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MINE GAMES: SECURING AMERICA'S CRITICAL MINERAL SUPPLY

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Summary

The Secretary of the Interior, in coordination with the Secretary of Defense, has listed 50 critical minerals that constitute a strategic vulnerability for the nation's security and prosperity. And now, with China's mineral export restrictions coupled with global supply chain challenges, there is greater pressure on the United States and allies to consider a coordinated strategy to weaken adversarial nations' grip on critical minerals. While the space industry is only one of many that consume critical minerals, the difficult engineering trade-offs associated with space operations make finding substitute materials more challenging. The space industry will need to collaborate with high-volume industries to strengthen its buying power and market influence as it considers a range of countervailing strategies to secure its critical mineral supply chain. Key options include recycling, stockpiling, domestic production, international partnerships, and consideration of new mineral frontiers. There is no one magic bullet. Instead, the United States will need to consider a range of industrial policy options to navigate competing and expanding national economies, mineral scarcities, and a complex geopolitical climate.

Introduction

On August 1, 2023, China imposed restrictions on its global exports of gallium and germanium for national security purposes, which effectively disrupted the global supply chain of both minerals. This recent move by China comes at a crucial time, particularly as the growing commercial space industry becomes increasingly reliant on predictable supplies of gallium for high-efficiency solar cells, compound semiconductor applications, and infrared image sensors. Likewise, the space sector has become more reliant on germanium for solar cell substrates, infrared optics, lasers, high-performance thermal imaging, and electron-optical systems, to name just a few. From an economic and national security perspective, what are the strategic options and policy implications for a limited supply of critical minerals, specifically germanium and gallium? China has already started to exert its strategic advantage over western economies amid ongoing trade battles and restrictions.[1] Now, the United States is in a vulnerable position and risks losing access to dozens of minerals crucial for national security programs. However, some options and strategies are available to reduce the nation's supply chain vulnerabilities.

For years, many western countries, including the United States, have emphasized "just-in-time" supply chain management. This strategy has worked to reduce upfront capital costs and inventory overhead. China, by contrast, has emphasized integrated supply chains to support its resourcehungry economy.[2] As a result, China has strengthened its control over minerals through significant investments in related industrial activities such as extracting, smelting, and refining. After the COVID-19 pandemic's global supply chain disruption, many companies worked to develop greater flexibility and redundancy in their supply chains, making the switch from just-in-time to "just-in-case" inventory management. More companies are now managing inventories with a higher priority on lowering risk rather than a sole focus on cash flow optimization.

Foreign sources, mainly China, provide 80 percent of the United States' critical mineral supplies.[3] Western countries, including the United States, are reviewing their options and are increasingly focused on strategies such as "nearshoring" and "ally-shoring," relying on operations and businesses that reside closer to home or are sourced from our allies, respectively. Other options may be considered that require an active role, such as strategic stockpiling, recycling, and building domestic supplies by reopening old mines and accelerating the permitting process for new mines. The need for new, domestic mineral sources has been reflected in recent initiatives such as the Defense Logistics Agency's (DLA) 2022 program to recycle optical-grade germanium, but this is expected to fulfill only 10 percent of the United States' germanium needs.[4] Despite recent efforts, supply chain disruptions from China are still able to adversely affect U.S. industrial supply.

What are Critical Minerals?

A 2017 Executive Order, "A Federal Strategy To Ensure Secure and Reliable Supplies of Critical Minerals," identifies "critical minerals" as essential to the economy and whose supply may be disrupted due to scarcity and dependence on foreign sources.[5] Critical minerals are often vital for a range of civil and military technologies, and the absence of these minerals could have "significant consequences for our economy or our national security."[6] In 2018, the United States Department of the Interior classified both gallium and germanium as part of 35 critical minerals.[7] As of 2022, the list has grown, and there are now 50 critical minerals ranging from aluminum to zirconium.[8]

The United States is now 100 percent reliant on gallium imports and over 50 percent dependent on germanium imports, both of which are largely sourced from China.[9] Furthering our dependence on China, the United States lacks the infrastructure for extracting, smelting, refining, and producing these minerals to meet domestic demand. China has cornered the market in an industry with high barriers to entry, high production costs, and specialized refinement "know-how." China's growing market advantages led countries such as Germany and Kazakhstan to halt their own production efforts within the last decade.

