Excerpt From:

BUILDING RESILIENT SUPPLY CHAINS, REVITALIZING AMERICAN MANUFACTURING, AND FOSTERING BROAD-BASED GROWTH

100-Day Reviews under Executive Order 14017

BUILDING RESILIENT SUPPLY CHAINS, REVITALIZING AMERICAN MANUFACTURING, AND FOSTERING BROAD-BASED GROWTH

100-Day Reviews under
Executive Order 14017

June 2021

A Report by
The White House

Including Reviews by
Department of Commerce
Department of Energy
Department of Defense
Department of Health and Human Services

THE WHITE HOUSE
WASHINGTON

BUILDING RESILIENT SUPPLY CHAINS, REVITALIZING AMERICAN MANUFACTURING, AND FOSTERING BROAD-BASED GROWTH

June 2021

TABLE OF CONTENTS

INTRODUCTORY NOTE

FROM NATIONAL ECONOMIC COUNCIL DIRECTOR BRIAN DEESE AND NATIONAL SECURITY ADVISOR JAKE SULLIVAN TO THE PRESIDENT

Mr. President:

It is our privilege to transmit to you the first set of reports that your Administration has developed pursuant to Executive Order 14017, "America's Supply Chains." The enclosed reports assess supply chain vulnerabilities across four key products that you directed your Administration to review within 100 days: semiconductor manufacturing and advanced packaging; large capacity batteries, like those for electric vehicles; critical minerals and materials; and pharmaceuticals and advanced pharmaceutical ingredients (APIs).

The enclosed reports are the work of a task force that we convened across more than a dozen departments and agencies, consultations with hundreds of stakeholders, public comments submitted by industry and experts, and deep analytic research by experts from across the government. We would like to particularly thank the four agencies that took the lead in authoring each of the enclosed reports: the Department of Commerce on semiconductor manufacturing and advanced packaging; the Department of Energy on large capacity batteries; the Department of Defense on critical materials and minerals; and the Department of Health and Human Services, particularly the Food and Drug Administration, on pharmaceuticals and APIs. This work has complemented other work your Administration has undertaken to strengthen U.S. supply chains, including the work to dramatically expand the supply of COVID-19 vaccines and other products essential to American's health.

Departments and Agencies across your Administration have already begun to implement the reports' recommendations. These include steps to strengthen U.S. manufacturing capacity for critical goods, to recruit and train workers to make critical products here at home, to invest in research and development that will reduce supply chain vulnerabilities, and to work with America's allies and partners to strengthen collective supply chain resilience. Both the public and private sector play critical roles in strengthening supply chains, and your Administration will continue to work with industry, labor, and others to make America's supply chains stronger.

We have already launched the second phase of the supply chain initiative you directed in E.O. 14017, which reviews six critical industrial base sectors that underpin America's economic and national security: the defense industrial base, public health and biological preparedness industrial base, information and communications technology industrial base, energy sector industrial base, transportation industrial base, and supply chains for production of agricultural commodities and food products. We will report back to you on those sectors by February 24, 2022, the one-year mark of your signing E.O. 14017.

The 100-day reports make clear: more secure and resilient supply chains are essential to our national security, our economic security, and our technological leadership. The work of strengthening America's critical supply chains will require sustained focus and investment. Building manufacturing capacity, increasing job quality and worker readiness, inventing and commercializing new products, and strengthening relations with America's allies and partners will not be done overnight. We are committed to carrying this work forward across your Administration to ensure that America's critical supply chains are resilient and secure for the years to come.

JAKE SULLIVAN, Assistant to the President for National Security Affairs

BRIAN DEESE, Assistant to the President for Economic Policy and Director of the National Economic Council

EXECUTIVE SUMMARY

FOR E.O. 14017 REPORTS DUE JUNE 4, 2021

I. Introduction:

The COVID-19 pandemic and resulting economic dislocation revealed long-standing vulnerabilities in our supply chains. The pandemic's drastic impacts on demand patterns for a range of medical products including essential medicines wreaked havoc on the U.S. healthcare system. As the world shifted to work and learn from home, it created a global semiconductor chip shortage impacting automotive, industrial, and communications products, among others. In February, extreme weather events—exacerbated by climate change—further exacerbated these shortages. In recent months the strong U.S. economic rebound and shifting demand patterns have strained supply chains in other key products, such as lumber, and increased strain on U.S. transportation and shipping networks.

On February 24, 2021, President Biden signed Executive Order (E.O.) 14017, "America's Supply Chains," in which he directed the U.S. government to undertake a comprehensive review of critical U.S. supply chains to identify risks, address vulnerabilities and develop a strategy to promote resilience. When the President signed the order, he invoked an old proverb: "For want of a nail, the shoe was lost. For want of a shoe, the horse was lost." And on, and on, until the kingdom was lost. Small failures at even one point in supply chains can impact America's security, jobs, families, and communities.

To undertake this comprehensive review, the Biden Administration established an internal task force spanning more than a dozen Federal Departments and Agencies. Administration officials consulted with hundreds of stakeholders from labor, business, academic institutions, Congress, and U.S. allies and partners to identify vulnerabilities and develop solutions. Federal Departments and Agencies received hundreds of written submissions in response to requests for public input into the supply chain initiative. Dozens of experts across the interagency have been conducting detailed studies of U.S. supply chains for critical products and developing policies that will strengthen resilience.

What follows summarizes the findings of the initial set of reviews of the supply chains of four critical products: semiconductor manufacturing and advanced packaging; large capacity batteries; critical minerals and materials and pharmaceuticals and active pharmaceutical ingredients (APIs).

Why Resilient Supply Chains Matter

More secure and resilient supply chains are essential for our national security, our economic security, and our technological leadership.

National security experts, including the Department of Defense, have consistently argued that the nation's underlying commercial industrial foundations are central to our security. Reports from both Republican and Democratic administrations have raised concerns about the defense industry's reliance on limited domestic suppliers;[1] a global supply chain vulnerable to disruption; and competitor country suppliers. Innovations essential to military preparedness—like highly specialized lithium-ion batteries—require an ecosystem of innovation, skills, and production facilities that the United States currently lacks. The disappearance of domestic production of essential antibiotics impairs our ability to counter threats ranging from pandemics to bio-terrorism, as emphasized by the FDA's analysis of supply chains for active pharmaceutical ingredients.

[1] Department of Defense, "Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency," 2018 (https://media.defense.gov/2018/Oct/05/2002048904/-1/-1/1/ASSESSING-AND-STRENGTHENING-THE-MANUFACTURING-AND-DEFENSE-INDUSTRIAL-BASE-AND-SUPPLY-CHAIN-RESILIENCY.PDF).

Our economic security—steady employment and smooth operations of critical industries—also requires secure and resilient supply chains. For more than a decade, the Department of Defense has consistently found that essential civilian industries would bear the preponderance of harm from a disruption of strategic and critical materials supply. The Department of Energy notes that, today, China refines 60 percent of the world's lithium and 80 percent of the world's cobalt, two core inputs to high-capacity batteries—which presents a critical vulnerability to the future of the U.S. domestic auto industry.

Finally, our domestic innovation capacity is contingent on a robust and diversified industrial base. When manufacturing heads offshore, innovation follows. The Department of Commerce notes that large-scale public investment in semiconductor fabrication has allowed Korean and Taiwanese firms to outpace U.S.-based firms. As the Department of Commerce warns, "ultimately, volume drives both innovation and operational learning; in the absence of the commercial volume, the United States will not be able to keep up […] with the technology, in terms of quality, cost, or workforce."

A New Approach

A resilient supply chain is one that recovers quickly from an unexpected event. Our private sector and public policy approach to domestic production, which for years, prioritized efficiency and low costs over security, sustainability and resilience, has resulted in the supply chain risks identified in this report. That approach has also undermined the prosperity and health of American workers and the ability to manage natural resources domestically and globally. As the Administration sets out on a course to revitalize our manufacturing base and secure global supply chains, rebuilding for resilience at the national level requires a renewed focus on broad-based growth and sustainability.

America's approach to resilient supply chains must build on our nation's greatest strengths—our unrivaled innovation ecosystem, our people, our vast ethnic, racial, and regional diversity, our small and medium-sized businesses, and our strong relationships with allies and partners who share our values.

As multiple reports note, the United States maintains an unparalleled innovation ecosystem with world-class universities, research centers, start-ups and incubators, attracting top talent from around the world. The Administration must double-down on our innovation infrastructure, reinvesting in research and development (R&D) and accelerating our ability to move innovations from the lab to the marketplace.

American workers must be the foundation for resilience. Resilient production requires quick problem-solving, driven by the knowledge, leadership, and full engagement of people on the factory floor. Decades of focusing on labor as a cost to be controlled—not an asset to be invested in—have depressed real wages and driven down union-density for workers, while also contributing to companies' challenges finding and keeping skilled talent. We must focus on creating pathways for all Americans to access well paid jobs with the free and fair choice to organize and bargain collectively.

We must ensure that economic opportunities are available in all parts of the country and for women, people of color, and others who are too often left behind. Inequality in income, race, and geography is keeping millions of potential workers, researchers, and entrepreneurs from contributing fully to growth and innovation. Today, children with the talents to become inventors, are less likely to become patent holders if they are low-income, women, African American, Latino, or from disadvantaged regions[2]. The Administration's approach must provide access and pathways for these "lost Einsteins"—workers, researchers, and businesses-owners in the growing industries of the 21st century.

