue = North America; Purple = South America; Orange = Europe; Green = Africa; Red = Asia and Russia; Dark Green = Australia; and Gray = Other countries that are not specifically mentioned in the previous columns. USGS reports Strontium reserve data only for China.

## Mineral Exploration

Exploration expenditures for minerals in the United States have been rising since 2001. The United States has maintained about 8% of the annual exploration budget for minerals worldwide from 1997 to 2017. In 2017, these expenditures in the United States were at 225 exploration sites (out of 2,317 exploration sites worldwide); 41% of the U.S. sites were in Nevada, 14% in Alaska, and 11% in Arizona.[61] It can take many years for mining firms to find and bring an economic deposit into production. Thus, it is important for the industry to keep mineral projects in the exploration-development process.

In general, mineral exploration in the United States remains focused on a few minerals, most of which not considered critical. Exploration activity in the western states is primarily for gold, copper, molybdenum, silver, tungsten, and uranium. There had been some reported interest in expanding silica sand operations in Nevada, developing a copper-cobalt-gold project in Idaho on Forest Service land,[62] and thorium production on federal lands along the Idaho/Montana border.

Globally, Canada leads with the most active exploration sites, mostly for gold and base metals (over 500 sites), followed by Australia (about 500 sites) with investments mostly in gold, base metals, and uranium.

### Locations and Minerals Being Explored

The locations and minerals being explored can be shape how critical mineral supply chains are or may evolve. These supply chains have relevance to various policy questions, including what is the long-term investment strategy in the United States to develop mineral extraction and downstream metal and manufacturing capacity; and, if the focus is on building a reliable supply chain, what part of that supply chain makes sense to develop in the United States?

There have been recent new additions to the annual USGS mineral exploration review. Data on lithium, niobium, rare earth elements, and tungsten are now included. Data for other minerals such as scandium, vanadium, and yttrium have been compiled since 2014.

The big global exploration story is about lithium. In 2016, global exploration dollars for lithium, cobalt, and gold rose significantly. The lithium exploration expenditures increased four-fold since 2015 and active exploration sites rose from 56 in 2012 to 167 sites in 2017. Lithium exploration expenditures, for example, rose from $22 million in 2015 to $128 million in 2017 as the number of lithium exploration companies grew from 23 in 2015 to 125 in 2017. The price of lithium rose by more than 150% from 2007 to 2016 and sits at 83% higher than its 10-year average. The number of cobalt sites rose by 121% since 2016.[63]

In the United States in 2017, gold remains in the top spot for the number of exploration sites (47%) followed by copper (12%), then lithium with 7% of the sites. USGS noted that there is continued interest in graphite, REEs, and tungsten in the United States, but the most notable sites are in gold exploration. Overall, 54% of the sites actively explored in the United States are for

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[61] SMME, *Annual Mining Review*, p. 47.

[62] 71 *Federal Register* 64237, "Idaho Cobalt Project Plan of Operations, Salmon Challis National Forest, Lemhi County, ID," November 1, 2006, http://www.govinfo.gov/app/details/FR-2006-11-01/E6-18362.

[63] SMME, *Annual Mining Review*, p. 35.

gold and silver and 22% for base metals. Worldwide, gold or silver accounts for 84% of the sites actively explored.[64]

The USGS reported that the United States has accounted for about 7% to 8% of overall global exploration budget over the past 10 years (about $611 million in 2017). However, the annual review is not exactly a country-by-country comparison because the USGS uses regions such as Latin America and Africa to compare with individual countries such as Canada, Australia, and the United States. The mineral exploration budget directed at U.S. mineral deposits is above that of China (5%), Russia (4%), and many countries in Latin America.[65]

Latin America attracts the most exploration dollars with $2.4 billion, most of which are for gold and silver (58%) followed by base metals at 22% of exploration expenditures. Chile has seen the most investment in Latin America, followed by Peru. Latin America is home to 70% of the world's known lithium deposits, known as the "lithium triangle" consisting of Chile, Argentina, and Bolivia. In Argentina, lithium exploration sites account for 44% of exploration expenditures followed by gold/silver at 42%, and copper at 9%. Lithium is most developed in Chile because of its superior infrastructure for mining. Most exploration projects in Chile are for copper (49%) and gold (29%).[66]

There has been an uptick in lithium exploration in Australia as well. China invested $650 million (in U.S. dollars) in Australia in 2016, looking for lithium and gold, primarily.[67] As ore grades decline at known reserve locations, many exploration companies are searching for high-grade deposits in remote locations, including the ocean floor.

# Demand: Critical Mineral End Uses and U.S. Import Reliance

## Demand for Critical Minerals

The demand for mineral commodities is a derived demand which differs from consumer goods demand. Minerals are used as inputs for the production of goods and services. For example, the demand for rare earth elements is derived from the production of their end-use products or use, such as flat panel displays, automobiles, or catalysts. As a result, the demand for critical minerals depends on the strength of the demand of the final products for which they are inputs. An increase in the demand for the final product will lead to an increase in demand for critical minerals (or their substitutes).

In the case of derived demand, when mineral and metal prices rise, the extent to which the quantity of a material declines depends largely on the degree to which its price increase can be passed on to the final consumer, as well as the proportion of the final good's price that is accounted for by the mineral/metal commodity. That is, it might depend on the amount of critical mineral or metal used per unit of output. The major variables that determine the growth in demand for consumer goods are price and income growth.[68]

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[64] Ibid, p. 40.

[65] Ibid, p. 49.

[66] Ibid, pp. 40-43.

[67] Ibid, p. 50.

[68] Gary A. Campbell, "Theory of Mineral Demand," *Economics of the Mineral Industries*, American Institute of Mining, Metallurgical, and Petroleum Engineering, 1985.

## U.S. and Global Demand

U.S. demand has declined for some critical minerals, and for others, demand has increased but not as much (in relative terms) as the increase in global supply. For example, over the past 20 years consumption fell for aluminum, chromium, manganese, platinum group metals, REEs, titanium, and tantalum, among others, and demand grew slowly for lithium, germanium, and graphite. Only for tellurium, niobium, and indium did the United States experience rapid demand growth (relative to supply).[69] Some of the demand drivers in recent decades for critical minerals include permanent magnets using REEs, batteries using cobalt and lithium, automobiles and electronics using tantalum and niobium, and vanadium for steel production.

Global demand data for each of the minerals listed as critical were not available at the time of this writing. Global demand data could shed more light on where the minerals are being used for metal alloying, the manufacturing of component parts, and final products. Embodied metals (those that are imported as final products) are not counted as demand.[70]

Many critical minerals, (e.g., manganese, tungsten, and vanadium) are used for steelmaking and infrastructure projects, such as roads, housing, rail lines, and electric power grids. Others (e.g., REEs, lithium, indium, tantalum, gallium, and germanium) are used in the manufacturing of high-value electronic products, such as laptops and batteries, renewable energy systems, and other consumer goods, such as automobiles and appliances (see **Table 5**).

## Demand for Critical Minerals in China

There has been a surge in demand for critical minerals in China. China's demand for natural resources rose to historic levels and may continue to rise over the long term, even with a slowing economy. In the recent past, China has been the fastest growing market for niobium, and in 2010 accounted for 25% of world niobium consumption.[71] Manganese consumption rose from about 2,200 metric tons (mt) in 2003 to about 9,000 mt in 2008.[72] China's demand for vanadium paralleled that of steel demand and rose 13% annually from 2003 to 2009. In general, vanadium demand in China is projected to double from 2010 to 2025 because of its continued use in steelmaking (including new steel-hardening requirements) and because of the potential for application in new battery technology used for large-scale renewable energy storage (e.g., vanadium-redux flow battery-VRFB).[73] In 2010, China accounted for 85% of chrome ore import demand[74] and is the world's leading producer of steel (accounting for over half the world's production in 2017 based on the most recent data).[75] Chromium is a major production input for stainless steel. China's chrome imports will likely continue to increase as stainless steel demand at the global level remains a big part of China's high-valued exports, urbanization, and future industrial practices.

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[69] USGS Mineral Commodity Summaries, Various Years, 1997–2019.

[70] Embodied minerals/metals are those embedded in the end use product such as an imported laptop or automobile.

[71] IAMGOLD Corporation, "Niobium 101," March 28, 2012.

[72] Shaw River Manganese Limited, "Manganese Fact Sheet," 2010, http://www.shawriver.com.au.

[73] Schauss, Steven, "A Bull Market Storm Brewing for Vanadium," January 2, 2019, http://www.mining.com/web/bull-market-storm-brewing-vanadium.

[74] International Chromium Development Association, "Industrial Minerals," *Mining Engineering,* June 2011.

[75] USGS, Mineral Commodity Summaries, 2019.