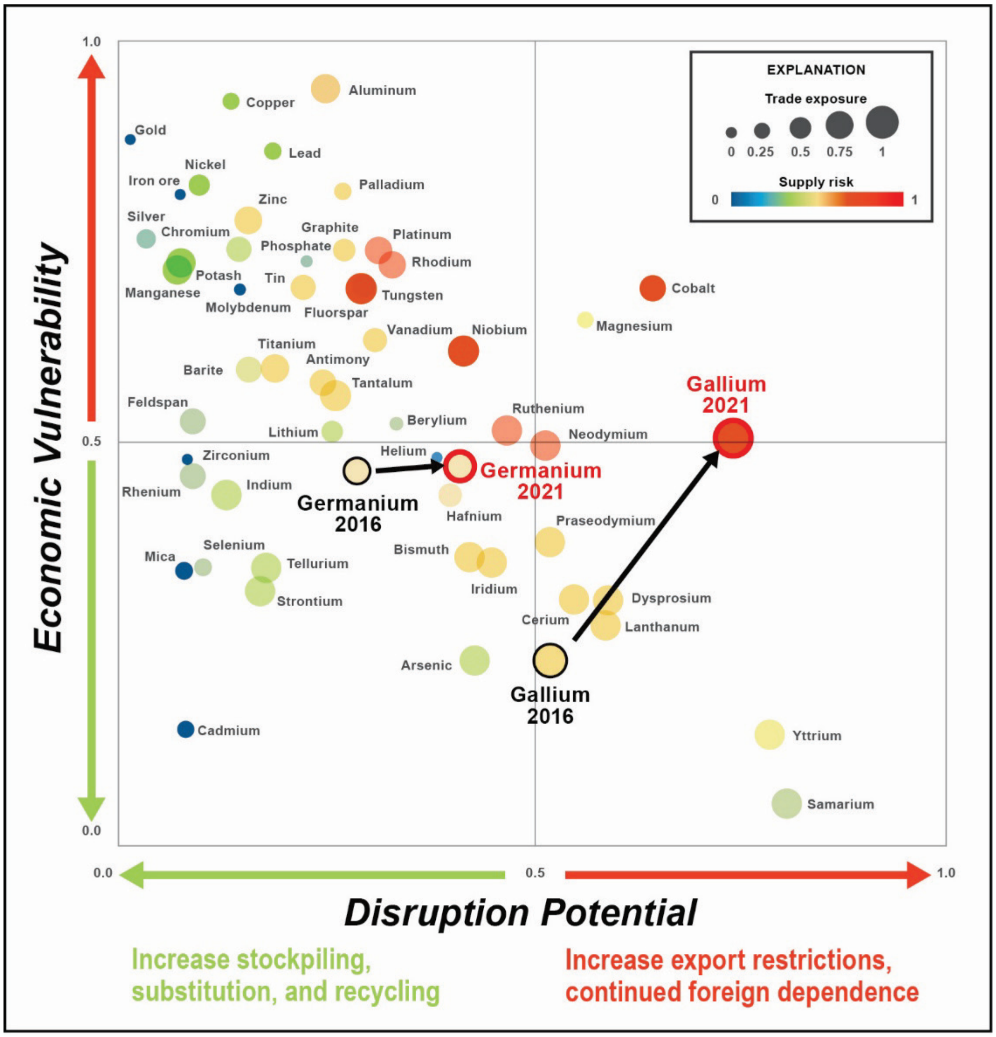

Figure 1: Vulnerability and Disruption. *Gallium and, to a lesser extent, germanium have become more economically vulnerable due to supply chain disruptions. China's recent restrictions have pushed both minerals into increasingly critical positions near the upper right quadrant, where minerals are prone to disruption and are economically vulnerable. (Source: Adapted from USGS 2021 Review and Revision of the U.S. Critical Minerals List)*

What Do Critical Mineral Import Limitations Mean for Space Supply Chains?

Of the 50 critical minerals listed by the United States Department of Interior, U.S. Geological Survey (USGS), many have implications for space supply chains (see Table 1). For instance, if germanium and gallium are not easily accessible to the space sector, manufacturers might need to default to inferior or lower flight heritage materials to meet domestic demand. This could result in a space system's degraded performance and potentially compromise support to U.S. civil and national security missions.