A robust and resilient supply chain must include a diverse and healthy ecosystem of suppliers. Therefore, we must rebuild our small and medium-sized business manufacturing base, which has borne the brunt of the hollowing out of U.S. manufacturing. We also need to diversify our international suppliers and reduce

[2] Alex Bell, Raj Chetty, Xavier Jaravel, Neviana Petkova, and John Van Reenan, "Who Becomes an Inventor in America? The Importance of Exposure to Innovation," November 2018, Harvard University, (http://www.equality-of-opportunity.org/assets/documents/inventors_summary.pdf).

geographic concentration risk. It is neither possible nor desirable to produce all essential American goods domestically. But for too long, the United States has taken certain features of global markets—especially the fear that companies and capital will flee to wherever wages, taxes and regulations are lowest—as inevitable. In the face of those same pressures, other countries successfully invested in policies that distributed the gains from globalization more broadly, including to workers and small businesses. We must press for a host of measures—tax, labor protections, environmental standards, and more—that help shape globalization to ensure it works for Americans as workers and as families, not merely as consumers. The Administration's approach to resilience must focus on building trade and investment partnerships with nations who share our values—valuing human dignity, worker rights, environmental protection, and democracy.

Finally, a new set of risks confronts U.S. policy makers and business leaders. Technological change and the power of cyber-attacks to derail the critical industries—from energy to agriculture—require new public-private approaches to resilience. And, we must confront the climate crisis. Meeting U.S. decarbonization aims will involve a massive domestic build out of clean energy technology; for an issue so central to U.S. economic and national security, we cannot afford to be agnostic to where these technologies are manufactured and where the associated supply chains and inputs originate.

A sector-by sector approach

The Biden-Harris Administration has already begun to take steps to address supply chain vulnerabilities. The Administration's COVID-19 Response Team has dramatically expanded the manufacture of vaccines and other essential supplies, enabling more than 137 million Americans to be fully vaccinated. The Administration has also worked with companies that manufacture and use computer chips to identify improvements in supply chain management practices that can strengthen the semiconductor supply chain over time. Just this year, the Department of Defense announced an investment in the expansion of the largest rare earth element mining and processing company outside of China. The Biden-Harris Administration is also working to address critical cyber vulnerabilities of U.S. supply chains and critical infrastructure, including issuing E.O. 14028 on "Improving the Nation's Cyber Security" just last month. The recommendations we are releasing today build on this work and provide a path forward for greater investment and growth.

Not all recommendations will be relevant to all sectors, and a sector by sector approach will continue to be necessary. Methods of guarding against single-source risk in the critical minerals supply chain, for example, is limited in part by where natural resources exist. Tools including ally and friend-shoring, and stockpiling, along with investments in sustainable domestic production and processing will all be necessary to strengthen resilience. Sectors where we seek to advance our technological competitiveness—like high-capacity batteries—will require an ecosystem-building approach that includes supporting domestic demand, investing in domestic production, recycling and R&D, and targeting support of the U.S. automotive workforce.

The remainder of this executive summary covers the E.O. 14017 process, key vulnerabilities across the four initial critical supply chains; recommendations for securing these vulnerable supply chains; and immediate actions the administration should take to address transitory supply chain challenges.

II. Critical Supply Chains Identified in E.0. 14017:

E.O. 14017 directed the government to focus initially on four key sets of products during the first 100 days following its signing. These initial priority products are:

- **Semiconductor manufacturing and advanced packaging:** Semiconductors are an essential component of electronic devices. The packaging, which may contain one or more semiconductors, provides an alternative avenue for innovation in density and size of products. Semiconductors have become ubiquitous in today's world. They enable telecommunications and grid infrastructure, run critical business and government systems, and are prevalent across a vast array of products from fridges to fighter jets. A new car, for example, may require more than 100 semiconductors for touch screens, engine controls, driver assistance cameras, and other systems.[3] The U.S. share of global semiconductor production has dropped from 37 percent in 1990 to 12 percent today, and is projected to decline further without a comprehensive U.S. strategy to support the industry.[4]

- **Large capacity batteries:** As the United States transitions away from fossil fuels for power generation and electrifies our automotive and trucking fleets, large capacity batteries for electric vehicles (EVs) and grid storage will be essential to U.S. economic and national security. Global demand for EV batteries is projected to grow from approximately 747 gigawatt hours (GWh) in 2020 to 2,492 gigawatt hours by 2025.[5] Absent policy intervention, U.S. production capacity is expected to increase to only 224 GWh during that period, but U.S. annual demand for passenger EVs will exceed that capacity.[6] Maintaining America's innovative and manufacturing edge in the automotive sector and other key industrial sectors will require the United States to undertake a concerted effort to shore-up sustainable critical material supply and processing capacity, expand domestic battery production, and support EV and storage adoption.

- **Critical minerals and materials:** The United States and other nations are dependent on a range of critical minerals and materials that are the building blocks of the products we use every day. Rare earths metals are essential to manufacturing everything from engines to airplanes to defense equipment. Demand for many of these metals is projected to surge over the next two decades, particularly as the world moves to eliminate net carbon emissions by 2050. For example, global demand for lithium and graphite, two of the most important materials for electric vehicle batteries, is estimated to grow by more than 4000 percent by 2040 in a scenario where the world achieves its climate goals, with graphite projected to grow nearly 2500 percent.[7] China was estimated to control 55 percent of global rare earths mining capacity in 2020 and 85 percent of rare earths refining.[8] The United States must secure reliable and sustainable supplies of critical minerals and metals to ensure resilience across U.S. manufacturing and defense needs, and do so in a manner consistent with America's labor, environmental, equity and other values.

- **Pharmaceuticals and active pharmaceutical ingredients (APIs):** The COVID-19 pandemic highlighted the critical importance of a resilient U.S. public health industrial base. We continue to address resilience challenges in the broader pandemic supply chain through actions prescribed in EO 14001, including a pandemic supply chain resilience strategy to be completed in July that will outline objectives and actions for long-term resilience. Thanks to the work by both government and the private sector, in less than a year the United States dramatically increased its capacity for vaccine production. But shortages of critical generic drugs and APIs have plagued the United States for years. Multiple factors, including lack of incentives to manufacture less profitable drugs and underinvestment in quality management, both at home and abroad, have resulted in

---

[3] Jack Ewing and Don Clark, "Lack of Tiny Parts Disrupts Auto Factories Worldwide," January 13, 2021, *The New York Times,* (https://www.nytimes.com/2021/01/13/business/auto-factories-semiconductor-chips.html).
[4] Antonio Varas, Raj Varadarajan, Jimmy Goodrich, and Falan Yinug, "Government Incentives and U.S. Competitiveness in Semiconductor Manufacturing," September, 2020, Boston Consulting Group and Semiconductor Industry Association, (https://www.semiconductors.org/wp-content/uploads/2020/09/Government-Incentives-and-US-Competitiveness-in-Semiconductor-Manufacturing-Sep-2020.pdf).
[5]"Lithium-Ion Battery Megafactory Assessment," Benchmark Mineral Intelligence, March 2021, (https://www.benchmarkminerals.com/megafactories/).
[6] Alice Yu and Mitzi Sumangil, "Top Electric Vehicle Markets Dominate Lithium-Ion Battery Capacity Growth," February 16, 2021, (https://www.spglobal.com/marketintelligence/en/news-insights/blog/top-electric-vehicle-markets-dominate-lithium-ion-battery-capacity-growth).
[7] International Energy Agency, "The Role of Critical Minerals in Clean Energy Transitions," May 2021, (https://iea.blob.core.windows.net/assets/24d5dfbb-a77a-4647-abcc-667867207f74/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf).
[8] Carl A. Williams, "China Continues Dominance of Rare Earths Markets to 2030, says Roskill," February 26, 2021, Mining.Com, (https://www.mining.com/china-continues-dominance-of-rare-earths-markets-to-2030-says-roskill).

fragile supply chains vulnerable to disruption. Further, 87 percent of generic API facilities are located overseas which has helped reduce costs by trillions of dollars in the past decade, but has left the U.S. health care system vulnerable to shortages of essential medicines.[9] While lack of data and supply chain transparency make it difficult to estimate the precise share of key U.S. drugs and APIs imported from abroad, China and India are estimated to control substantial parts of the supply chain.[10] A new approach is needed to ensure that Americans have reliable access to the life-saving medicines they need.

III. Drivers of Supply Chain Vulnerability:

Across the four critical products—and the diverse supply chains that underpin them—the Administration assessed a wide range of supply chain risks and vulnerabilities. The Administration examined risks throughout the supply chains, from the sourcing of raw materials through the manufacture and distribution of finished goods. Across the reports, there are a set of inter-related themes and findings that contribute to supply chain vulnerabilities. These are:

1. **Insufficient U.S. manufacturing capacity:** U.S. manufacturing capabilities have declined over the several decades. The first decade of the century was particularly devastating for U.S. manufacturing with the loss of one-third of manufacturing jobs between 2000 and 2010.[11] Small and medium enterprises (SMEs) were particularly hard hit. Some of this decline can be attributed to competition from low wage nations—economists have estimated that about 25 percent of the job losses can be attributed to the rise of China, particularly following its entrance into the World Trade Organization.[12] But the United States has also seen productivity growth stagnate internally and compared to economic peers, for example, trailing Germany on average and in most industries.[13] Today, in the Unites States, SMEs are often less productive than large manufacturers. Counter to popular beliefs that "the robots are coming," many SME manufacturers are underinvesting in new technology to increase their productivity.

   Our loss of manufacturing capabilities has led to a loss in innovation capacity.[14] Manufacturing capabilities underpin innovation in a range of products and once lost, are challenging to build back. In recent decades, when production capacity headed overseas, the R&D and broader industrial supply chains often followed.