Overall, in 2017, China's cobalt smelters accounted for 60% of global supply, and 77% of cobalt demand in China went into batteries.[76] In 2017, China accounted for about 25% of platinum demand, primarily used in jewelry making, and 26% of palladium demand, much of which is used in catalytic converters in automobiles.[77]

In order for this increasing demand scenario in China to play out, the cities would need to fill up with enough people who are making high enough wages to support the economic growth that China is seeking. It is uncertain whether such a high level of consumer demand will materialize. China's economic growth has slowed considerably in the recent past from around 10% annually in the first decade of the 2000s, to around 6% in 2014.[78] However, China's demand for minerals will continue to put pressure on U.S. access to reliable supplies.

## U.S. Imports of Strategic and Critical Minerals

Aside from a small amount of recycling, the United States is 100% import reliant on 14 minerals on the critical minerals list, minerals that provide critical support for the U.S. economy and national security such as, graphite, manganese, niobium, rare earths, and tantalum, among others. The United States is more than 75% import reliant on an additional 10 critical minerals, including antimony, barite, bauxite, bismuth, potash, rhenium, tellurium, tin, titanium concentrate, and uranium.

The United States has increased its mineral imports from China over the past 20 years. Although the United States has diversified its sources for some of its material requirements since 1997, the United States imports significant quantities of critical minerals and metals and is dependent on China as either a primary or major provider of raw materials and several metals as of 2017 (see **Table 5** and **Figure 3**).

While import reliance may be a cause for concern (and high levels of import reliance potentially a security risk), high import reliance is not necessarily the best measure, or even a good measure, of supply risk. A more relevant measure may be the reliability of the suppliers. The supply risk for potash or bauxite, for example, may not be the same as that for REEs or niobium due to the multiplicity of potential sources. There are a number of factors that affect the availability of mineral supplies that may have little to do with import reliance. A company that is the sole supplier, or a single country as a primary source, with export restrictions, would likely constitute supply risks. But any number of bottlenecks that might arise among both domestic and foreign producers, such as limited electric power, skilled labor shortages, equipment shortages, labor unrest, weather or transportation delays, and opposition on environmental policy grounds, could also pose supply risks. Any of these above-mentioned potential supply disruptions could raise costs or prices, and exacerbate the tightness of supplies. For other minerals, such as iron ore and molybdenum, the United States is self-sufficient. For aluminum, uranium, potash, cesium, and rubidium, the United States' chief trading partner is Canada, a stable ally. Also, U.S. companies have invested in overseas operations—for example, copper and bauxite mines—and, thus, U.S. supply sources for some materials are diversified, of higher quality, or lower cost, and located in

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[76] "Global and China Cobalt Market Report, 2018-2023 Featuring 5 Chinese and 14 Global Manufacturers," News Provided by Research and Markets, November 9, 2018, https://www.prnewswire.com/news-releases/global-and-china-cobalt.

[77] Johnson Matthey, *PGM Market Report*, February 2018.

[78] Wright, Andrew, "This Is How China's Economy Has Changed in the Last 10 Years," World Economic Forum, June 22, 2016.

countries that have extensive reserves and production capacity. Such conditions may not always exist in the United States, even when resources are present.

### Table 5. Critical Minerals: Major End Uses and Net U.S. Import Reliance

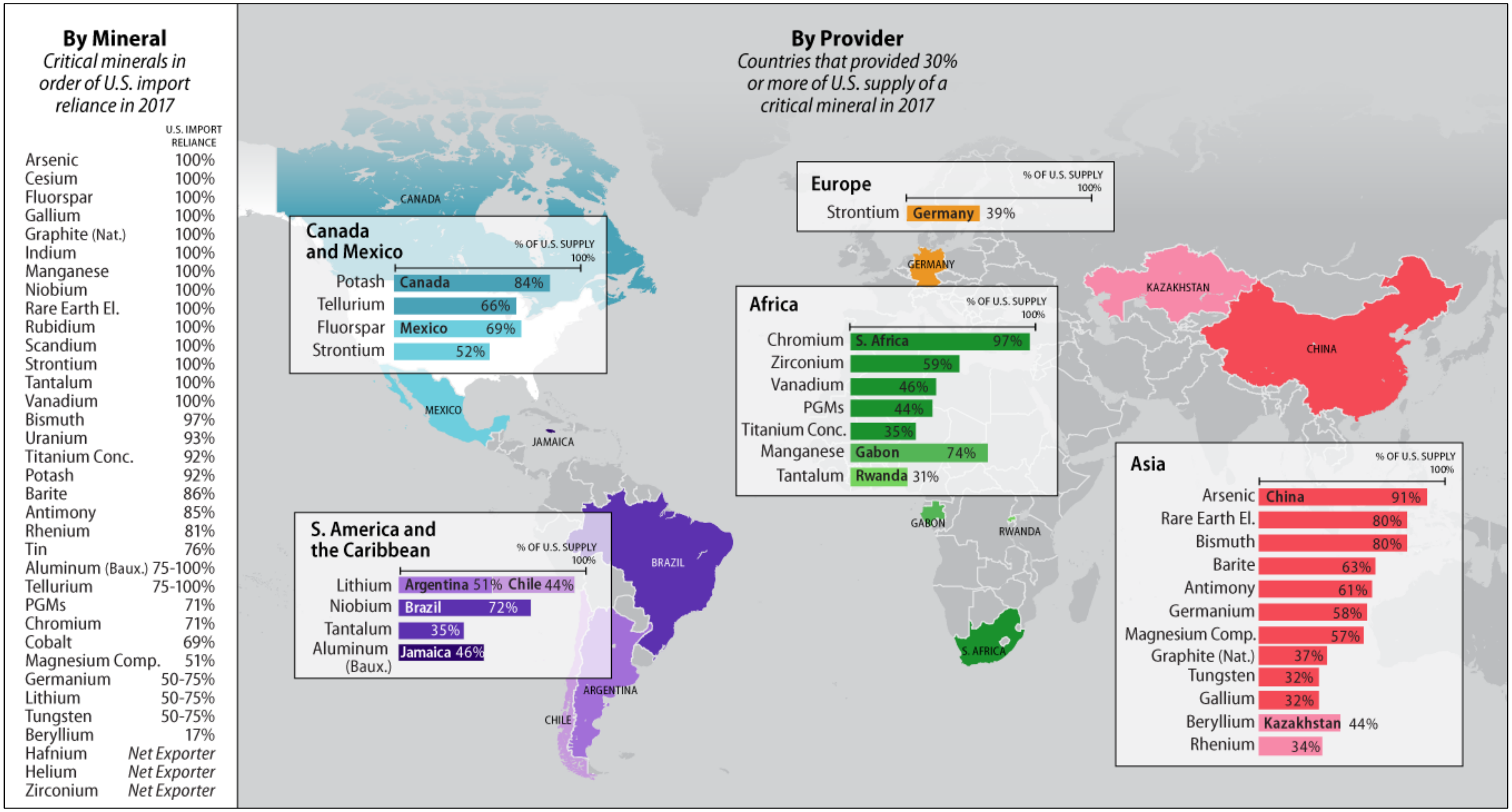
| Mineral | Major End Uses | Import Reliance (%) | Major Sources | Comments |
|---|---|---|---|---|
| **Aluminum (Bauxite)** | transportation, packaging, building, electrical | >75 | Jamaica (46%), Brazil (25%), Guinea (15%), Other (14%) | The data reflect the import reliance for bauxite, the source mineral for aluminum |
| **Antimony** | ceramics, glass, and rubber products, fire retardant | 85 | China (61%), Other (39%) | Major sources are for antimony oxide |
| **Arsenic** | lead storage batteries, herbicides, insecticides, military applications | 100 | China (91%) | Import of arsenic metal |
| **Barite** | filler, extender, and weighing agent in paint, plastics and rubber | 86 | China (63%), India (14%), Others (23%) | |
| **Beryllium** | auto and consumer electronics, defense applications | 17 | Kazakhstan (44%), Japan (14%), Others (42%) | |
| **Bismuth** | additives for lead-free pipe fittings | 97 | China (80%), Others (20%) | |
| **Cesium** | photoelectric cells, and energy conversion devices | 100 | Canada | According to USGS, Most imports are from Canada, but percentage from Canada unavailable |
| **Chromium** | transportation, packaging, building, electrical | 71 | South Africa (97%) | Import reliance for chromite ore |
| **Cobalt** | super alloys, aircraft engines, batteries, permanent magnets | 69 | Norway (18%), China (12%), Japan (12%), Others (58%) | These imports reflect cobalt contained in metal, oxides and salts |
| **Fluorspar** | used in processing aluminum, and uranium | 100 | Mexico (69%), Vietnam (10%), South Africa (8%), Other (13%) | |
| **Gallium** | integrated circuits (in high-tech equipment), light emitting diodes (LEDs), solar cells | 100 | China (32%), UK (28%), Germany (15%), Ukraine (14%), Other (11%) | |
| **Germanium** | fiber optics, infrared optics, solar cells, other solar energy applications | >50 | China (58%), Belgium (26%), Other (14%) | Import reliance for germanium metal |
| **Graphite (Natural)** | steelmaking, refractory applications, foundry operations, brake linings | 100 | China (37%), Mexico (29%), Canada (17%), Other (17%) | |