Gallium, an uncommon metal in the Earth's crust, is extracted as a trace element in other minerals like zinc ore and bauxite, or aluminum ore.[10] The U.S. Geological Survey (USGS) states that large reserves of gallium exist globally, but that "less than 10% of the gallium in bauxite and zinc resources is

Table 1: Critical Minerals for Space Technologies

Mineral	Space Application	Producers
Cerium (Ce)	Polishing compound, gamma-ray spectrometer, cover glass doping for III-V solar cells	Canada, Australia
Dysprosium (Dy)	Doping material in ceramic capacitors	China
Erbium (Er)	Doping material for optical fibers, space gyroscopes, and ceramic capacitors	Primarily China
Gallium (Ga)	Radar, integrated circuits	China
Germanium (Ge)	Lenses, solar cells, electronics	China, Belgium, United States
Lithium (Li)	Rechargeable batteries	Argentina, Chile, China
Niobium (Nb)	Alloys and metal used in rocket engines and nozzles	Brazil, Canada
Palladium (Pd)	Semiconductors	Russia, South Africa
Samarium (Sm)	Permanent magnets, cryocoolers	Primarily China
Vanadium (V)	Aircraft engines, cabin frameworks, strengthens titanium	Canada, China, Brazil, Austria, Russia
Ytterbium (Yb)	Doping optical fibers	Primarily China

potentially recoverable."[11] The United States has not recovered primary gallium since 1987.[12] It imports 100 percent of its gallium, with around 53 percent of the United States' gallium imports originating from China.[13] China produces about 80 percent of the world's gallium and 98 percent of primary low-purity gallium.[14]

In addition to gallium, China has recently targeted another rare element, germanium (Ge), as part of its recent initiative to monopolize critical minerals. Germanium is acquired through zinc ore processing and can also be found in ash and coal fly dust.[15] Over half of U.S. germanium demand is satisfied through imports, primarily from Belgium and China.[16] China is the leading germanium producer, producing approximately 60 percent of the world's germanium and 54 percent of U.S. germanium imports.[17] The United States has a limited stockpile of germanium reserves and produces only a small amount of germanium domestically.[18]

The Aerospace Corporation tracks strategic materials and performs systematic analysis for space applications. These results were outlined in the detailed study "Strategic Materials List for National Security Space," initially published in 2013, which included periodic updates since the initial report. Joe Cheng, one of the report's authors, notes that the recent restrictions by China elevate risk postures for certain minerals—including both gallium and germanium.

Gallium and Germanium Applications. Gallium is used in integrated circuits, optoelectronic devices, LED displays, radar devices, and laser diodes. Gallium arsenide (GaAs), the most common form of gallium usage, is crucial for technical applications such as high-efficiency III-V solar cells, satellite microwave power transistors, semiconductor wafers, and telecommunications.[19] GaAs has a higher bandgap* than silicon for semiconductor applications, which significantly increases efficiency and speed.[20] Gallium solar panels were used to power the Mars exploration rovers, Spirit and Opportunity, with solar energy due to gallium solar panel's high efficiency and resiliency.[21] Furthermore, gallium nitride (GaN) has led to large technical and electrical performance advancements in space. GaN field-effect transistors are particularly ideal for power in small satellites as they allow more efficient switching, higher frequency operation, reduced circuit voltage†, and offer smaller and lighter weight solutions compared to their traditional silicon counter parts.[22]

Germanium is used for "electronics and solar applications, fiber-optic systems, infrared optics, and polymerization catalysts." [23] Germanium is essential for telecommunications, lenses, solar cells, satellite imagery sensors, and night-vision devices.[24] The space sector uses germanium to produce infrared optical systems for lenses and windows as well as high-efficiency solar cell substrates that are utilized in most national security missions. According to one commercial manufacturer, germanium-based solar cells convert up to twice as much light into electricity as their silicon-based counterparts and are more resistant to damaging cosmic radiation than silicon.[25]

Market and Substitution Risks. The fates of most industrial economies are tightly tethered to a reliable supply of raw materials and minerals. But the space industry has certain attributes that make it even more vulnerable to supply chain disruptions and critical mineral uncertainty.

Volume and Volatility. The space sector is expanding quickly, due in part to the massive rollout of low Earth orbit (LEO) broadband constellations.[26] Despite the impressive growth, satellite quantities are relatively small compared to other industries, and suppliers often prioritize high-volume industry customers when fulfilling orders.[27] Additionally, the space industry has not achieved a steady production tempo. Instead, the space industry functions by using a launch-on-need approach that depends on a range of customer specific factors such as sporadic constellation refresh schedules and government acquisition programs.[28] This type of demand volatility can lead to fluctuations in parts and materials demand, which can create ripple effects throughout the supply chain. And unlike other industries that might build supply chain resilience by seeking out replacement materials, the space industry knows all too well the unpredictable nature of metals in the harsh environment of space and the risks that new substitute materials can introduce.