2. **Misaligned Incentives and short-termism in private markets:** All four reports make clear that current U.S. market structures fail to reward firms for investing in quality, sustainability or

---

[9] Food and Drug Administration, Testimony before the House Committee on Energy and Commerce, Subcommittee on Health regarding "Safeguarding Pharmaceutical Supply Chains in a Global Economy," October 30, 2019, (https://www.fda.gov/news-events/congressional-testimony/safeguarding-pharmaceutical-supply-chains-global-economy-10302019).

[10] Yangzong Huang, "U.S. Dependence on Pharmaceutical Products from China," August 14, 2019, Council on Foreign Relations Blog, (https://www.cfr.org/blog/us-dependence-pharmaceutical-products-china).

[11] Organization for Economic Cooperation and Development (OECD), "U.S. Manufacturing Decline and the Rise of New Production Innovation Paradigms," 2016, (https://www.oecd.org/unitedstates/us-manufacturing-decline-and-the-rise-of-new-production-innovation-paradigms.htm#:~:text=The%20number%20of%20manufacturing%20jobs,just%2012.3%20million%20in%202016).

[12] David H. Autor, David Dorn, and Gordon H. Hanson, "The China syndrome: Local Labor Market Effects of Import Competition in the United States." *American Economic Review* 103, no. 6, 2013 (https://pubs.aeaweb.org/doi/pdfplus/10.1257/aer.103.6.2121).

[13] Martin Neil Baily, Barry Bosworth, and Siddhi Doshi, "Productivity Comparisons: Lessons from Japan, the United States, and Germany," 2019, The Brookings Institution (https://www.brookings.edu/wp-content/uploads/2020/01/ES-1.30.20-BailyBosworthDoshi.pdf).

[14] Gary P. Pisano and Willy C. Shih, Producing *Prosperity: Why America Needs a Manufacturing Renaissance* (Boston: Harvard Business Press, 2012).

long-term productivity. For example, about drug shortages over the past decade, the Department of Health and Human Services writes in its report, "the core of these failures is the inability of the market to reward quality." A lower-wage and lower-skilled workforce may increase a firm's quarterly earnings, but research suggests that "high-road' strategies can improve wages without harming profits.[15] Other kinds of investments—in capabilities for continuous improvement or in reducing lead time—incur an upfront cost, but lead to improved performance in both normal and crisis periods.[16] Under-investment in cyber security has left companies and critical infrastructure vulnerable to hacks and other cyberattacks.

A focus on maximizing short-term capital returns has led to the private sector's underinvestment in long-term resilience. For example, firms in the S&P 500 Index distributed 91 percent of net income to shareholders in either stock buybacks or dividends between 2009 and 2018.[17] This has meant a declining share of corporate income going into R&D, new facilities or resilient production processes.

3. **Industrial Policies Adopted by Allied, Partner, and Competitor Nations:** As U.S. investment in the domestic industrial base has declined, our allies, partners and competitors have adopted strategic programs to advance their own domestic competitiveness. The Department of Energy's analysis of the advanced battery supply chain documents the European Union's (EU) support for demand policies, investment incentives, and regulatory tools—at both the EU and member-state level—to stimulate domestic production of electric vehicles and lithium-ion batteries. After a 2019 EU report designating the battery of "strategic interest," the EU announced a $3.5 billion R&D fund to increase the industry's competitiveness. The Department of Commerce's analysis of the global semiconductor supply chain notes Taiwan—the global leader in production of the most advanced semiconductor chips—provides subsidies for fabrication facilities including 50 percent for land costs, 45 percent for construction and facilities and 25 percent for semiconductor, in addition to R&D investments and other incentives. South Korea's and Singapore's semiconductor subsidies reduce the cost of facility ownership by 25-30 percent.

   Across all four reports, China stands out for its aggressive use of measures—many of which are well outside globally accepted fair trading practices—to stimulate domestic production and capture global market share in critical supply chains. Several strategies, including public investments in R&D, domestic demand incentives, and strategic international partnerships have been used to support both resilience and competitiveness of key economic sectors.

4. **Geographic concentration in global sourcing:** To ensure resilient supply chains, it is essential that they be globalized. However, the search for low-cost production, combined with the effective industrial policy of key nations, has led to geographic concentrations of key supply chains in a few nations, increasing vulnerabilities for United States and global producers. Such concentration leaves companies vulnerable to disruption, whether caused by a natural disaster, a

---

[15] Thomas A. Kochan, Eileen Appelbaum, Jody Hoffer Gittell, and Carrie R. Leana, "The Human Capital Dimensions of Sustainable Investment: What Investment Analysts Need to Know," February 22, 2013 (https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2222657).

[16] Suzanne de Treville and Lenos Trigeorgis, "It May Be Cheaper to Manufacture at Home." *Harvard Business Review,* October 2010, (https://hbr.org/2010/10/it-may-be-cheaper-to-manufacture-at-home). JP MacDuffie, Daniel Heller, and Takahiro Fujimoto, "Building Supply Chain Continuity Capabilities for a Post-Pandemic World," Wharton School Working Paper, 2021 (https://mackinstitute.wharton.upenn.edu/2021/building-supply-chain-continuity-capabilities-for-a-post-pandemic-world).

[17] William Lazonick, Mustafa Erdem Sakinç, and Matt Hopkins, "Why Stock Buybacks are Dangerous for the Economy," *Harvard Business Review,* January 7, 2020 (https://hbr.org/2020/01/why-stock-buybacks-are-dangerous-for-the-economy).

geopolitical event or indeed, a global pandemic. From the studies conducted pursuant to E.O. 14017, it is clear in the Department of Commerce's report that the United States is dangerously dependent on specific countries for parts of the value chain of all of these products. The global economy depends on Taiwanese firms for 92 percent of leading-edge semiconductor production. China has over 75 percent of global cell fabrication capacity for advanced batteries, as noted in the Department of Energy's report. While the Department of Health and Human Services' data suggests India and China compete for market share of many U.S. medicines, industry analysis suggests India imports nearly 70 percent of its APIs from China.

5. **Limited International Coordination:** Prior to the COVID-19 pandemic, the U.S. government under-invested in international diplomatic efforts to develop collective approaches to supply chain security. While expanded domestic production of critical goods must be part of the solution to America's supply chain vulnerabilities, the United States cannot manufacture all needed products at home. Moreover, the United States has a strong national interest in U.S. allies and partners improving the resilience of their critical supply chains in face of challenges—such as the COVID-19 pandemic, extreme weather events due to climate change, and geopolitical competition with China—that affect both the United States and our allies. Yet aside from a handful of pilot projects and other comparatively small diplomatic and multilateral initiatives to secure supply chains, the United States has not systematically focused on building international cooperative mechanisms to support supply chain resilience.

It will take a concerted effort over the short-, medium- and long-term to adequately address these and put U.S. supply chains on stronger footing. The following recommendations provide an overarching framework for doing so that will ensure the country's national and economic security as well as technological leadership going forward.

RECOMMENDATIONS

The four reports delivered to the President today contain numerous recommendations to strengthen the individual product supply chains. There are also several cross-cutting themes and recommendations that, collectively, will not only strengthen the four prioritized supply chains, but also will rebuild the U.S. industrial base and innovation engine.

We divide the recommendations into six categories: 1) Rebuilding our production and innovation capabilities; 2) supporting the development of markets with high road production models, labor standards, and product quality; 3) leveraging the government's role as a market actor; 4) strengthening international trade rules, including trade enforcement mechanisms; 5) working with allies and partners to decrease vulnerabilities in the global supply chains; and 6) partnering with industry to take immediate action to address existing shortages.

1. Rebuild our production and innovation capabilities

Long-term competitiveness will require an ecosystem of production, innovation, skilled workers, and diverse small and medium-sized suppliers. Those ecosystems, grounded in regions across the country, are the infrastructure needed to spur private sector investment in manufacturing and innovation. But that infrastructure will not be rebuilt or sustained without the support and leadership of the federal government. Specific recommendations to rebuild our industrial base include:

Enact new federal legislation that will strengthen critical supply chains and rebuild our industrial base—including transformative investments within the American Jobs Plan:

- **Provide dedicated funding for semiconductor manufacturing and R&D:** We recommend that Congress support at least $50 billion in investments to advance domestic manufacturing of leading edge semiconductors; expand capacity in mature node and memory production to support critical manufacturing, industrial, and defense applications; and promote R&D to ensure the next generation of semiconductors in developed and produced in the United States.

- **Provide consumer rebates and tax incentives to spur consumer adoption of EVs:** We recommend Congress authorize new and expanded incentives to spur consumer adoption of U.S.-made electric vehicles. In addition, we recommend Congress approve $5 billion to electrify the federal fleet with U.S.-made EVs and $15 billion in infrastructure investment to build a national charging infrastructure to facilitate the nationwide adoption of EVs.

- **Provide financing across the full battery supply chain**: In line with the American Jobs Plan, we recommend that Congress establish new incentives to support battery cell and pack manufacturing in the United States, including grant programs that can help entrepreneurs who do not have the ability to access tax credits in the short run. In the immediate term, the Department of Energy's Loan Programs Office should use the Advanced Technology Vehicles Manufacturing Loan Program, which has approximately $17 billion in loan authority, to expeditiously review applications from critical material and mineral refining and processing facilities and to re-equip, expand, or establish facilities for manufacturing advanced technology vehicle battery cells and packs in the United States.

- **Establish a new Supply Chain Resilience Program:** We recommend that Congress enact the proposed Supply Chain Resilience Program at the Department of Commerce, to monitor, analyze, and forecast supply chain vulnerabilities and partner with industry, labor, and other stakeholders to strengthen resilience. We recommend Congress back this program with $50 billion in funding that will give the federal government the tools necessary to make transformative investments in strengthening U.S. supply chains across a range of critical products.