| Mineral | Major End Uses | Import Reliance (%) | Major Sources | Comments |
|---|---|---|---|---|
| **Hafnium** | super alloys | NA | Germany, France, UK | Percentage from each country unavailable |
| **Helium** | lifting gas, lab applications, MRI, welding | — |  | United States is a net exporter |
| **Indium** | electrical conduction, liquid crystal displays (LCDs), solar cells and photovoltaics | 100 | China (27%), Canada (22%), Other (51%) |  |
| **Lithium** | rechargeable batteries, ceramics, glass, chemical compounds | >50 | Argentina (51%), Chile (44%), Others (4%) |  |
| **Magnesium Compounds** | Agriculture, chemicals, construction, and industrial applications | 51 | China (57%), Canada (22%), Others (21%) |  |
| **Manganese** | production of steel and other metals | 100 | Gabon (74%), South Africa (13%), Australia (8%), Others (5%) |  |
| **Niobium** | steel and super alloys | 100 | Brazil (72%), Canada (18%), Others (10%) | Imports of niobium include ore and concentrate, niobium oxides, ferroniobium, and niobium metal |
| **Platinum Group Metals** | auto catalysts, fuel cells, jewelry | 71 | South Africa (44%), Germany (15%), UK (10%). Others (31%) | This row represents platinum only. The United States is 38% import reliant on palladium most of which comes from Russia and South Africa |
| **Potash** | fertilizer, chemical industry applications | 92 | Canada (84%) |  |
| **Rare Earth Elements** | permanent magnets, petroleum refining, glass, lasers, steel alloys, fluorescent lighting | 100 | China (80%) |  |
| **Rhenium** | super alloys in high temperature turbine engine components and petroleum-reforming catalysts | 81 | Kazakhstan (34%), Canada (19%), South Korea (13%), Germany (10%), Others (24%) |  |
| **Rubidium** | biomedical research, electronics, specialty glass | 100 | Canada | Percentage from Canada unavailable |

| Mineral | Major End Uses | Import Reliance (%) | Major Sources | Comments |
|---|---|---|---|---|
| **Scandium** | Ceramics, electronics, lasers, radioactive isotopes, lighting | 100 | Mostly from China, Europe, Japan, and Russia | Percentage from each country unavailable |
| **Strontium** | additive in drilling fluids for oil and gas wells | 100 | Mexico (52%), Germany (39%), Others (9%) | |
| **Tantalum** | capacitors for electronic devices | 100 | Brazil (35%), Rwanda (31%),<br>Australia (15%), Others (19%) | |
| **Tellurium** | photovoltaic panels, solar cells, thermoelectric devices | >75 | Canada (66%), China (27%), Others (7%) | |
| **Tin** | Chemicals, tinplate, solder and alloys | 76 | Indonesia (23%), Malaysia (23%), Peru (22%), Bolivia (17%), Others (15%) | |
| **Titanium Concentrate** | aerospace applications | 92 | South Africa (35%), Australia (27%), Canada (12%), Mozambique (11%), Others (15%) | |
| **Tungsten** | cutting tools, wear-resistant materials used in construction and metal making | >50 | China (32%), Germany (9%), Bolivia (9%), Canada (8%), Others (42%) | |
| **Uranium** | fuel for nuclear reactors | 93% | Canada, Australia, Russia | The United States supplied 7% of the uranium purchased by U.S. power plants in 2017. |
| **Vanadium** | steelmaking, aerospace applications | 100 | South Africa (46%), Russia (18%), Brazil (13%), China (10%), Others (13%) | |
| **Zirconium** | Used in ceramics, foundry sand, refractories, and abrasives | — | South Africa (59%), Australia (22%), Senegal (14%) | The United States is a net exporter |

**Source:** USGS, Mineral Commodity Summaries, 2019.
**Note:** > = greater than.

**Figure 3. Critical Minerals: Net U.S. Import Reliance (2017)**



**Source:** Figure created by CRS based on USGS Minerals Commodities Summaries data, 2019.
**Note:** Countries listed in the bar graph represent the leading supplier of U.S. imports.

# Materials Analysis of Critical Minerals Content in Finished Products and Systems

Materials analysis is a useful tool to better understand various aspects of mineral demand. For example, such analysis can provide information on how material inputs are used in component parts and how components are used in larger systems such as solar arrays, wind turbines, and automobiles. Using a material analysis, an analyst can obtain information on the material intensity of a unit of production.[79] This analysis can lead to manufacturing efficiencies (i.e., getting the same or better performance using fewer materials) or show where and how material substitution, if possible, could occur. Manufacturing firms could then make short-term or long-term adjustments to their production processes.[80]

Even with materials efficiencies, where less metal is used per unit of output, overall demand growth and lack of short-term supply capacity often drives up mineral prices.[81] For example, households in some countries are likely to have multiple units of a variety of products such as laptops, flat panel televisions, and cell phones, etc. And because the materials intensity (small amounts per unit output) of critical minerals is relatively low for most end-use applications, low-cost manufactured goods may contain some high-cost materials.

The remainder of this section of the report provides information on the materials content of lithium-ion batteries, solar energy arrays, wind technologies, and permanent magnets, with a more detailed discussion of the material requirements for wind and solar energy systems.

## Lithium-Ion Batteries

The use of lithium-ion batteries for the rapidly growing electric vehicle market is expected to transform the material requirements for battery technology. Material analysis of lithium-ion batteries would bring to light useful insights on materials composition, cost, technologies, and supply chains. In the case of the lithium-ion (li-ion) battery[82] for electric vehicles, what is the material composition of the battery?[83] In other words, how much cobalt, lithium, nickel, and other materials are needed per battery, how much are the material costs for each battery, and what percent of the total battery manufacturing cost do the materials represent? Then, further, what is the battery cost per electric vehicles? Analysts would want to know the point at which material price increases would warrant a shift in the use of those materials. Other useful insights in materials analysis would be to understand the suite of battery technologies being developed, their manufacturing capacity, and the ownership structure of the supply chain for the materials and the batteries.

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[79] Material intensity is the measure of the mineral input per unit of output in energy or in units over time.

[80] Short-term adjustments are adjustments to production and do not require any major capital investment; long-term adjustments require major capital investment in equipment or facilities.

[81] David Humphreys, "The Great Metals Boom: A Perspective," *Resources Policy*, v. 35, 2010.

[82] Helbig, et al., "Supply Risks Associated with Lithium-ion Battery Materials," *Journal of Cleaner Production*, October 12, 2017 (hereinafter referred to as Helbig 2017).

[83] Material composition of a product (MCP) is a unit of measurement used to study impact of metal/minerals on demand for traditional material. MCP measures the efficiency of converting raw materials into final end use products. The greater the efficiency, the less demand for the material per unit of output.

A 2017 study by a group of battery technology researchers examined the supply risks associated with lithium-ion batteries and other battery technologies to examine the implication for a carbon-reduced environment.[84] The authors posed the question: What are the material requirements for the battery? They identified features of a li-ion battery, e.g., low cost, high energy, and long life. They examined the raw material requirements for li-ion batteries, secondary supply potential, and supply risks associated with an exhaustible resource (e.g., mineral extraction may become uneconomic), the structure of the industry (e.g., whether there is a cartel or a monopoly producer involved), and a surge in demand. They used supply risk indicators discussed earlier, such as the risk of supply reduction, the risk of a surge in demand, market concentration, political stability, substitutability, and recyclability.

The researchers' second step was to determine the supply risk score on the technology level, for each of the six battery types.[85] There is a lithium-cobalt oxide battery which has a high energy density but also a high cobalt content and price. The steep country risk associated with cobalt production in the Democratic Republic of the Congo (DRC) led researchers to look for alternative suppliers and materials that would provide high energy density and long life with less or no cobalt. One example would be to use a manganese-oxide battery, wherein cobalt is partially replaced by nickel and manganese. They pointed out that there are several new battery types that use combinations of lithium, aluminum, cobalt, iron, nickel, copper, graphite, phosphate, titanium, and manganese. The researchers identified lithium as needed for all battery types and graphite used for all except the lithium-iron-phosphate (LFP-LTO) type, which uses titanium instead. They reported that with a market breakthrough (by 2035) in the use of electric vehicles containing lithium battery technology, an annual growth rate of 7.5% is needed for lithium supply and 3% growth rate in cobalt supply to meet electric vehicle demand.[86]

## Solar Energy Arrays and Wind Technologies

In the case of solar arrays and wind turbine technologies, USGS Minerals Information Center conducted a technical analysis of byproduct minerals that are contained in solar energy systems: silver, cadmium, tellurium, indium, gallium, selenium, germanium, and four of the REEs used in wind technologies (dysprosium (Dy), neodymium (Nd), terbium (Te), and praseodymium (Pr)), using Clean Power Plan (CPP) and no-CPP scenarios.[87] USGS concluded that regardless of the scenario, the transition to renewables is very likely to accelerate in the coming decades and that a number of minor metals are likely to be constrained; thus rates of production of those metals would need to be increased to meet demand unless there are manufacturing shifts. The analysis concluded that the supply of heavy REEs used in permanent magnets (currently used in some of the new wind turbines) will not keep pace with demand from multiple end uses. The USGS assumed an aggressive electric vehicle market, the increased use of the magnets in electric vehicles, and new wind turbines' use of permanent magnets containing REEs. There is some

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[84] Helbig 2017. The li-ion battery is used in consumer electronics such as cell phones, laptops, notebooks, power tools, electric vehicles, and grid storage.