Substitutions Risks. The performance bar is high for both germanium and gallium in national security applications. Most critical minerals are irreplaceable, and substitutes decrease performance quality and efficiency. Silicon–germanium alloys have provided thermal to electrical conversion for many of NASA's lightweight, compact spacecraft

*A band gap, the distance between the valence band of electrons and the conduction band, represents the minimum energy that is required to excite an electron up to a state in the conduction band where it can participate in conduction.
†Gate drive voltage is one of the primary considerations when designing switch-mode converters for optimum performance, efficiency, and speed of the circuit.

power systems for nearly all deep space flights, such as Pioneer I and II, Voyager I and 11, Ulysses, Galileo, and Cassini. Even after one billion cumulative hours, there has never been a failure of these nuclear battery systems—a remarkable success that sets a high standard for any potential substitute material.[29]

The performance bar is equally high for GaN, an inherently radiation-resistant material that is critical for surviving the harsh space environment. Recognizing GaN as a "key enabling technology for space," the European Space Agency (ESA) went so far as to establish the "GaN Reliability Enhancement and Technology Transfer Initiative," known as GREAT.[30] Created in 2008, GREAT brings together industry and research initiatives to assist in the formation of an independent European GaN supply chain for space applications.

Given the unique features and high-performance statistics for germanium and gallium, are there substitute materials that can measure up? Perhaps, but the wrong substitute material can be devastating. For instance, worldwide efforts to eliminate lead, a toxic metal, has introduced other challenges. The electronics industry has shifted away from lead, a popular choice for coating and plating electronics hardware. As a response to the shift away from lead, the satellite industry replaced a tin-lead alloy with pure tin plating for coating metal surfaces of electrical connectors, components, and adjacent conductors. However, it soon became clear that tin is prone to spontaneous production of "whiskers" which can cause electrical shorts.[‡]

According to The Aerospace Corporation's Maribeth Mason, "the substitution of pure tin-plated parts for tin-lead plated parts has introduced costly complications for space programs with high reliability requirements. Today it should come as no surprise that working with any new material requires development of additional processes for risk mitigation, training, and inventory management."

One clear lesson is that industries must conduct due diligence and verify alternatives to ensure substitute materials do not compromise spacecraft reliability. Also, at least during the first few years, the introduction of substitute materials for gallium and germanium will decrease "proven flight heritage," an often-used risk indicator. Over time, however, operating satellites with new materials will help establish flight heritage and gain confidence in new substitute materials.

Government agencies such as the National Aeronautics and Space Administration (NASA), the Defense Advanced Research Projects Agency (DARPA), the U.S. Air Force, and the Department of Commerce National Institute of Standards and Technology (NIST) research, test, and set standards for materials used in space technologies. These organizations could assist in researching suitable alternatives to critical minerals amid shortages.

What Are the Policy and Strategy Options?

The age of increasing geopolitical complexity has intensified supply chain risks faced by the United States and other countries. A precise understanding of any country or industry supply chain is virtually impossible because modern supply chains are dynamic with multiple tiers; quantifying the risk is difficult; and proprietary data restrictions impede progress to sharing supply chain information.[31] Still, there are a range of existing commercial software and artificial intelligence (AI)-based tools that could offer some predictive insight into supply chain risks.[32] Gaining an understanding of where a country's

[‡] Most metals are capable of whisker production when under stress. However, tin is particularly prone to this phenomenon.

supply chain vulnerabilities lie is the first step toward considering targeted and coordinated industrial policy actions.