- **Deploy the Defense Production Act (DPA) to expand production capacity in critical industries:** We recommend establishing a new interagency DPA Action Group to recommend ways to leverage the authorities of the DPA to strengthen supply chain resilience to the extent permitted by law. The DPA has been a powerful tool to expand production of supplies needed to combat the COVID-19 pandemic, and has been used for years to strengthen Department of Defense supply chains. The DPA has the potential to support investment in other critical sectors and enable industry and government to collaborate more effectively.

Increase public investments in R&D and commercialization of key products:

- **Invest in the development of next generation batteries***:* We recommend that the Energy Department and other federal agencies continue to support technologies that will reduce the critical mineral requirements of next generation electric vehicle and grid storage technologies, and that improve U.S. competitiveness in this critical sector. Among other priorities, the United States should focus on: (1) reducing or eliminating critical or scarce materials needed for EV or stationary storage, including cobalt and nickel; (2) accelerating battery technology advances including next generation lithium ion and lithium metal batteries and solid state design, and (3) developing innovative methods and processes to profitably recover "spent" lithium batteries, reclaim key materials, and re-introduce those materials to the battery supply chain.

- **Invest in the development of new pharmaceutical manufacturing and processes**: We recommend the Department of Health and Human Services, the Department of Defense, and other agencies increase their funding of advanced manufacturing technologies to advance continuous manufacturing and the biomanufacturing of APIs. American Rescue Plan funds could be targeted to increase production of key pharmaceuticals and ingredients, including using both traditional manufacturing techniques and accelerating on-demand manufacturing capabilities for supportive care fluids, API and finished dosage form drugs in modular, highly portable platforms.

Use immediate administrative authorities to support an ecosystem of producers and innovators including SMEs and skilled workers:

- **Work with industry and labor to create pathways to quality jobs, with a free and fair choice to join a union, through sector-based community college partnerships, apprenticeships and on-the-job training:** The Department of Labor's Employment and Training Administration (ETA) should support sector-based pathways to jobs, for example in the semiconductor industry. We recommend that the Administration use ETA funds to work with industry and labor, community colleges, and non-profit partners to support pathways to advanced manufacturing employment through Registered Apprenticeship programs and by supporting other labor-management training programs.

- **Support small, medium and disadvantaged businesses in critical supply chains:** The Small Business Administration (SBA) should support the diversification of critical suppliers through a targeted effort to better coordinate SBA's range of investment and technical assistance programs for small businesses and disadvantaged firms in the four targeted industries and firms seeking to enter those industries. SBA lending and investment products provide vital capital to small businesses, and the Small Business Investment Company program offers long-term equity investment in critical competitiveness sectors. The Small Business Innovation Research and Small Business Technology Transfer competitive programs, will support a diverse portfolio of small businesses to meet research and development needs, and increase commercialization.

- **Examine the ability of the U.S. Export-Import Bank (EXIM) to use existing authorities to further support domestic manufacturing:** We recommend that EXIM develop a proposal for Board consideration regarding whether and how to implement a new Domestic Financing Program to support the establishment and/or expansion of U.S. manufacturing facilities and infrastructure projects in the United States that would support U.S. exports. The proposal would support and facilitate U.S. exports while rebuilding U.S. manufacturing capacity.

2. Support the development of markets that invest in workers, value sustainability, and drive quality

The resilience of national supply chains is only as good as the resilience of supply chains at the firm level. Harnessing and unleashing the power and ingenuity of the private sector to improve resilience will lead to stronger national supply chain resilience. Standards and data are powerful tools that allow firms to differentiate their products and services on more than just price and create market "pull" toward a "race to the top". These reports identify key areas where government could play a more active role in setting standards and incentivizing high-road business practices. By establishing strong domestic standards or advocating for the establishment of global standards, the United States can support the private sector's ability to create and adopt resilient practices.

- **Create 21st century standards for the extraction and processing of critical minerals:** We recommend that the government, working with private sector and non-governmental stakeholders, encourage the development and adoption of comprehensive sustainability standards for essential minerals, such as lithium, cobalt, nickel, copper, and other minerals. We further recommend establishing an interagency team with expertise in mine permitting and environmental law to identify gaps in statutes and regulations that may need to be updated to ensure new production meets strong environmental standards throughout the lifecycle of the project; ensure meaningful community consultation and consultation with tribal nations, respecting the government-to-government relationship, at all stages of the mining process; and examine opportunities to reduce time, cost, and risk of permitting without compromising these strong environmental and consultation benchmarks.

- **Identify potential U.S. production and processing locations for critical minerals:** We recommend that federal agencies, led by the Department of Interior with the support of the White House Office of Science and Technology Policy, establish a working group comprised of agencies such as the Department of Agriculture, the Environmental Protection Agency, and others to identify potential sites where critical minerals could be sustainably and responsibly produced and processed in the United States while adhering to the highest environmental, labor, community engagement, and sustainability standards. We recommend that federal agencies work with the private sector, states, tribal nations, and stakeholders—including representatives of labor, impacted communities, and environmental justice leaders—to expand sustainable, responsible critical minerals production and processing in the United States.

- **Improve transparency throughout the pharmaceuticals supply chain:** HHS should develop and make recommendations to Congress on providing the department with new authorities to track production by facility, track API sourcing, and require API and finished dosage form sources can be identified on labeling for all pharmaceuticals sold in the United States. Currently, there is little transparency into the origins of API within generic drugs, which represent, 90 percent of all pharmaceuticals consumed in the United States.

3. Leverage the government's role as a purchaser of and investor in critical goods

As a significant customer and investor, Federal Government has the capacity to shape the market for many critical products. The public sector can deploy this power in times of crisis—such as in the recent public-private partnerships to facilitate development and delivery of a COVID-19 vaccine—or in normal times. The Administration should leverage this role to strengthen supply chain resilience and support national priorities.

- **Use federal procurement to strengthen U.S. supply chains:** We recommend that, in connection with the Administration's "Made in America" process directed by E.O. 14005, the Biden Administration establish a list of designated critical products that it recommends receive additional preferences under the Buy American Act and FAR Council regulations to ensure that the federal government procures U.S.-made critical products. President Biden has directed the Administration to strengthen federal Buy American requirements, which require that U.S. taxpayer dollars generally be spent on products made in the United States. Federal procurement has the potential to support U.S. production of critical products by creating a stable source of demand for U.S.-made products—thereby providing an incentive for the private sector to invest in U.S. manufacturing.

- **Strengthen domestic production requirements in federal grants for science and climate R&D:** In line with the President's campaign commitments, we recommend that Biden-Harris Administration should update manufacturing requirements in federal grants, cooperative agreements and R&D contracts to ensure that taxpayer funded R&D leads to products made in the United States. We recommend that the Department of Energy immediately strengthen domestic manufacturing requirements for grants, cooperative agreements and R&D contracts, including those related to lithium batteries, using the Determinations of Exceptional Circumstances under the Bayh-Dole Act and other legal means. In addition, an interagency working group should be established to identify best-practices and develop and implement further improvements across the government.

- **Reform and strengthen U.S. stockpiles:** For too long, the strategic stockpiles of the United States have been neglected, and at times, its funds have been used to offset other costs. The rehabilitation of stockpiles of medical goods and devices, especially those to fight the ongoing COVID-19 pandemic, is already under way. However, similar action needs to be taken to recapitalize and restore the National Defense Stockpile of critical minerals and materials. In the private sector, we recommend that industries that have faced shortages of critical goods evaluate mechanisms to strengthen corporate stockpiles of select critical products to ensure greater resilience in times of disruption.

- **Ensure that new automotive battery production in the United States adheres to high labor standards:** Tax credits, lending and grants offered to businesses to produce batteries domestically should, to the extent permitted by law, ensure the creation of quality jobs with the free and fair choice to organize and bargain collectively for workers. In new appropriations, we recommend that Congress include prevailing wage requirements, similar to those included in the American Recovery and Reinvestment Act of 2009. We recommend that Congress also include standards that cover construction, such as: (1) mandated hiring percentages from registered apprenticeships and other labor or labor-management training programs; (2) project labor, community labor and local hire requirements; and (3) employer neutrality agreements. We recommend implementing similar standards for production workers. The resulting high productivity allows these firms both to pay high wages and be profitable. [18]

4. Strengthen international trade rules, including trade enforcement mechanisms

While the Administration welcomes fair competition from abroad, in too many circumstances unfair foreign subsidies and other trade practices have adversely impacted U.S. manufacturing and more broadly, U.S. competitiveness. The practice of "pumping and dumping," in which countries heavily subsidize an industry, gain market share and then flood the market with cheaper products to wipe out competition, has been documented in a number of industries including pharmaceuticals and clean energy.[19] The U.S. government must implement a comprehensive strategy to push back on unfair foreign competition that erodes the resilience of U.S. critical supply chains and industries more broadly.

- **Establish a trade strike force:** We recommend the establishment of a U.S. Trade Representative-led trade strike force to identify unfair foreign trade practices that have eroded U.S. critical supply chains and to recommend trade actions to address such practices. We also recommend that supply chain resilience be incorporated into the U.S. trade policy approach towards China. We also recommend that the trade strike force examine how existing U.S. trade agreements and future trade agreements and measures can help strengthen the United States and collective supply chain resilience.

- **Evaluate whether to initiate a Section 232 investigation on imports of neodymium magnets:** Neodymium (NdFeB) permanent magnets play a key role in motors and other devices, and are important to both defense and civilian industrial uses. Yet the U.S. is heavily dependent on imports for this critical product. We recommend that the Department of Commerce evaluate whether to initiate an investigation into neodymium permanent magnets under Section 232 of the Trade Expansion Act of 1962.