[85] Battery types include LCO-C (lithium-cobalt-oxide), LMO-C (lithium manganese oxide), NCA-C (nickel cobalt aluminum), NMC-C (lithium nickel manganese cobalt), LFP-C (lithium iron phosphate), and LFP-LTO (lithium iron phosphate). All battery types use lithium and all except the LFP-LTO use graphite.

[86] Helbig 2017 reports on the study by Marscheider-Weidemann, et al., *Raw Materials for Emerging Technologies*, 2016.

[87] Nassar, et al., *Byproduct Metal Requirements for U.S. Wind and Solar Photovoltaic Electricity Generation Up to 2040 Under Various Clean Power Plan Scenarios*, Applied Energy, 183 (2016) 1209-1226, http://dx.doi.org/10.1016/j.apenergy.2016.08.062. The Clean Power Plan was an Obama Administration rule to cut carbon dioxide emissions by 32% of 2005 levels by 2030.

disagreement over whether significant increases in REEs for magnets that would be used in wind energy systems will occur.[88]

Additionally, USGS concluded that the growth in demand for byproduct metals in solar and wind energy systems would compete with usage in electric and hybrid vehicles, and consumer electronics. The report asserts that a key uncertainty is net material intensity, i.e., the quantity of the byproduct metal required per unit of installed electric generating capacity, minus the amount of recycled material. For solar cells, net material intensity per generating capacity is dependent on the conversion efficiency of solar cells.

Related questions are: Where are the wind turbines and solar arrays being manufactured and which countries and firms would be impacted the most by any disruption in critical mineral supply for these end uses?

## Permanent Magnets

REEs in permanent magnets is another example of how materials analysis for end uses may inform understanding of critical minerals vulnerability. For example, some of the pertinent questions that might be raised with respect to permanent magnets include: How much Dy, Nd, Te, and Pr go into a neodymium-iron-boron (NdFeB) permanent magnet and what fraction of the total cost is each element? What are permanent magnet unit production costs and what portion of the total costs of a wind turbine or an automobile do the permanent magnets represent? And what is the likelihood and the economics of substitution?

## Materials Review of Wind and Solar Energy Systems

Below are simplified examples of material requirements for wind and solar systems.

### Materials for Wind Energy

Based on the Department of Energy Report, *20% Wind Energy by 2030*, wind power installations consist of four major parts: wind tower, rotor, electrical system, and drivetrain (e.g., generator, gearbox, and motor).[89] Most of the common large wind turbines have tower heights over 200 feet and rotor blades as long as 150 feet. The average rated capacity of an onshore wind turbine is between 2.5 megawatts (MW) and 3 MW.[90] DOE lists the following as the most important materials for large-scale manufacturing of wind turbines: steel, fiberglass, resins (for composites and adhesives), core materials, permanent magnets, and copper. Some aluminum and concrete is also required (see **Table 6** below). DOE considers the raw materials for large-scale wind turbines to generally be in ample supply. Turbine manufacturing, however, would be 100% dependent on permanent magnet imports, primarily from China, as that country produces 75% of the world's permanent magnets which contain REEs (assuming certain drivetrains are used). But DOE and other wind power analysts also identify, as a potential concern, the need for increased manufacturing capacity for fiberglass and other components such as generators, and gear boxes. Wind power development trends at the time of the 20% Wind Energy by 2030 study were moving towards lighter-weight materials and high-strength composites such as glass fiber-reinforced

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[88] Lovins, Amory**,** *Clean Energy and Rare Earths: Why Not to Worry*, May 21, 2017, http://thebulletin.org/2017/05/clean-energy-and-rare-earths-why-not-to-worry. The articles states that magnet-free machines can perform any function required in electric vehicles and wind turbines and that the most effective substitute is better auto or turbine design.

[89] U.S. Department of Energy, Energy Efficiency and Renewable Energy*, 20% Wind Energy by 2030, Increasing Wind Energy's Contribution to U.S. Electricity Supply*, July 2008.

[90] Offshore wind farms are deploying much taller structures, with longer blades and greater MW capacity.

plastic and carbon fiber-reinforced plastic. Increased production of fiberglass, commercial-grade carbon fiber, and permanent magnets (containing REEs) would be necessary if the United States were to achieve 20% wind energy by 2030.

Recent analysis indicates that the offshore wind industry could be a major driver for increasing REE demand. There are indications that the larger turbines which are better suited for offshore locations, which also contain REEs, may be more reliable and require less maintenance than onshore turbines.[91]

### Table 6. Selected Materials for Wind Power

| **Turbine Materials** | **U.S. Supply** | **Comments** |
|---|---|---|
| Permanent magnet | No U.S. production, little supply from secondary recovery | China produces nearly 75% of the world's permanent magnets. Significant production increases needed for future wind power needs. |
| Concrete | U.S. production | |
| Steel | U.S. production | |
| **Aluminum** | U.S. production (50% import reliant) | |
| Copper | U.S. production | |
| Glass fiber-reinforced plastic | U.S. production of fiberglass | |
| Carbon fiber-reinforced plastic | U.S. production | Globally, production of commercial grade carbon fiber is about 50 million lbs. per year. Significant production increases needed for future wind power needs. |
| Adhesives (petrochemical based) | U.S. production | |
| Core (petrochemical based) | U.S. production | |
| Battery technology containing the following materials | | |
| Sodium sulfur | U.S. production | |
| Zinc-bromide | U.S. production | |
| Vanadium-redox | No U.S. production or reserves of vanadium | |
| Lithium-ion | Some U.S. production of lithium carbonate, small reserves | |
| Polysulfide-bromide | U.S. production | |

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[91] Fishman, Tomer, and T.E. Graedel, "Impact of the Establishment of U.S. Offshore Wind Power on Neodymium Flows," *Nature Sustainability*, vol. 2, April 2019; Dodd, Jan, "Rethinking the Use of Rare Earth Elements," *WindPower Monthly*, November 30, 2019, https://www.windpowermonthly.com/article/1519221/rethinkingtheuseofrare-earthelements.

**Source:** U.S. DOE, *20% Wind Energy by 2030 (2009) and Xcel 2007 Resource Plan*, "Appendix E. Wind Storage Research and Experiments." Wilburn D.R., *Wind Energy in the United States and Materials Required for the Land-Based Wind Turbine Industry From 2010 Through 2030*. Scientific Investigations Report 2011-5036.

**Notes:** The critical minerals that could go into the manufacturing of wind turbines include the rare earth elements used in permanent magnets, vanadium and lithium for battery technology, and aluminum. These are shown in bold in the table.

### Materials for Solar Energy

There are two major types of photovoltaic (PV) cells: crystalline silicon cells (most widely used) and thin film solar cells. The silicon based PV cells are combined into modules (containing about 40 cells) then mounted in an array of about 10 modules. Ethylene-vinyl acetate and glass sheets typically frame the PV module with additional aluminum frames for added protection.[92] Thin-film solar cells use layers of ultra-thin semi-conductor materials that can serve directly in rooftop shingles, roof tiles, and building facades. Thin-film PV cells have been noted to use cadmium-telluride or copper-indium-gallium-diselenide (see **Table 7** below). A separate category of solar technology is concentrating solar power; these systems use mirrors to convert the sun's energy into heat and then into electricity.

**Table 7. Selected Materials for Photovoltaic Solar Cells and Panels**

| Solar Energy Materials | U.S. Supply | Major Import Sources |
|---|---|---|
| Glass | Large sand production and reserves for making glass | Net exporter in 2008 |
| **Aluminum** | U.S. supply | Net exporter in 2008 |
| Copper | U.S. supply (32% import reliant) | Chile and Canada |
| **Indium** | Negligible U.S. supply from secondary sources | China, Japan, and Canada |
| **Gallium** | Negligible U.S. supply as byproduct of bauxite production | China, Ukraine and Germany |
| **Tellurium** | Byproduct of zinc production | Belgium, Canada, and China |
| Selenium | Byproduct of copper production | Belgium and Canada |
| Cadmium | Byproduct of copper production | Net exporter in 2008 |
| Silicon Metal | Some U.S. production (less than 50% import reliant) | Brazil, South Africa, and Canada |

**Source:** U.S. DOE, *Solar America Initiative*; "Emissions from Photovoltaic Cycles," *Environmental Science and Technology*, v. 2, no. 6, 2008.