United States industrial policy has traditionally followed a market-led approach. While there are many advantages to a free market approach, competing with centrally planned economies can lead to an uneven playing field. Chinese industrial policies, for instance, often steer the government to heavily subsidize certain mineral industries that are strategic for its national and economic security. By contrast, U.S. industrial policies have historically yielded control, risks, and rewards to the commercial sector, such as mining companies who must carefully consider market and operational viability before investing.[§]

Despite a historical reliance on free markets for natural resources, mineral security concerns stretch back to 1939, when the U.S. Congress enacted the "Strategic and Critical Materials Stock Piling Act," a federal law intended to address situations where "certain strategic and critical materials are deficient or insufficiently developed to supply the military, industrial, and essential civilian needs of the United States for national defense." It also provided "for the acquisition and retention of stocks of certain strategic and critical materials" and to "decrease and to preclude, when possible, a dangerous and costly dependence by the United States upon foreign sources or a single point of failure for supplies of such materials in times of national emergency." This legislation (50 USC 98) established the National Defense Stockpile to serve the interest of national defense only.[33]

More recently, the White House has acknowledged the "geopolitical necessity" to be more proactive and has called for "supply-chain diplomacy" — working with "18 close trading partners to make our collective supply chains more secure, diverse, resilient, and sustainable against disruptions".[34] Congress has also responded to mineral security concerns. In December 2023, the National Defense Authorization Act, or NDAA, was signed into law[**] and authorized annual military spending and policies, including allowing the Secretary of Defense to enter into "one or more multiyear contracts for the procurement of critical minerals that are processed in the United States by domestic sources." The NDAA notes that these multiyear contracts are "deemed to be an acquisition under the Strategic and Critical Materials Stock Piling Act (50 U.S.C. 98 et seq.).[35] The NDAA also calls out the Secretary of Defense to issue policies and establish procedures to identify DOD end-of-life equipment that "contains rare earth elements and other materials" pursuant to the Strategic and Critical Materials Stock Piling Act (50 U.S.C. 98b(a)).

With a growing recognition that the globalization pendulum is swinging away from offshoring production to cut costs and toward greater supply chain reliability, many countries, including the United States, are encouraging industrial policy changes. In fact, the International Energy Agency (IEA) has identified over 200 regulations from 25 countries and regions. These policies "address many different goals, including ensuring supply reliability and resilience, promoting exploration, production, and innovation as well as encouraging sustainable and responsible practices."[36]

To this end, the United States and its allies are increasingly recognizing the need for effective

[§] Unlike the United Kingdom and most countries in Europe, subsurface minerals in the United States are largely owned by the private sector which can limit government's active control of mining operations.
[**] The U.S. Congress passes this major piece of legislation every year and authorizes spending for the DOD and national security programs within the Department of Energy (DOE). The 2024 NDAA authorized $886 billion.

policies to support industries that rely heavily on critical minerals. For instance, The Inflation Reduction Act of 2022 states a commitment to increase the domestic U.S. supply of critical minerals, specifically lithium, nickel, manganese, and graphite to support the increased production of electric vehicles (EVs), batteries, and renewable power production infrastructure. Likewise, the European Union's Critical Raw Materials Act (2023), Australia's Critical Minerals Strategy (2019), and Canada's Critical Minerals Strategy (2022) emphasize the need to increase and diversify their own critical raw materials supply. As the space industry develops a critical mineral strategy, collaboration with high-volume industries could strengthen the space industry's buying power and market influence.[37] For instance, the amount of critical minerals needed for utility scale solar energy plants or windfarms is enormous. Similarly, the manufacturing scale of EVs dwarfs the satellite industry. Accordingly, the following five policy or strategy options should be considered within the broader context of collaboration with other industries and friendly nations (listed in approximate order of time and feasibility constraints).

1. **Recycling.** Extract strategic minerals from scrap and by-products.
2. **Stockpiling.** Increase the amount of required domestic strategic stockpiles.
3. **Domestic Production.** Stimulate production and processing of minerals within the United States and Canada.
4. **Partnerships.** Strengthen our agreements and reliance on mineral-rich allies.
5. **Seabed Frontiers.** Influence future policies for seabed mineral extraction.

For addressing key mineral shortfalls in the defense industrial base, the Defense Production Act (DPA) of 1950 can be invoked to ensure resilient supply chains and to reduce reliance on foreign manufacturing. The DPA, specifically Title III, allows the president to direct industry to prioritize contracts that the government deems important for national security, including expanding the supply of materials. The DPA could be applied to encourage the following five types of supply chain responses.