---

[18] Susan Helper, Ryan Noonan, Jessica R. Nicholson, and David Langon, "The Benefits and Costs of Apprenticeship: A Business Perspective," Department of Commerce with Case Western Reserve University, November 2016 (https://files.eric.ed.gov/fulltext/ED572260.pdf).

[19] Chris Martin, "China Flooded U.S. with Solar Panels Before Trump's Tariffs," *Bloomberg*, February 16, 2018 (https://www.bloomberg.com/news/articles/2018-02-16/china-flooded-u-s-with-solar-panels-before-trump-s-tariffs).

5. Work with allies and partners to decrease vulnerabilities in the global supply chains

The United States cannot address its supply chain vulnerabilities alone. Even as we make investments to expand domestic production capacity for some critical products, we must work with allies and partners to secure supplies of critical goods that we will not make in sufficient quantities at home. Moreover, in an interconnected world, the United States has a strong interest in ensuring its allies and partners have resilient supply chains as well. We must work with America's allies and partners to strengthen our collective supply chain resilience, while ensuring high standards for labor and environmental practices are upheld.

- **Expand multilateral diplomatic engagement, including hosting a new Presidential Forum:** We recommend expanding multilateral diplomatic engagement on supply chain vulnerabilities, particularly through groupings of like-minded allies such as the Quad and G7. We also recommend that the President convene a global forum on supply chain resilience that will convene key government officials and private sector stakeholders from across key U.S. allies and partners to collectively assess vulnerabilities and develop collective approaches to supply chain resilience.

- **Leverage the U.S. Development Finance Corporation (DFC) and other financing tools to support supply chain resilience:** We recommend that the DFC increase capacity for investments in projects that will expand production capability for critical products, including critical minerals and other products identified pursuant to the E.O. 14017 process. U.S. development and international finance tools offer a powerful avenue for working with allies and partners to strengthen supply chains for key products. While the United States cannot manufacture or mine all products, it can use financial tools to ensure that the manufacturing and mining that takes place elsewhere supports supply chain resilience and upholds international standards of environmental and social performance.

6. Monitor near term supply chain disruptions as the economy reopens from the COVID-19 pandemic

The U.S. economic relief efforts, paired with the Administration's successful vaccination campaign, have helped to revive the U.S. economy after a historic pandemic. As the United States and the broader global economy emerge from the pandemic, we have already seen signs of new pressures on supply chains as shifts in demand and supply emerge, and as the global vaccination campaign continues.

While these short-term disruptions are to be expected, the Administration has the responsibility to monitor these developments closely and identify actions that can be taken to minimize the impacts on workers, consumers, and businesses.

Building off the lessons from the 100-day review, the Administration should:

- **Establish a Supply Chain Disruptions Task Force:** We recommend the Administration establish a new Supply Chain Disruptions Task Force that will provide an all-of-government response to address near-term supply chain challenges to the economic recovery. The Task Force will be led by the Secretaries of Commerce, Transportation, and Agriculture and will focus on areas where a mismatch between supply and demand has been noted over the past several months: homebuilding and construction, semiconductors, transportation, and agriculture and food. The Task Force will bring the full capacity of the federal government to address near-term supply/demand mismatches. It will convene stakeholders to diagnose problems and surface solutions—large and small, public or private—that could help alleviate bottlenecks and supply constraints.

- **Create a data hub to monitor near term supply chain vulnerabilities:** We recommend that the Commerce Department lead a coordinated effort to bring together data from across the federal government to improve the federal government's ability to track supply and demand disruptions and improve information sharing between federal agencies and the private sector to more effectively identify near term risks and vulnerabilities.

REVIEW OF CRITICAL MINERALS AND MATERIALS

DEPARTMENT OF DEFENSE

EXECUTIVE SUMMARY

Strategic and critical materials are the building blocks of a thriving economy and a strong national defense. They can be found in nearly every electronic device, from personal computers to home appliances, and they support high value-added manufacturing and high-wage jobs, in sectors such as automotive and aerospace.

The global supply chain that delivers strategic and critical materials is nominally distributed, diverse, and embraces market competition. Upon closer inspection though, these supply chains are at serious risk of disruption—from natural disasters or *force majeure* events, for example—and are rife with political intervention and distortionary trade practices, including the use of forced labor. Contrary to a common belief, this risk is more than a military vulnerability; it impacts the entire U.S. economy and our values.

Furthermore, the need for strategic and critical materials is likely to intensify, in so far as these materials also enhance or enable the performance of many environmentally friendly "green" technologies, such as electric vehicles, wind turbines, and advanced batteries. A recent report by the International Energy Agency (IEA) notes: "A typical electric car requires six times the mineral inputs of a conventional car and an onshore wind plant requires nine times more mineral resources than a gas-fired plant. Since 2010, the average amount of minerals needed for a new unit of power generation has increased by 50 percent as the share of renewables in new investment has risen."[1]

In brief, the challenges and opportunities in strategic and critical material supply chains are emblematic of the intense geopolitical competition of the 21st century. Its complexity, global scope, and cross-cutting nature compel a whole-of-government approach by the United States, as well as close collaboration with our allies, partners, and the private and non-profit sectors.

To that end, this is an interagency assessment, for which the Department of Defense served as the lead. Nearly every agency of the U.S. Government has a unique capability that can be brought to bear to increase the sustainability of strategic and critical materials supply chains. This is illustrated in prior studies under Executive Order (E.O.) 13817 and E.O. 13953, and this foundation and the civilian-centric nature of the challenge have infused the entirety of this assessment under E.O. 14017, *America's Supply Chains*.

To address defense and essential civilian supply chain risk for strategic and critical materials, the President designated the Secretary of Defense as the National Defense Stockpile (NDS) Manager. Congress established this position, and the National Defense Stockpile program, in the summer of 1939, with conflict in the Pacific already underway and the threat of a European conflict looming. Later, throughout the Cold War, the NDS program was a cornerstone of the U.S. Government's mobilization enterprise, alongside robust investment programs led by multiple non-defense agencies under the Defense Production Act (DPA) of 1950.

The end of the Cold War in 1991, three decades ago, marked the beginning of a global reorientation of supply chains for strategic and critical materials. Sources of supply, previously locked behind the Communist "Iron Curtain," became available to Western manufacturers in significant quantities. The economy of China, which at that time was only 6 percent of the size of the U.S. economy,

[1] International Energy Agency, *The Role of Critical Minerals in Clean Energy Transitions* (May 2021), https://iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

began its meteoric rise. Trade liberalization and global, just-in-time supply chains became the order of the day.

Economic efficiency took priority over diversity and sustainability of supply—made manifest in the slow erosion of manufacturing capabilities throughout the United States and many other nations. In addition, as the point of consumption drifted farther and farther from the point of production, U.S. manufacturers increasingly lost visibility into the risk accumulating in their supply chains. Their suppliers of strategic and critical materials, and even the workforce skills necessary to produce and process those materials into value-added goods, became increasingly concentrated offshore. In such opaque conditions, the exploitation of forced labor and a disregard for environmental emissions and workforce health and safety could thrive.

In parallel, the impetus for national mobilization programs fell by the wayside. The Federal Government reaped a multi-billion dollar "peace dividend" from the sale of NDS materials, and core capabilities at non-defense agencies to study, characterize and mitigate risk in the strategic and critical materials sector atrophied.

Today, at the beginning of the third decade of the 21st century, a new industrial era of low-carbon and increasingly energy efficient products is converging with autonomous and Internet-of-Things devices, which may lead to massive gains in productivity and economic growth. If the United States wants to capture the full benefits of this new era, we must also look to the sustainability of our strategic and critical materials supply chains. The Department of Defense can play an important role, but the Department cannot carry-out this task alone. This is a task for the Nation.

The U.S. Government, collectively, has examined the risk in strategic and critical materials supply chains for decades. Now is the time for decisive, comprehensive action by the Biden-Harris Administration, by the Congress, and by stakeholders from industry and non-governmental organizations to support sustainable production and conservation of strategic and critical materials.

INTRODUCTION

Strategic and critical materials and their supply chains are the bedrock of value-added manufacturing and the development, production, delivery, and sustainment of essential services, such as telecommunications and computing, food and agriculture, finance, healthcare, education, transportation, and public safety.

In civilian sectors of the U.S. economy, strategic and critical materials and their supply chains are essential to countless manufactured goods, ranging from personal electronics and consumables for fuel, food, and medical supplies, to home construction and sustaining the nation's critical infrastructure. Reliable access to strategic and critical materials strengthens the global economy and helps improve the quality of life.

In the defense industrial base, strategic and critical materials ensure that U.S. Armed Forces and those of our allies can conduct and sustain operations, while expanding the output and development of military items to maintain technical dominance over adversaries. Without these materials, history shows that industrialized nations have been compelled to make performance trade-offs and suboptimal capital allocations, which contributed to their defeat on the battlefield.

Though domestic strategic and critical materials production represents only a small fraction of total U.S. employment and Gross Domestic Product (GDP), downstream manufacturing and related service sectors support substantially greater economic output and jobs. For example, annual domestic mining activities, valued at less than $100 billon, enable more than $3 trillion in domestic value-added industry sectors, out of a

$20 trillion economy.2 This contribution to downstream manufacturing and service sectors is indicative of the derivative value of strategic and critical materials.

Strategic and Critical Materials Defined[3]

This collaborative work builds upon recurring assessments of strategic and critical materials across the interagency, such as recent work led by the Departments of Commerce and the Interior under E.O. 13817, A Federal Strategy To Ensure Secure and Reliable Supplies of Critical Minerals, and E.O. 13953, Addressing the Threat to Domestic Supply Chain from Reliance on Critical Minerals from Foreign Adversaries and Supporting the Domestic Mining and Processing Industries. As directed by E.O. 14017, America's Supply Chains, the Department of Defense (DoD) assessed the resilience of supply chains for "strategic and critical materials" in its role as the NDS Manager,4 with support from the interagency.