**Notes:** The critical minerals that could go into the manufacturing of solar cells and panels include aluminum, indium, gallium, and tellurium: these are shown in bold.

## Selected Supply Chain Analysis

With a supply chain analysis, it is just as important to know where new downstream capacity (processing, refining, and metals alloying) is being built or likely to be built in the world as it is to know the likely investors in upstream production capacity for critical minerals.

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[92] Vasilis M. Fthenakis, Hyung Chul Kim, and Erik Alsema, "Emissions from Photovoltaic Life Cycles," *Environment Science and Technology*, vol. 42, no. 6, 2008.

When looking at the complete supply picture it could be more easily determined where the potential risks are and what mitigation efforts may be available. Below, two illustrative supply chains are described: rare earth elements and tantalum.

## Rare Earth Elements

### REE Supply

Rare earth elements often occur with other elements, such as copper, gold, uranium, phosphates, and iron, and have often been produced as a byproduct. The lighter elements, such as lanthanum, cerium, praseodymium, and neodymium, are more abundant and concentrated and usually make up about 80%-99% of a total deposit. The heavier elements—gadolinium through lutetium and yttrium—are scarcer but very "desirable," according to USGS commodity analysts.[93]

Most REEs throughout the world are located in deposits of the minerals bastnaesite[94] and monazite.[95] Bastnaesite deposits in the United States and China account for the largest concentrations of REEs, while monazite deposits in Australia, South Africa, China, Brazil, Malaysia, and India account for the second-largest concentrations of REEs. Bastnaesite occurs as a primary mineral, while monazite is found in primary deposits of other ores and typically recovered as a byproduct. Over 90% of the world's economically recoverable rare earth elements are found in primary mineral deposits (e.g., in bastnaesite ores).[96]

### REE Supply Chain

The supply chain for rare earth elements generally consists of mining, separation, refining, alloying, and manufacturing (devices and component parts). A major issue for REE development in the United States is the lack of refining, alloying, and fabricating capacity that could process any rare earth production.

An April 2010 GAO report illustrates the lack of U.S. presence in the REE global supply chain at each of the five stages of mining, separation, refining oxides into metal, fabrication of alloys, and the manufacturing of magnets and other components. According to the 2010 GAO report, China produced about 95% of the REE raw materials and about 97% of rare earth oxides, and was the only exporter of commercial quantities of rare earth metals (Japan produced some metal for its own use for alloys and magnet production). About 90% of the metal alloys were produced in China, and China manufactures 75% of the NdFeB magnets and 60% of the samarium cobalt (SmCo) magnets. Thus, even as U.S. rare earth production ramps up, without significant supply chain investments, much of the processing and metal fabrication would likely occur in China.

In the case of rare earths, it is not enough to develop REE mining operations outside of China alone without building the value-added refining, metal production, and alloying capacity that would be needed to manufacture component parts for end-use products. According to rare earth analyst Jack Lifton, vertically integrated companies may be more desirable. It may be the best

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[93] DOI/USGS, *Rare Earth Elements-Critical Resources for High Technology*, Fact Sheet 087-02, 2006.

[94] Bastnaesite is a mineral that may contain other rare earth elements.

[95] Monazite is a mineral with the chemical composition of (Ce, La, Nd, Th) $PO_4$ also may contain other rare earth elements.

[96] DOI/USGS *International Strategic Minerals Inventory Summary Report—Rare Earth Oxides*, by Wayne Jackson and Grey Christiansen, Circular 930 N, 1993.

way to secure investor financing for REE production projects.[97] Joint ventures, consortiums, and cooperatives could be formed to support production at various stages of the supply chain at optimal locations around the world. Each investor or producer could have equity and offtake commitments. Where U.S. firms and U.S. allies invest may contribute to meeting the goal of providing a secure and stable supply of REEs, intermediate products, and component parts needed for the assembly of end-use products.

In 2019, rare earth analyst James Kennedy of ThREE Consulting writes that China's dominance and "absolute advantage" in the rare earth space is fundamentally reflected in its R&D efforts at its national labs and the Baotou Research Institute of Rare Earths in the fields of basic sciences, materials science, and rare earth metallurgy.[98] ThREE Consulting has shown that China has filed more rare earth patents than the rest of the world combined and Kennedy states that patents acquired in the rare earth space are likely a proxy for next generation rare earth-related technology.

China's whole-of-government approach in the field of rare earths and other critical minerals may keep China in its position of dominance for the foreseeable future.

## Tantalum

Tantalum is a metallic element contained in the mineral tantalite and is extracted from primary and placer mineral deposits.[99] It often occurs with niobium but is also present with other minerals such as rare earths, uranium, and cassiterite (tin ore). Tantalum has been produced as a primary product, a co-product, and as a byproduct of other ores. Tantalum's high melting point (3,000 degrees Centigrade) and corrosion resistance makes it super-capacitive, (i.e., characterized by a high capacity to store and release electrical charges). This metal, which is used in numerous high-tech electronic devices, is produced and traded in conflict areas in Central Africa; thus, in certain instances, tantalum is classified as a conflict mineral and subject to disclosure rules promulgated from the Dodd-Frank Wall Street Reform and Consumer Protection Act (P.L. 111-203, 15 U.S.C. §78).[100] Section 1502 of the law includes a sense of the Congress that conflict minerals in the Democratic Republic of the Congo or adjoining countries are financing extreme levels of violence in the DRC.

### Tantalum Supply

There are four major sources of tantalum market supplies: primary production (industrial and artisanal[101]); tin slag processing; scrap reprocessing and recycling; and byproduct production (also referred to as secondary concentrate).[102] Primary production accounts for about 70% of

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[97] The Gold Report, *Rare Earth Strategic Supplies More Important Than Price,* Industrial Metals/Minerals Interview with Jack Lifton, December 14, 2009.

[98] Kennedy, James, "China Solidifies Dominance in Rare Earth Processing," *National Defense Magazine*, March 21, 2019, https://www.nationaldefensemagazine.org/articles/2019/3/21/viewpoint-china-solidifies-dominance.

[99] Placer deposits are those formed when material is removed from primary deposits and accumulates in other locations, typically after being moved by water (alluvial sedimentation), other forms of erosion, or other natural forces.

[100] Section 1502, which amends the Securities and Exchange Commission Act (SEC) of 1934, defines conflict minerals as "columbite-tantalite (coltan), cassiterite, gold, wolframite, or their derivatives." Coltan is a colloquial expression for the combined columbite (niobium)–tantalite ores that are found in Central Africa.

[101] Artisanal mining refers to small-scale operators, usually very labor intensive (using picks and shovels), as compared with capital intensive industrial production.

[102] Ulric Schwela, "Focus: Tantalum: Regulating the Supply Chain," *Mining Journal*, March 22, 2013,

global supply.  Historically, tantalum obtained from tin slag (waste) was primarily produced in Malaysia, Thailand, and Brazil. Tantalum has also been a byproduct of niobium, titanium, tin, and uranium produced in Malaysia, Brazil, China, and Russia.

Recycled tantalum contributes to 30% of global supply, mostly recovered from "pre-consumer scrap" at the manufacturing plant. The United States and Mexico account for 61% of tantalum scrap recovery and it is estimated that scrap could provide 50% of global tantalum supply by 2025.[103]

Based on USGS data, Brazil, Canada, Mozambique, and Nigeria were countries that led in primary tantalum production during the 1970s. Brazil and Canada continued to be the major producing countries in the 1980s.[104] Australia took over the top spot in the late 1980s and 1990s, followed by Brazil until 2009, after which no primary production was reported for Australia by the USGS.  The Australian mines were closed following the 2008 recession, reopened in 2012, but closed again shortly thereafter in 2012. Since about 2009, it has been noted by several sources that the DRC, with tens of thousands of artisanal miners, is a leading producing country (see **Table 4**).[105] Recorded production for tantalum by the USGS indicates a shift in production—at least what has been reported—since 2000 from Australia and Brazil, to the DRC and Rwanda.[106]

Over the past several decades, there were material gaps in the publically available data for tantalum; production data reported has been much less than processor receipts. In one example, the average producer's supply to total processor's receipts gap measured over six quarters was 73%. On average, reported production represents about 27% of total processors' receipts over the period. There was an average material difference of 381 metric tons.[107]

Part of the explanation for such reporting patterns may be the highly unregulated nature of tantalum ore production and trade in Central Africa.[108] High production in the unreported (informal) sector of the mining community drove prices down and forced many of the major production regions to close their operations. With low prices, investor interest is limited; investors are thus constrained by high risk in greenfield projects, (i.e., new projects or work that does not follow previous work).[109]

The USGS data does not reflect the amount of production from unauthorized (often illegal) mining operations—usually artisanal mining operations. The USGS collects its data from a variety of sources but considers the tantalum industry as operating under "a shroud of secrecy" with incomplete access to data and not very transparent. Generally, there is insufficient data to make definitive determinations on the true production, capacity, and reserve levels for tantalum

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https://www.mining-journal.com/africa/news/1164441/focus-tantalum-regulating-supply-chain.