1. Increase Domestic Recycling Efforts. The U.S. government could issue guidelines on sustainability and recycling to increase the domestic supplies of gallium and germanium. Mineral recycling can be challenging, especially with germanium and gallium. A 2023 study showed that the European Union (EU) met 0 percent of its gallium demand and 2 percent of its germanium needs from end-of-life recycling.[38] End-of-life recycling for gallium is extremely difficult due to the nature of the mineral, yet opportunities exist, such as reprocessing industrial production residue, to increase the amount of gallium.[39] For example, Gallium recycling for GaAs is extremely limited, and many technological designs do not optimize the amount that could be recycled.[40] However, companies are now emphasizing resource depletion[††] as a key metric for environmental, sustainability, and governance (ESG) scores. Following recent Title III applications, domestic companies working with the Department of Defense (DOD) are now prioritizing large germanium recovery projects from product waste and scrap. Strategic recycling efforts could also address other important materials with vulnerable supply chains such as titanium, a key metal for rocket bodies and space structures; lithium that is specially adapted for space satellite batteries; as well as gallium and

[††]Resource depletion occurs when resources are consumed at a rate faster than their replenishment.

germanium. Notably, coal fly ash contains gallium and germanium, and mineral recovery from burnt coal is feasible. Although germanium and gallium recovery from post-consumer finished products presents difficulties, both can be reclaimed and recycled at high rates from new scrap and fed back into the manufacturing process.[41]

2. Augment Domestic Stockpiles. Executive Order 14051 from 2021, "Designation to Exercise Authority Over the National Defense Stockpile," attempted to increase the National Defense Stockpile for critical materials. Today, the United States still has no domestic gallium reserves and limited germanium reserves.[42]

The United States could allocate more funding and efforts toward creating a strategic reserve of critical minerals for the National Defense Stockpile to hedge supply risk. Since 1992, Canadian companies can assist in stockpiling efforts and receive grants due to Canada's explicit inclusion as a "domestic source" in the Defense Production Act.[43] Last year, the White House stated that, "Canada is a preferred partner…with critical mineral resources and expertise that could be leveraged to expand processing capacity and the manufacturing of intermediate and final goods." [44]

U.S.–Canada collaboration can be used to support stockpiling. There are successful examples of stockpiling, such as the Defense Logistics Agency's 2012 grant to Utah's Sylarus Technologies, LLC (a subsidiary of 5N Plus; Montreal, Canada) to manufacture germanium substrates.[45] The grant provided the United States with a domestic supplier[‡‡] of germanium wafers and contributed to the National Defense Stockpile high-purity germanium metal inventory for unfinished germanium substrates, used in the manufacture of multijunction photovoltaic solar cells.

3. Stimulate Domestic Production. The United States has a wealth of domestic mineral resources and could stimulate domestic production; for example:

- **Apex Mine** (Utah) is the first mine in the world to be operated primarily for germanium and gallium, produced until the mine's closure in the 1980s.[46]

- **USA Rare Earth LLC** (Tampa, Florida) is the majority owner of the Round Top deposit in Texas[§§] and plans on beginning domestic gallium production.[47]

At the same time, the high costs of production, environmental consequences, and stringent permitting have stifled domestic production of critical minerals. The federal government has made efforts to stimulate domestic production by addressing industry concerns such as a White House directive to expedite federal agency permitting and update mining laws in May 2023.[48] While expedited mining permits do not bypass regulations designed to protect human health and the environment, they can sometimes allow the United States to move faster to enable domestic mining of minerals. An Arizona manganese[***] and zinc mine, for instance, is using the Permitting Council, a unique federal agency charged with improving timeliness, transparency, and predictability for environmental review of critical infrastructure projects. The domestic recovery of gallium and germanium as by-products from other mineral processes could also be

[‡‡]"domestic" in terms of geography, not by corporate control or ownership.
[§§]There are currently no domestic producers of gallium.
[***]The Hermosa project in southern Arizona intends to supply battery-grade manganese to the rapidly forming North American electric vehicle supply chain. Currently, the United States is 100 percent reliant on foreign sources for manganese.

a viable option that does not require significant regulatory changes. The DOD is already planning to leverage the DPA for gallium recovery from other waste streams, including end-of-life equipment recycling which is authorized by the 2024 NDAA.[49]

Another constraint is that mining is a water-intensive industry, with large amounts used for mineral processing, tailings and waste management, and dust suppression. The western United States enjoys a bounty of minerals,[†††] but the top mineral producing states have suffered long periods of drought and water shortages. The situation is dire for Arizona, the top mining producer. With competing demands from agriculture and a growing population, mining in the western United States has become particularly challenging.[50] The DPA may be able to stimulate mining within the United States, but limited domestic production will not be able to counteract supply chain shortages in a meaningful, high-volume way. Thus, other options must be considered in tandem with or as an alternative to domestic production, such as increasing imports of raw and refined materials from allies.