Though similar to "critical minerals,"[5] the definition of strategic and critical materials for the purposes of the Strategic and Critical Materials Stockpiling Act of 1979 (50 U.S.C. 98 *et seq.*) (the Stockpiling Act) encompasses any materials that are:

> Needed to supply the military, industrial, and essential civilian needs of the United States during a national emergency, and
>
> Not found or produced in the United States in sufficient quantities to meet such need.

Functionally, the analytical framework for "critical minerals" and "strategic and critical materials" overlap but with two fundamental differences. First, the organizing principle for critical minerals is mining, mineral processing, and related metal products or compounds. In contrast, "strategic and critical materials" is broader, including downstream products and materials produced outside of mining activities (e.g., carbon fibers). Second, the NDS Manager function presupposes a national emergency scenario or a more stressful mobilization scenario.

In light of these differences, recurring assessments of critical minerals under E.O. 13817 have identified 35 commodities and minerals as "critical minerals."[6] DoD, as the NDS Manager, monitors more than 250 unique strategic and critical materials; some findings of this modeling are in the *Risk Factors at the Level of Armed Conflict* section of this report. Thus, this report subsumes issues in critical minerals supply chains into the broader discussion of strategic and critical materials.

Notwithstanding DoD's assessment framework, which is emergency-driven, this report's observations, strategy, and recommendations represent the consolidated views of the interagency

---

[2] U.S. Geological Survey, *Mineral Commodity Summaries 2022* (January 29, 2021), https://pubs.usgs.gov/periodicals/mcs2021/mcs2021.pdf.

[3] Note: Significant quantities of strategic and critical materials may be found on the seabed, but the industry to extract these resources remains nascent, given both technical challenges of mining in the marine environment and the potential for significant environmental harm. On the other hand, substantial portions of mineral exploration leases are held by foreign sources, providing not only a potential supply benefit, but also dual-use technology development associated with unmanned undersea vessels and hyrographic mapping. Though seabed resources may provide a significant future source of strategic and critical materials, they are not covered by this report.

[4] As appointed in the Strategic and Critical Materials Stock Piling Act of 1979 (50 U.S.C. 98 *et seq.*), specifically 50 U.S.C. 98h–7.

[5] As defined in E.O. 13817, a critical mineral is "a mineral identified by the Secretary of the Interior [pursuant to the E.O.] to be (i) a non-fuel mineral or mineral material essential to the economic and national security of the United States, (ii) the supply chain of which is vulnerable to disruption, and (iii) that serves an essential function in the manufacturing of a product, the absence of which would have significant consequences for our economy or our national security." 82 Fed. Reg. 60835. 2017, https://federalregister.gov/documents/2017/12/26/2017-27899/a-federal-strategy-to-ensure-secure-and-reliable-supplies-of-critical-minerals

[6] Department of the Interior, "Final List of Critical Minerals 2018," 83 Fed. Reg. 23295; 2018, https://federalregister.gov/documents/2018/05/18/2018-10667/final-list-of-critical-minerals-2018.

and provide a concise whole-of-government approach to the strategic and critical materials sector. This approach also mirrors DoD's longstanding results from macroeconomic modeling of the sector under national emergency scenarios. For more than a decade, DoD has consistently found that the *essential civilian industry* would bear the preponderance of harm from a disruption of strategic and critical materials supply.

MAPPING THE SUPPLY CHAIN

Description of Strategic and Critical Materials Production

Overview

The supply chain for strategic and critical materials generally begins with mining the raw material. Open pit or underground mining techniques are used to extract ore, which is then crushed and ground into a size that enables its separation into metal oxides and or other chemical forms (e.g., halides). Some strategic and critical materials, such as lithium, may be extracted by in-situe mining and extraction techniques. After this beneficiation or concentration process, the material is smelted or refined using electrolytic or pyrometallurgical processes to produce a purified powder, metal, or other material in a semi-final form. Final steps include further refining, manufacturing, cutting, and polishing into a semi-finished or finished product with unique material properties depending on the material's final use. Additional detail on these stages are described below.

- **Beneficiation** consists of physical processing techniques in which mined ore is sorted and crushed into smaller particle sizes for subsequent downstream processing operations. Beneficiation processes may be as simple as hand-picking and sorting to mechanical or chemical processes such as froth flotation, in which air bubbles are injected into an ore-chemical mixture to allow foam-carrying ore particles to be separated from waste rock. In rare earth and other mineral processing operations, the result of beneficiation often is called a "mineral concentrate" or a "chemical concentrate" with a total rare earth oxide (TREO) content ranging from 40 percent to 60 percent.

- **Hydrometallurgy** consists of multiple liquid-to-liquid processing operations that further remove trace element impurities and separate individual strategic and critical materials from one another. Common hydrometallurgical processes include ion exchange and solvent extraction, with the former dating to World War II and the latter developed in the 1970s. Industry and the U.S. Government have sponsored significant research and development (R&D) in this area to minimize environmental impact and increase process efficiency, given the significant quantities of chemical reagents and potential waste-water discharges associated with hydrometallurgical operations. In a rare earth processing operation, the result of hydrometallurgical processes generally is in the form of a rare earth oxide, with a TREO content ranging from not less than 99 percent (2N) to 99.999 percent (5N).

- **Pyrometallurgy and Electrolysis** consists of multiple processing operations which use heat or electricity to separate the oxide, halide, or other non-metal component of a metal salt from a resulting hydrometallurgical or beneficiation process. There are key tradeoffs associated with both processing routes. Electrolysis can have higher production rates since it runs continuously, but due to its continuous nature, it can be more costly in the long run when an electrolytic process is shut down and re-started, rather than simply absorb its short-run operating losses. This is a significant challenge in the aluminum sector. On the other hand, pyrometallurgical processes, like metal reduction or distillation, generally are batch-type operations, but they can produce significantly higher purity metal products. The resulting metal products from either pyrometallurgy or electrolysis also may undergo subsequent purification steps, such as zone refining, to further improve metal purity. Metal products resulting from this processing step or subsequent purification can range from 2N to much greater than 5N.

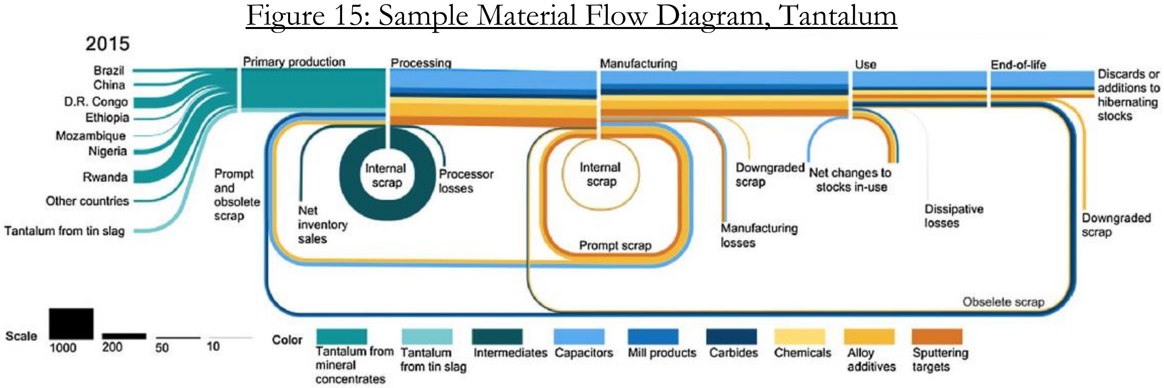
- **Finishing** consists of dozens of different downstream production processes, which lead a metal product towards its specific end-use. "Finishing" in this context incorporates numerous subsequent production steps such as melting and alloying with other materials, casting, milling of alloys to fine powders, sintering and pressing of metal powders, and machining of the consolidated metal products to the desired form.

Each step in this production chain — beneficiation, hydrometallurgy, electrolysis and pyrometallurgy, and finishing — is a distinct technical discipline that can require years of practice to perfect. Once those workforce skills are lost, reconstituting them is extremely expensive, both in terms of higher costs and inefficient production, and may require importing technical expertise from foreign sources to catch-up to global production and quality benchmarks. Ultimately, each strategic and critical material has a unique version of the above generalized process description, with further examples in Appendix A.[7]

Material Flow Analyses

Material flow analyses are an important tool to cross-walk the above processing steps to global production and demand for strategic and critical materials from primary sources (e.g., mining) as well as the in-process and post-consumer recycling of strategic and critical materials. Analysis of potential supply shortages, supply diversification and security, resource efficiency, and the potential for future recycling is facilitated by such studies. The flow of materials through the various stages of a supply chain can be illustrated using a Sankey diagram, an example of which is shown in Figure 15 for tantalum.[8]

Figure 15: Sample Material Flow Diagram, Tantalum



Tantalum is a strategic and critical material for which the United States meets 100 percent of its mineral consumption needs from foreign sources. The most significant demand driver for tantalum is in the electronics market, in the form of tantalum capacitor and wire products, but DoD has important tantalum requirements in the form of commercial and dual-use goods (e.g., aerospace alloys and electronics), as well as defense-unique items (e.g., explosively formed projectiles). Tantalum is of sufficient importance to defense supply chains that Congress implemented sourcing restrictions on this material and others through 10 U.S.C. 2533c.

Material flow analyses are also an important tool to identify outsized foreign reliance and vertical integration in supply chains. The neodymium-iron-boron (NdFeB) magnet supply chain is an example of a strategic and critical materials supply chain where one country is able to maintain vertical capabilities throughout the supply chain, while multiple other countries operate at only select tiers (see Figure 2). These examples show that material flows can potentially be relatively concentrated within a country, or they can follow a circuitous

[7] All appendicies to this document are classified as UNCLASSIFIED//CONTROLLED UNCLASSIFIED INFORMATION.