[103] N.A. Mancheri, et al., "Resilience in the Tantalum Supply Chain," *Resources, Conservation, and Recycling*, October 18, 2017.

[104] USGS, *Shift in Global Tantalum Production, 2000-2014*, Fact Sheet 2015-3079, December 2015.

[105] USGS, Mineral Commodity Summaries, Various Years.

[106] USGS, *Shift in Global Tantalum Production, 2000-2014*.

[107] Data from USGS Mineral Commodity Receipts and the Titanium-Niobium International Study Center (TIC) various years. The TIC is an international trade association comprising of around 85 members, all involved in the industries of tantalum and/ or niobium, at various positions along the supply chain.

[108] Raimund Bleischwitz, et al., "Coltan from Central Africa, International Trade and Implications for Any Certification," *Resources Policy*, March 2012.

[109] N.A. Mancheri, et al., "Resilience in the Tantalum Supply Chain," *Resources, Conservation, and Recycling*, October 18, 2017.

on a global basis. There are several reasons for this supply/demand material difference, including the following:[110]

- Nonreporting or under-reporting all forms of supply (primary, byproduct, tin slag, and scrap) through the Tantalum-Niobium International Study Center (TIC) or elsewhere.
- High inventories. Several analysts have noted that since the recession of 2008 many companies were selling from their above-ground stocks.
- Illicit mining and trading. There are well-established networks for smuggling tantalum and other minerals out of Central Africa (and elsewhere) and into the marketplace.

Dependence on Africa's supply and that disruption could have consequences, e.g., price rises. Africa provides 80% of the primary tantalum production (60% from the DRC and Rwanda) as China dominates downstream processing and manufacturing capacity. The illicit mining component in the tantalum market makes it vulnerable and possibly unsustainable because it prevents large-scale producers from entering the market. Illegal tantalum trade has long-term implications for the entire supply chain leading to lower investment in all phases of the supply chain.[111]

In 2016, the USGS listed Australia and Brazil as having 85% of the world's tantalum reserves, but the USGS regularly states that data is not available for other countries or is just unknown. The USGS lists Australia, Brazil, and Canada as having the majority of the world identified tantalum resources.

## The Tantalum Supply Chain

In 2017, Mancheri, et al., published a study that assessed the tantalum supply chain for regional production dependence, the potential for supply disruptions, and mechanisms to prevent disruptions using a "resiliency" of supply model.[112] This method examines four resilience of supply indicators: diversity of supply, material substitution, recycling, and stockpiling, and is dependent on three factors: resistance, rapidity, and flexibility. Mancheri's study concludes that the tantalum market is flexible and resilient based on its handling of unreported and presumably illegal trade along with its impact on conventional large-scale tantalum producers. Mancheri's study concluded that stockpiling and substitution can mitigate some supply disruption.

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[110] Raimund Bleischwitz, et al., "Coltan from Central Africa, International Trade and Implications for Any Certification," *Resources Policy*, March 2012. United Nations sanctions monitors also track trade in coltan ore in Central Africa and have repeatedly documented unofficial, often black market cross-border movements of the ore. Also see, USGS Fact Sheet 2015-3079, *Shift in Global Tantalum Mine Production, 2000-2014*, December 2015. Mancheri, et al. reports on this information gap as well in "Resilience in the Tantalum Supply Chain," *Resources, Conservation, and Recycling*, October 18, 2017.

[111] NA Mancheri, et al., "Resilience in the Tantalum Supply Chain," *Resources, Conservation, and Recycling*, October 18, 2017.

[112] According to Mancheri, "resilience theory" shows how a supply chain would respond to disruptions in short-term and long term-constraints. This theory is discussed in Mancheri, et al., "Resilience in the Tantalum Supply Chain," *Resources, Conservation, and Recycling*, October 18, 2017.

Generally, tantalum follows the following supply chain steps:[113]

- The primary ore is crushed and milled into an ore concentrate which is further refined into oxides (metal or powder) or K-Salt (which is reduced to tantalum metal),[114] which is used for the manufacture of capacitors, wire, super alloys, and other fabricated forms. Downstream manufacturers use these materials for parts that are used by consumer product manufacturers and others.[115] China has 16 tantalum processing plants; the United States has one, according to the Mancheri study. There are four processing plants in Germany and four in Japan.
- The metal or powder form is then used by electronics manufacturers to produce capacitors and other products. The manufactured parts are shipped to consumer product producers such as Motorola, Sony, Apple, Dell, and others. China dominates the production of capacitors.

# Current Policy Framework

## U.S. Mineral Policy

As noted in two key statutes, the current goal of U.S. mineral policy is to promote an adequate, stable, and reliable supply of materials for U.S. national security, economic well-being, and industrial production. U.S. mineral policy emphasizes developing domestic supplies of critical materials and encourages the domestic private sector to produce and process those materials.[116] But some raw materials do not exist in economic quantities in the United States, and processing, manufacturing, and other downstream ventures in the United States may not be cost competitive with facilities in other regions of the world. However, there have been public policies enacted or executive branch measures taken (for example, the percentage depletion allowance[117] for U.S. mining operations and royalty-free production on public domain lands) to offset the U.S. disadvantage of its potentially higher-cost operations. The private sector also may achieve lower-cost operations with technology breakthroughs.

Based on this policy framework, Congress has held numerous legislative hearings on the impact of the U.S. economy's high import reliance on many critical materials, and on a range of potential federal investments that would support the development of increased domestic production and

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[113] British Geological Survey, *Niobium-Tantalum*, April 2011, pp. 11-13.

[114] Tantalum (Ta) extraction uses solvent extraction ammonium to precipitate tantalum as Ta-hydroxide which is calcined to form Ta-oxide or potassium tantalum fluoride (K-Salt). K-Salt is directly crystallized by adding potassium fluoride to the extract solution. The molten sodium is used to form Ta metal.

[115] British Geological Survey, *Niobium-Tantalum*, April 2011, pp. 11-13.

[116] U.S. mineral policies provide a framework for the development of domestic metal mineral resources and for securing supplies from foreign sources. Specifically, the Mining and Minerals Policy Act of 1970 (30 U.S.C. §21a) declared that it is in the national interest of the United States to foster the development of the domestic mining industry "... including the use of recycling and scrap." The National Materials and Minerals Policy, Research and Development Act of 1980 (30 U.S.C. §1601) declares, among other things, that it is the continuing policy of the United States to promote an adequate and stable supply of materials necessary to maintain national security, economic well-being, and industrial production, with appropriate attention to a long-term balance between resource production, energy use, a healthy environment, natural resources conservation, and social needs. There is also a provision to develop an early warning system for critical materials.

[117] A percentage depletion allowance is a tax deduction to recover investments in mineral properties, (e.g., property acquisition costs and capitalized exploration expenses).

production from reliable suppliers. There has been a long-term policy interest in mineral import reliance and its impact on national security and the U.S. economy.

## General Mining Law of 1872: Mining on Federal Lands

Mining of locatable minerals (also referred to as hardrock minerals) on federal lands is governed primarily by the General Mining Law of 1872 (30 U.S.C. §§21-54). The original purposes of the Mining Law were to promote mineral exploration and development on federal lands in the western United States, offer an opportunity to obtain a clear title to mines already being worked, and help settle the West. The Mining Law grants free access to individuals and corporations to prospect for minerals on open public domain lands, and allows them, upon making a discovery, to stake (or "locate") a claim on the deposit. A valid claim entitles the holder to develop the minerals. The 1872 Mining Law originally applied to all valuable mineral deposits except coal (17 Stat. 91, 1872, as amended).

Public domain lands are those retained under federal ownership since their original acquisition by treaty, cession, or purchase as part of the general territory of the United States, including lands that passed out of but reverted back to federal ownership. "Acquired" lands—those obtained from a state or a private owner through purchase, gift, or condemnation for particular federal purposes rather than as general territory of the United States—are subject to leasing only and are not covered by the 1872 Law. Acquired lands are governed under the authority of the Mineral Leasing for Acquired Lands Act of 1947.

Under the General Mining Law, mineral claims may be held indefinitely without any mineral production. Once lands were patented to convey full title to the claimant, the owner could use the lands for a variety of purposes, including nonmineral ones. However, using land under an unpatented mining claim for anything but mineral and associated purposes violates the General Mining Law. Critics believe that many claims are held for speculative purposes. However, industry officials argue that a claim may lie idle until market conditions make it profitable to develop the mineral deposit. Congress has placed a moratorium on patenting lands since 1994 under annual appropriation bills.[118]

The vast majority of mineral production in the United States occurs on private land and is regulated by the states which may use a leasing and permitting framework. The regulatory framework described below applies primarily to minerals produced on federal land but has implications for the entire U.S. mining industry.