In addition to ore extraction to produce critical minerals, the United States should examine how to advance domestic mineral processing, smelting, and refining capabilities to reduce its reliance on other nations with unique strategic mineral specialties. Consider the cautionary tale of Magnequench, an Indianapolis-based company that supplies 85 percent of the rare-earth magnets used in rotary actuators for precise control of guided missiles and bombs. The acquisition of Magnequench by a Chinese company underscores the need to preserve critical mineral refinement expertise within the United States to help secure the nation's defense supply chain.[51] After the acquisition of Magnequench, domestic producers shifted to outsourcing to cheaper mineral processing and refining plants overseas. As a result, the United States lost its rare earth element processing expertise.

4. Invest in Partnerships with Key Nations. Although the United States has critical mineral resources, the environmental and legal regulations to begin mining domestically require significant capital investment and time. It is inevitable that the United States will need to rely on foreign nations for certain minerals.

The Belt and Road Initiative[‡‡‡] has become the leading vision directing China's international engagements, including its expansion into new mineral markets. China already depends on critical mineral imports, such as bauxite from Australia and cobalt from the Democratic Republic of the Congo, to avoid the costs and consequences of mining.

For certain countries with high corruption rates and/or poor credit ratings, China has adeptly used resource back loans (RBLs), allowing repayment in commodities. These loans are repaid with or collateralized with natural resources, such as minerals.[52] RBLs have paved the path to new resources for China, including Latin American and African mineral markets. For instance, China buys most of Brazil's niobium and acquires African minerals, like bauxite from Ghana, from loan financing repayments.[53]

[†††]The United States Geological Survey (USGS) rated states by value of minerals extracted. The top four mineral producing states are Arizona (10.3 percent), Nevada (9.1 percent), Texas (8.2 percent) and California (5.7 percent).
[‡‡‡]China's Belt and Road Initiative (2013) involves enormous infrastructure investments to support trade and growth. However, China's borrowing arrangements with some countries might leave debt traps for borrowing governments. (Source: Council on Foreign Relations, "China's Massive Belt and Road Initiative," February 2, 2023.)

Fortunately, the United States benefits from strong alliances with two preeminent mineral producers, Canada and Australia, to support its own supply chain. Since the September 2021 signing of the trilateral partnership between Australia, the United Kingdom, and the United States, the AUKUS security pact has focused on military capabilities, such as nuclear-powered submarines. However, given Australia's extensive mining industry, this partnership could be leveraged to address critical mineral shortages that are strategic for both civilian and defense purposes. The Australian Strategic Policy Institute has also suggested that the Quad, a partnership between Australia, India, Japan, and the United States, could also be a pillar in Australia's foreign policy to provide the world with an alternative, resilient rare-earth, and critical-mineral supply chain.[54]

Australia is a mineral-wealthy nation with a robust mining industry. In 2021 and 2022, Australia's exports of minerals, metals, and energy commodities were worth $413 billion and accounted for 69 percent of total export revenue.[55] Australia has the world's second largest bauxite resources, 22 percent of the global supply.[56] In comparison, China has a mere 4 percent of global bauxite resources. However, China's competitive advantage extends beyond mineral wealth. China has extensive expertise with processing, refining, and smelting industrial minerals.[57] These strategic capabilities allow it to process and refine almost as much bauxite as Australia. Most of Australia's bauxite is refined domestically, yet 95 percent of Australia's bauxite exports go to China to supply its vast manufacturing operations.[58]

Supported by two partnership pillars, AUKUS and the Quad, Australia is in a prime position to capitalize on its critical mineral resources. Furthermore, partnerships to secure critical mineral supply chains already exist between the United States and Australia, such as the Minerals Security Partnership, which includes other friendly nations such as Canada, Finland, France, Germany, Japan, the Republic of Korea, Sweden, the United Kingdom, and the European Commission.[59] Additionally, the U.S.-Australia Critical Minerals Working Group focuses on similar bilateral collaboration. Lastly, the United States is considering adding Australia as a "domestic source," like Canada, to be able to invoke DPA Title III powers and other policy levers to encourage foreign supply chain investments.[60]