[8] N.T. Nassar, "Shifts and trends in global anthropogenic stocks and flow of tantalum," *Resources, Conservation and Recycling*, Vol. 124 (October 2017), pp 233-250, https://sciencedirect.com/science/article/abs/pii/S0921344917301556?via percent3Dihub

global path. Though only China has all essential supply chain tiers, at least some nominal capacity exists for each tier in a combination of countries outside China.

Figure 2: Global Locations for NdFeB Supply Chain Tiers[9]

Country	Mining	Mixed Compounds	Separation to REO[10]		Oxide to Metal	Magnet Alloys	NdFeB Sintered Magnets
			LREE[11]	HREE[12]			
Australia	•	PILOT					
Burma (Myanmar)	•	•					
Burundi	•						
China	•	•	•	•	•	•	•
Estonia			•				
Germany							•
France			•	•			
Malaysia		•	•				
Russia	•	•	•				
India	•	•	•				
Japan				•	•	•	•
Kazakhstan			IDLE				
United States	•	**	**	**	IDLE	IDLE	**
United Kingdom					•	•	
Vietnam					•	•	•
Other	•	•	•		•	•	•

In-Process and Post-Consumer Recycling

The National Minerals Information Center at the U.S. Geological Survey collects information on recycling for various mineral commodities. Recycling rates for major metals often are very high; steel recycling rates typically exceed 80 percent annually, satisfying a substantial proportion of annual consumption. The data surrounding recycling rates for strategic and critical materials, however, is highly variable and relies on voluntary submissions of business proprietary information. In some cases, little or no data is available to the U.S. Government, though at the opposite extreme, some strategic and critical materials are derived exclusively from post-consumer recycling processes, such as certain fire-supression and refrigerant gases. When available, data related to secondary supply is incorporated into U.S. Government supply and demand forecasts for strategic and critical materials, within Appendix A and Appendix B.

Recycling of rare earth permanent magnets is an area of increasing activity among domestic entities, including one company sponsored by the DoD under a Defense Production Act (DPA) Title III award and an active area of research funded by the Department of Energy. Interest in recycling lithium ion batteries also is developing rapidly, supported by research funding from the Department of Energy and an expectation of increased supply as the first generation of hybrid-electric and full electric vehicles become available for recycling. Though increasing recycling rates for strategic and critical materials is advantageous, recycling alone is typically inadequate to supply the volumes of material required for domestic consumption. Even if 100 percent recycling rates were achieved for a particular supply chain, increasing demand necessitates primary production. Copper, for example, has very high recycling rates but recycled copper currently supplies

[9] ** Represents supply chain tiers in which the U.S. Government is currently working with industry to re-establish capacity.
[10] Rare Earth Oxide.
[11] Light Rare Earth Element.
[12] Heavy Rare Earth Element.

less than 40 percent of annual U.S. consumption, the balance of which is made up of primary mined ore and processed metal.

Domestic Sources of Strategic and Critical Materials

Development Timelines for Domestic Operations

As a series of complex extraction, chemical, and refining operations, establishing strategic and critical material production is an extremely lengthy process. Independent of permitting activities, a reasonable industry benchmark for the development of a mineral-based strategic and critical materials project is not less than ten years.

Figure 3: Overview of Development Timeline for Greenfield Strategic & Critical Materials Projects[13]

1. Establish Resource (2-5 years)	2. Mineralogy (1-3 years)	3. Scoping Studies (1-3 years)	4. Beneficiation/Extraction/ Separation Pilot Plant (2-10 years)
▪ Establish resource that meets local stock market regulations	▪ Identification of minerals bearing the target product	▪ Inferred resource ▪ Bench scale process ▪ Baseline environmental study	▪ Demonstrate viability ▪ Generate data for feasibility studies ▪ Samples sent for customer evaluation ▪ Generate data for environmental studies
5. Environmental Assessments & Approvals (Variable)	**6. Letters of Intent (Concomitant with 1-5 years)**	**7. Feasibility Study & Funding (2-4 years)**	**8. Construction & Startup (2-3 years)**
▪ Public review	▪ Integrate operations with customer supply chains	▪ ±15 percent accuracy for capital expenditure and operating expenditure estimates	▪ Sophisticated engineering, procurement and construction studies ▪ De-bugging/Optimizing operations

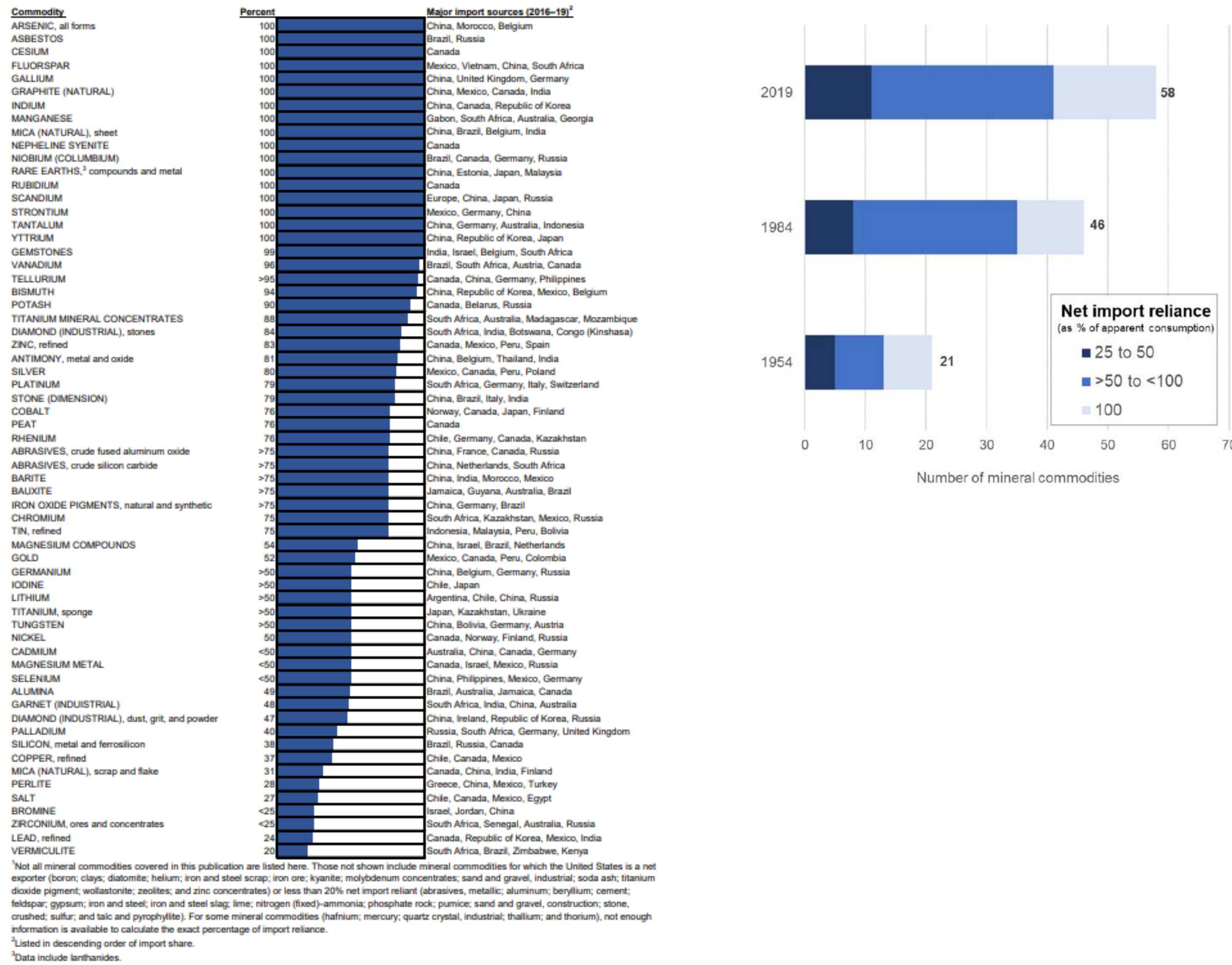
Moreover, it is quite common for most companies to fail to reach the end of this development process, simply due to the long project development time without cash flows to offset expenses and the technical challenges associated with large, complex project financing for materials production. For example, at the peak of industry and market interest in the rare earth sector in early 2011, the *Technology Metals Research* "Advanced Rare-Earths Project Index" tracked approximately 275 rare earth projects under development by 180 publicly-traded companies in 30 countries, excluding projects in China, Russia, and India.[14] As of April 2021, only two of these projects entered full-scale production, and two others remain in pilot-plant production—a combined success rate of 1.5 percent over the past decade.

U.S. Production and Net Import Reliance

The United States has always relied on imports of strategic and critical materials to meet its public and private sector needs, even in wartime. Over the last sixty years[15] and especially since the end of the Cold War, U.S. production has decreased and our net import reliance has grown across multiple strategic and critical materials. Net import reliance is defined as the amount of imported material (including changes in existing stocks) minus exports as a percentage of domestic consumption. Though encompassing all strategic and critical materials, the number of non-fuel mineral commodities for which the United States is at least 25 percent import reliant has grown from 21 products to 58 products from 1954 to the present, with current net import reliance shown in Figure 4.