There is debate over whether streamlining the permitting process on federal lands would make investing in mining in the United States more attractive or would incentivize investors. Proponents of streamlining the framework maintain that mining firms would be more likely to invest in the United States given a more rapid turnaround of the mine permitting process. However, mining firms have multi-factor decision making processes; they go to where the minerals are, and they often look for low political and country risk (good governance) and a sense of certainty of the regulatory environment, as well as low-cost production opportunities.

A debate has emerged over the past several decades over whether the federal government should impose a royalty on the value of minerals produced on public lands, as is the practice on other lands in the United States (i.e., state lands and private lands) and other parts of the world. Further discussion of this debate is beyond the scope of this report.

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[118] For example, see P.L. 109-54, Section 408 for standard appropriation language prohibiting further patenting of mining claims.

## Federal Land Management and Mineral Development: Regulatory Framework for Mineral Development on Federal Land

Mineral development activities in the United States are subject to a suite of federal regulatory requirements. The specific statutes and regulations that will apply and how compliance is accomplished will vary depending on the specific mineral development project (e.g., specific actions may be required for compliance with federal law if the mining project may affect a federally protected species). That is, for mining on federal lands, there are various federal regulatory requirements that may apply in addition to the Federal Mining Law of 1872. These requirements encompass environmental reviews, adequate proof of financing, permits, surface management requirements, bonding, and public participation, among other requirements. The **Appendix** provides a list of the selected statutes and regulations related to mineral development on federal land. A discussion of the regulatory compliance process and the various federal, state, and other entities that may be involved is beyond the scope of this report. The following discussion focuses on the regulatory framework associated with management of and access to minerals for development on federal land.

During the 1960s and 1970s, the Multiple Use Sustained Yield Act (16 U.S.C. §§528-531), Wilderness Act of 1964 (16 U.S.C. §§1131-1136), National Forest Management Act of 1976 (43 U.S.C. §§1701 et seq.), National Environmental Policy Act of 1969 (NEPA, 42 U.S.C. §§4321 et seq.), and Federal Land Policy Management Act (FLPMA) (43 U.S.C. §1701 et seq.) addressed environmental protection, multiple use, and management of federal land generally. By imposing requirements on agency actions, these acts have affected mineral development under both the leasing system and the General Mining Law of 1872 claim-patent system. The General Mining Law contains no direct environmental controls, but mining claims are subject to all general environmental laws as a precondition for development.

The Bureau of Land Management (BLM)[119] administers the mineral program on all federal land but other land managing agencies, such as the Forest Service (FS) must approve surface disturbing activity on its land. BLM and FS use the mine plan review process (which includes mining methods and reclamation plans) to determine the validity of the mine proposal and to determine how extensive of an environmental review is required under the Federal Land Policy and Management Act of 1976.

### Federal Land Policy Management Act

Under the Federal Land Policy and Management Act of 1976, Resource Management Plans (RMPs) are required for tracts or areas of public lands prior to development. BLM must consider environmental impacts during land-use planning when RMPs are developed and implemented. RMPs can cover large areas, often hundreds of thousands of acres across multiple counties.[120]

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[119] The Bureau of Land Management is an Interior Department agency that is responsible for approximately 700 million acres of federal subsurface minerals, and supervises the mineral operations on about 56 million acres of Indian trust lands. According to the BLM, approximately 150 million acres have been withdrawn from mineral entry, leasing, and sale, subject to valid existing rights. Lands in the National Park System (except National Recreation Areas) and the Wilderness Preservation System are among those that are statutorily withdrawn. Also, of the 700 million acres, mineral development on 182 million acres is subject to the approval of the surface management agency (e.g., the Forest Service), and must not be in conflict with land designations and plans.

[120] 43 U.S.C. §1712.

Through the land-use planning process, BLM determines which lands are open for mining claims and potential development.[121]

Regarding land use plans FLPMA states: "the Secretary [of the Interior] shall with public involvement and consistent with the terms and conditions of this Act, develop, maintain and, when appropriate, revise land use plans which provide by tracts or areas for the use of the public lands."[122] Current planning regulations require preparation of an environmental review document for the land use plans under the National Environmental Policy Act.[123]

FLPMA requires that RMPs reflect diverse uses—such as timber, grazing, wildlife conservation, recreation, and energy—and consider the needs of present and future generations. Impacts of various uses are identified early in the process so that they can be weighed equitably against one another by the BLM. The plans are also intended to weigh the various benefits associated with public lands.

## Withdrawals from Mineral Entry and Access to Federal Land

The President and executive branch agencies historically issued executive orders, secretarial orders, and public land orders to withdraw federal lands from mineral entry and other uses under what was viewed as the President's authority, including certain statutory authorities such as the Antiquities Act (34 Stat. 225). Since 1976 executive withdrawals are governed by FLPMA. FLPMA repealed earlier land withdrawal authorities. Withdrawals of parcels exceeding 5,000 acres require congressional approval.[124]

A withdrawal pursuant to FLPMA restricts the use of land under the multiple-use management framework, typically segregating the land from some or all public land laws as well as some or all of the mining and mineral leasing laws for a period of 20 years.[125] Initially, the area is segregated for two years during which time an environmental review is conducted to determine whether a longer-term withdrawal of 20 years is warranted. The longer-term withdrawal is often subject to renewal by the Department of the Interior.

The withdrawal can be temporary or permanent. Under this section of the code the Secretary of the Interior may make, modify, extend, or revoke withdrawals.[126]

Generally, federal land withdrawals are subject to valid existing rights, meaning that the minerals rights holder may develop those minerals subject to terms of the federal land-managing agency (e.g., the National Park Service, BLM, or the Forest Service).

Mineral industry representatives maintain that federal withdrawals inhibit mineral exploration and limit the reserve base even when conditions are favorable for production. Thus, they state that without new reserves or technological advancements mineral production costs may rise. They

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[121] Ibid.

[122] Ibid.

[123] 43 C.F.R. 1601.06.

[124] Congress may adopt a concurrent resolution not approving the withdrawal.

[125] Under FLPMA, (43 U.S.C.A. §1702(j)), Congress defined a withdrawal as "withholding an area of Federal land from settlement, sale, location or entry under some or all of the general land laws for the purpose of limiting activities under those laws in order to maintain other public values in the area or reserving the area for a particular public purpose or program; or transferring jurisdiction over an area of federal land from one department, bureau or agency to another department, bureau or agency."

[126] Ibid.

further contend that higher domestic costs may lead to greater exploration on foreign soil, potentially boosting U.S. import dependence.

Critics of U.S. mineral development state that mining often is an exclusive use of land inasmuch as it can preclude other uses, and that in many cases there is no way to protect other land values and uses short of withdrawal of lands from development under the General Mining Law. They point to unreclaimed areas associated with previous hardrock mineral development, Superfund sites related to past mining and smelting, and instances where development of mineral resources could adversely affect or destroy scenic, historic, cultural, and other resources on public land.

Congressional debate has been ongoing for decades over how much federal land should be available for the extractive industries or other uses and how much should be set aside (e.g., off limits or restricted) for conservation or environmental purposes.

# Selected Critical Minerals-Related Legislation in the 115th and 116th Congresses

## 116th Congress

**H.R. 2531, National Strategic and Critical Minerals Production Act**, introduced by Representative Mark E. Amodei on May 7, 2019, and referred to House Committee on Natural Resources. The bill would define critical and strategic minerals and seeks to streamline the federal permitting process for domestic mineral exploration and development. It would establish responsibilities of the "lead" federal agency to set mine permitting goals, minimize delays, and follow time schedules when evaluating a mine plan of operations. The review process would be limited to 30 months, and the bill would establish the priority of the lead agency maximizing the development of the mineral resource while mitigating environmental impacts.

**H.R. 2500, National Defense Authorization Act (NDAA) for Fiscal Year 2020**, reported in the House. The bill would require the Secretary of Defense to provide guidance on acquiring items containing rare earth elements and guidance on establishing a secure rare earth materials supply chain within the United States. The bill provides authority for the Secretary to acquire rare earth cerium and lanthanum compounds and electrolytic manganese metal. And further, for DOD purposes, the bill would prohibit the acquisition of tantalum from nonallied foreign nations.

The reported Senate version (S. 1790) of the FY2020 NDAA does not contain similar language.

**S. 1317, American Mineral Security Act**, introduced by Senator Murkowski on May 2, 2019, and referred to the Senate Committee on Energy and Natural Resources.