5. Influence Future Policies for Seabed Mining as a Mineral Frontier

While countries continue to exploit and deplete terrestrial ore deposits, new sources for mineral recovery are also being evaluated, like seabed mining. The growth of clean technologies and the demand for minerals associated with rechargeable batteries, wind turbine magnets, and electric vehicle motors is driving interest in seabed mining. Minerals such as nickel, cobalt, manganese, iron, copper, and rare earth elements can be found in seafloor deposits, such as polymetallic nodules, polymetallic sulfides, and ferromanganese or cobalt crusts.[61]

Due to increasing interest in valuable seabed minerals, the International Seabed Authority (ISA) was established in 1994 as an autonomous organization under the 1982 United Nations Convention on the Law of the Sea (UNCLOS). However, the United States' nonratification of UNCLOS leaves American interests in an ambiguous situation. Some legal experts assert that the Unites States is authorized "to claim and exploit natural resources" beyond the boundaries of national jurisdiction and is not bound by UNCLOS and ISA regulations while others argue that the "US is in fact barred from any deep sea mining activities beyond national jurisdiction."[62] Either way, China is not waiting for legal clarification. As a signatory to UNCLOS, and despite its assertive claims over the South China Sea that are contrary to UNCLOS, China is now wielding influence at ISA where it is "by far the most powerful player."[63]

While there is currently no commercial scale mining of seabed minerals, the International Seabed Authority granted some exploration licenses for polymetallic nodules[§§§] in the Pacific Ocean. These nodules sit on the ocean floor and can be harvested and brought to the surface relatively quickly using a riser system and a surface transport vessel. Compared to land-based mine operations requiring open pits, drilling, blasting, and excavation, seabed mining is relatively straightforward. Not surprisingly, some believe that deep sea mining could trigger the next global resource scramble. However, controversy exists. Environmentalists have already pointed out the effects of sediment plumes and the potential destruction of ocean floor ecosystems. Some research scientists have warned that once these ecosystems are damaged, they never fully recover.[64]

Because the United States has not ratified UNCLOS and is merely an observer state, it risks "being sidelined as the rules for this future industry are being made." To avoid such a fate, the satellite sector can work in concert with other influential industries to protect seabed ecosystems and ensure that China and other competing nations are not allowed a competitive advantage due to biased and opportunistic interpretations of UNCLOS and emerging seabed mining regulations.[65]

Conclusion

The time is now for the United States to mitigate key mineral shortages. Gallium, germanium, and other critical minerals are accessible globally to the United States and its allies, yet China remains the primary supplier for many critical minerals. With China tightening its grip on limited mineral supplies, the United States and its allies could respond with a multifaceted strategy to secure critical mineral supplies including recycling, stockpiling, stimulating domestic production, near-shoring, and ally-shoring. The DOD has already invoked the DPA to support production and stockpiling of minerals like lithium and cobalt and, more recently, an expedited mining permit for manganese and zinc.[66]

The Secretary of the Interior, in coordination with the Secretary of Defense, has listed 50 critical minerals that constitute a strategic vulnerability for the security and prosperity of the United States. Moving forward, the United States may face further limitations on access to these minerals.[67] A former Chinese deputy commerce minister was quoted as saying that the germanium and gallium export restrictions were "just the start."[68] As impactful as the restrictions on gallium and germanium are for the U.S. space sector, these issues are part of a larger picture. Access to other minerals just as vital for the space sector, like titanium and niobium, are already controlled by China and risk the same supply interferences and market manipulations. One U.S. mining company representative noted that "China has the power to control global prices of rare earths, which gives them the opportunity to shut out competitors on the world stage."[69] However, the ability to dominate and control the mineral market is tempered by China's need to generate revenue from mineral exports. For this reason, export restrictions can only go so far before they become self-destructive to China's own economy.

China's state-level mineral strategy will most likely put greater pressure on the United States and its allies to consider a coordinated strategy to ensure a reliable critical minerals supply. Responding to

[§§§]Polymetallic nodules are known to contain metals such as manganese, iron, copper, nickel, cobalt, lead and zinc, with important but minor concentrations of molybdenum, lithium, titanium, and niobium, among others.

market dominance and gamesmanship requires an agile countervailing strategy that is contrary to the more laissez faire free market approach that the United States has historically relied on and expects. In all, not just one policy lever will fulfill the demand for critical minerals. Instead, a comprehensive approach must be taken to strengthen supply chains, now and in the future. For now, every critical mineral is essential for U.S. national and economic security, and a diversified agile and resilient mineral supply chain will benefit not only the space sector but the nation as a whole.

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