The bill would define what critical minerals are, but also would request that the Secretary of the Interior establish a methodology that would identify which minerals qualify as critical. The Secretary of the Interior would be required to maintain a list of critical minerals. The bill would establish an analytical and forecasting capability on mineral/metal market dynamics as part of U.S. mineral policy. The Secretary of the Interior would be required to direct a comprehensive resource assessment of critical mineral resource potential in the United States, assessing the most critical minerals first.

The bill would require that an agency review and report be intended to facilitate a more efficient process for critical minerals exploration on federal lands, and specifically would require performance metrics for permitting mineral development activity and report on the timeline of each phase of the process.

The bill would require that the Department of Energy establish an R&D program to examine the alternatives to critical minerals and explore recycling and material efficiencies through the supply chain. The Department of the Interior would be required to produce an Annual Critical Minerals Outlook report that would provide forecasts of domestic supply, demand, and price for up to 10 years.

The Secretary of Labor, in consultation with the National Science Foundation and other relevant institutions, would be required to assess the availability of domestic technically trained personnel in the exploration production, manufacturing, recycling, forecasting, and analysis of minerals critical to the United States, noting, among other things, skills in short supply now, and those projected to be in short supply in the future. The Secretary would be required to design an interdisciplinary curriculum study on critical minerals and further, establish a competitive grants program for new faculty positions, internships, equipment needs, and research related to critical minerals. There would be $50 million authorized to carry out this act each year for fiscal years 2020-2029.

## 115th Congress

**H.R. 520, National Strategic and Critical Minerals Production Act**, introduced by Representative Mark E. Amodei on January 13, 2017, and referred to House Committee on Natural Resources. This bill is similar to H.R. 2531 described above (in the 116th Congress).

**H.R. 1407, METALS Act**, introduced by Representative Duncan Hunter on March 7, 2017, and referred to the House Committee on Armed Services.

This bill would have established a strategic materials investment fund and allowed the Secretary of Defense to provide loans for domestic production and domestic processing of strategic and critical materials, and supported the development of new technologies for more efficient processing of strategic and critical materials.

For fiscal years 2018 through 2023, 1/10 of 1% of the amounts appropriated for "covered programs" would have been deposited into the fund. Covered programs would have been all major defense acquisition programs for development or procurement of aircraft or missiles. The bill would have established a prohibition on sale of domestic rare earth mines to foreign firms.

**H.R. 5515 (P.L. 115-232), John S. McCain National Defense Authorization Act for Fiscal Year 2019**, included a provision to direct the Secretary of Defense to purchase rare earth permanent magnets and certain tungsten, tantalum, and molybdenum from sources outside of China, Russia, North Korea, and Iran to the extent possible.

**S. 1460, Energy and Natural Resources Act of 2017, Subtitle D—Critical Minerals**, introduced by Senator Murkowski on June 18, 2017, and referred to the Senate Committee on Energy and Natural Resources. This bill is similar to S. 1317 above (in the 116th Congress).

**S. 145, National Strategic and Critical Minerals Production Act** (similar to H.R. 520 in the 115th Congress), introduced by Senator Heller on January 12, 2017, and referred to the Senate Committee on Energy and Natural Resources.

## Previous Congresses

Similar bills on critical minerals were introduced in earlier Congresses. For example, in the 113th Congress, there was S. 1600, Critical Minerals Policy Act of 2013, and H.R. 761, the National Strategic and Critical Minerals Production Act of 2013, which passed the House on September 18, 2013. Another bill in the 113th Congress, H.R. 4883, the National Rare Earth Cooperative Act of 2014, proposed to advance domestic refining of heavy rare earth oxides and the safe storage of thorium for future uses using a cooperative ownership approach. Thorium is associated with certain rare earth deposits and waste materials. The cooperative would have operated under a federal charter composed of suppliers and consumers as owners.

# Additional Policy Options

This section provides a discussion of selected policy options related to critical minerals that were included in legislation introduced in the 115th and 116th Congresses. In addition to weighing the advantages and disadvantages of the various policy options discussed above and below, policymakers have the option of maintaining the status quo of current policies.

## Minerals Information Administration

The USGS could establish a Minerals Information Administration for information and analysis on the global mineral/metal supply and demand picture. Companies producing minerals on public lands could be required to report production data to the federal agency.

## Greater Exploration for Critical Minerals

Encouragement of greater exploration for critical minerals in the United States, Australia, Africa, and Canada could be part of a broad international strategy. There are only a few companies in the world that can provide the exploration and development skills and technology for critical mineral development. These few companies are located primarily in the above four regions and China, and may form joint ventures or other types of alliances for R&D, and for exploration and development of critical mineral deposits worldwide, including those in the United States. Whether there should be restrictions on these cooperative efforts in the United States is a question for congressional deliberations.

## Other Policy Options

Other action by Congress could include oversight of free trade issues associated with critical mineral supply. Two raw material issues associated with China export restrictions were taken up by the World Trade Organization (WTO). One case, settled in 2011, was filed by the United States against China and was related to restrictions on bauxite, magnesium, manganese, silicon metal, and zinc, among others (using export quotas and export taxes). The other case, resolved in 2012, was filed by the United States, Japan, and the European Union on export restrictions of rare earth oxides, tungsten, and molybdenum. The WTO ruled against China in both cases, concluding that China did not show the link between conservation of resources or environmental protection (and protection of public health) and the need for export restrictions.

The United States could support more trade missions; support U.S. commercial delegations to China and other mineral-producing countries; and assist smaller and less-developed countries in improving their governance capacity. Although there are concerns that trade tariffs with China could impact the prices and availability of critical minerals and downstream metals imported from China, the effects would depend on the specifics of the tariffs as well as the particular mineral and metal involved.

## Additional Considerations

In China and other emerging economies, economic development will continue to have a major impact on the world supply and availability of raw materials and downstream products. Various countries may be faced with making adjustments to secure needed raw materials, metals, and finished goods for national security and economic development. China, Japan, and others are already actively engaged in securing reliable mineral supplies. Many firms have moved to China to gain access to its market, raw materials, or intermediate products, and generally lower-cost minerals production. At the same time, China is seeking technology transfer from many of these firms to expand its downstream manufacturing capacity. Despite China's current overcapacity and increased exports of some commodities, in the long run it may be in China's interest to use its minerals (plus imports) for domestic manufacturing of higher-valued downstream products (e.g., component parts and consumer electronics). Higher-cost, inefficient facilities and mines may close, resulting in China seeking more imports as mining industry consolidations are implemented.

The effects on China's dominance in the supply and demand of global raw materials could be addressed in part through consistent development of alternate sources of supply, use of alternative materials when possible, efficiency gains, aggressive R&D in development of new technologies, and comprehensive minerals information to support this effort. China is likely entering an era of fewer raw material exports which may instigate long-term planning by the private sector and government entities that want to meet U.S. national security, economic, and energy policy interests and challenges. Some stakeholders may seek to have some concerns addressed through the WTO.

Additional questions that may be deliberated by Congress include how long would it take to develop the skill set in the United States for downstream manufacturing activities? Would an international educational exchange program with those countries already involved in the refining and recycling of critical minerals be appropriate?

More analysis would be useful to investigate U.S. firms' capacity to adjust to supply bottlenecks such as restrictions in other countries' exports, underinvestment in capacity, materials use in other countries and domestically, single source issues, strikes, power outages, natural disasters, political risk, and lack of substitutes. Having such analysis and understanding may inform public policy. More information could inform deliberations as Congress and other policymakers evaluate the available policy options and their effectiveness at minimizing the risk of potential supply interruption of critical and strategic minerals and metals.

# Appendix. Selected Statutes and Regulations Related to Mining on Federal Lands

## Selected Statutes that May Impact Mining Activities on Federal Lands (in alphabetical order)

American Indian Religious Freedom Act (P.L. 95-341)

Clean Air Act, 42 U.S.C. §7401 et seq.

Clean Water Act, 33 U.S.C. §1251 et seq.

Endangered Species Act, 16 U.S.C. §1531 et seq.

Federal Land Policy and Management Act, 43 U.S.C. §1701-1784

Federal Mine Safety and Health Act of 1977 (P.L. 95-164)

General Mining Law of 1872, 30 U.S.C. §21-54

Historic Preservation Act (P.L. 89-665)

Mineral Leasing For Acquired Lands Act of 1947, 30 U.S.C. §351-359

Mining and Minerals Policy Act of 1970, 30 U.S.C. §21a

National Environmental Policy Act, 42 U.S.C. §4321 et seq.

National Forest Management Act 16 U.S.C. §1600-1687

National Materials and Minerals Policy, Research, and Development Act of 1980, 30 U.S.C. §1601

Resource Conservation and Recovery Act, 42 U.S.C. §6901 et seq.

Toxic Substance Control Act (P.L. 94-469)

## Mining-Specific Regulations

Bureau of Land Management (BLM): 43 C.F.R. 3809—Regulations on surface management

U.S. Forest Service (FS): 36 C.F.R. Part 228—Regulations on minerals

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