[13] Derived from Dudley Kingsnorth, *Rare Earths: Reducing Our Dependence Upon China*, Metal-Pages Rare Earths Conference (September 2011); note that the development timeline for recycling projects or adding new processing circuits to existing primary production facilities may have a significantly shorter (1-3 years) development cycle.
[14] Gareth Hatch, "Introducing the TMR Advanced Rare-Earth Projects Index," *Futures Magazine* (January 6, 2011), http://m.futuresmag.com/2011/01/06/introducing-tmr-advanced-rare-earth-projects-index
[15] United States Geological Survey, *Comparison of U.S. Net Import Reliance for non-fuel mineral commodities – A 60-Year Retrospective (1954-1984-2014)*, https://pubs.usgs.gov/fs/2015/3082/fs20153082.pdf

<u>Figure 4: U.S. Net Import Reliance (2020)</u>[16]



This evaluation of net import reliance is constrained to observable U.S. and international trade statistics for direct demand. Direct demand records imports of strategic and critical materials, as "materials," for use by domestic manufacturing operations. However, certain sectors of the industrial base may have so atrophied that no U.S. manufacturer is purchasing said strategic and critical materials. At this point, U.S. net import reliance for materials is captured by an evaluation of embedded demand—imports of intermediate goods and value-added finished products that already contain strategic and critical materials.

An excellent example of embedded demand versus direct demand is the rare earth market. U.S. mine production of rare earth elements was approximately 28,000 metric tons in 2019, with direct U.S. imports of approximately 13,000 metric tons (rare earth oxide equivalent basis). U.S. production and imports, respectively, constitute about 12 percent and 5 percent of global rare earth production.17 The bulk of U.S. production is in the form of mineral/chemical concentrates and some light rare earth oxides, and similarly,

[16] U.S. Geological Survey, *Mineral Commodity Summaries 2021* (January 29, 2021), https://pubs.usgs.gov/periodicals/mcs2021/mcs2021.pdf

[17] U.S. Geological Survey, *Mineral Commody Summaries – Rare Earths* (January 2021), https://pubs.usgs.gov/periodicals/mcs2021/mcs2021-rare-earths.pdf

the preponderance of direct imports (by weight) are in the form of light rare earth compounds, principally lanthanum, to support the domestic petrochemical industry.

The United States imports substantially greater quantities of rare earth elements in value-added products, such as those listed in Figure . Implicit in this trade phenomenon is the gradual decline in value-creation, innovation, research, and human capital development (see Appendix A for more detail).

Figure 5: Downstream Applications for Rare Earth Elements

Element		Major Applications
LREE	**Lanthanum**	Fluid catalytic cracking for petroleum refining, nickel metal hydride (NiMH) batteries, metallurgical applications, glass and polishing ceramics lighting.
	Cerium	Automobile catalysts and additive, FCC additives, catalysts, metallurgy, polishing, powders and glass and others such as fertilizer, paint drying, and a stabilizer in plastics. Applications often overlap with lanthanum.
	Praseodymium	NdFeB, metallurgical applications, pigments, batteries, and catalysts.
	Neodymium	NdFeB magnets, glass and ceramics applications such as ceramic capacitors, metallurgical applications such as a minor alloying element for iron and steel alloys and magnesium alloys, luminophores, and other applications such as NiMH batteries, catalysts, and lasers. NdFeB magnets are used in products such as computer hard disk drives, magnetic resonance imaging (MRI), precision guided munitions, automotive motors, wind turbines, and loudspeakers.
	Samarium	Samarium cobalt permanent magnets, which are used in electronics (including military systems), automobiles, aerospace, pumps, and medical devices. Other applications include infrared absorption glass, optical glass, fuel cells, for nuclear applications, and capacitors for microwave frequencies.
HREE	**Europium**	Phosphors and luminophores, which are used in TV and computer screens, compact fluorescent lighting, light emitting diodes (LEDs), and sensors. Other applications include nuclear and medical applications and for some specialty alloys and lasers.
	Gadolinium	Metallurgical applications such as magnetic refrigeration, magnesium alloys, and specialty alloys. Also used in small amounts for samarium cobalt magnets. Other uses include MRI contrasting agent and phosphors for dental and medical applications.
	Terbium	Phosphors (green) for displays, LEDs, and in medical applications, in permanent magnets, and for other applications such as high-temperature fuel cells, lasers, and magnetostrictive alloys for solid-state transducers and actuators used in sonar and other dual use technologies.
	Dysprosium	Neodymium iron boron permanent magnets in which it makes up generally about 0.8 percent to 1.2 percent by weight of the magnet; magnetostrictive alloys.
	Holmium	Magnets, magnetostrictive alloys for sensors and actuators.
	Erbium	Nearly all erbium is used in polishing and in highly specialized glass lens applications and fiber optics.
	Thulium	Portable X-ray devices, research, and a dopant in solid-state lasers and highly specialized fiber optics.
	Ytterbium	Metallurgical applications for rare earth magnesium alloys and specialty aluminum alloys.
	Lutetium	Used in medical equipment and small quantities in phosphors.
	Yttrium	Yttrium-stabilized zirconia (YSZ) ceramics, phosphors, and metallurgy. Some specific applications include thermal barrier coatings, lasers, oxygen sensors, and solid electrolytes for solid oxide fuel cells (SOFCs). Phosphors, optical glasses, rotary-wing aircraft alloys, and nickel-metal hydride (NiMH) batteries.
	Scandium	Solid oxide fuel cells (SOFC), aluminum alloys for aerospace and sporting goods, scandium-sodium lamps for outdoor venues, laser, optoelectronic materials, LEDs.

U.S. and Allied[18] Production Base for Strategic and Critical Materials

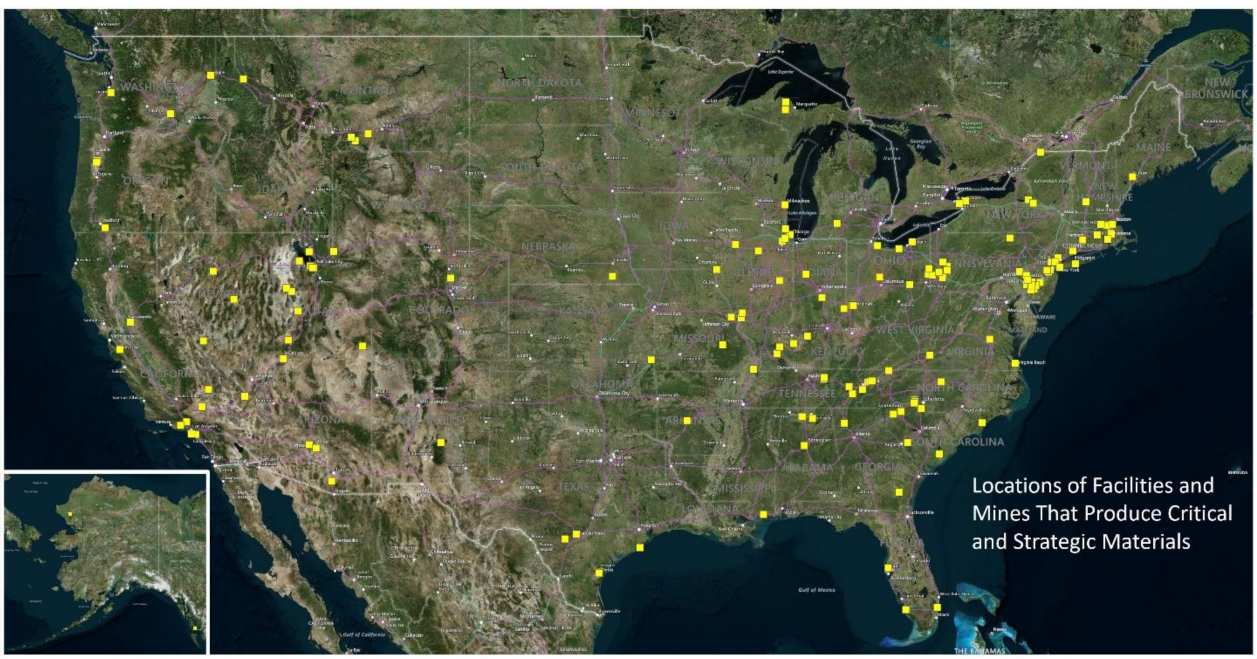
The Domestic Production Base

Working in close collaboration with the private sector and multiple interagency partners, DoD has mapped multiple upstream tiers of the strategic and critical materials sector. This digital mapping tool, called the Strategic Materials Assessment and Risk Topography (SMART), includes key domestic and international nodes within strategic and critical material supply chains, the output and capacity for primary extraction and downstream processing at these sites, as well as the relationships amongst these industry nodes and downstream manufacturing sectors. DoD constantly updates SMART with data-feeds from across the U.S. Government, open sources, and other business proprietary data in an effort to understand sub-tier supply chain vulnerabilities in the strategic and critical materials sector.

Outputs from SMART have been included in multiple reports to Congress pursuant to 50 U.S.C. 98h–5, and DoD continues to use SMART, along with several other industrial base mapping tools, to identify and proactively mitigate potential vulnerabilities in the industrial base from the spread of COVID-19.

For DoD's modeling of strategic and critical materials vulnerabilities (see Risk Factors at the Level of Armed Conflict and Appendix A), DoD used SMART to track 189 domestic facilities that currently produce or could produce the strategic and critical materials within the mitigation timeframe19 of those models. Given the significant shortfalls identified in this analysis, the U.S. industrial base has significant latent capacity that could support U.S. essential civilian and defense requirements given appropriate market incentives. The precise capabilities at the facilities indicated in Figure 6 are not labeled for security purposes, but these facilities represent a variety of mining, processing, and advanced materials capabilities.

Figure 6: Domestic Active and Potential Production Sites for Strategic & Critical Materials



[18] Note: The United States has multiple allies and security and trading partners that play a critical role in the strategic and critical materials industrial base. This section provides an overview of only select partners in the interest of brevity.

[19] 50 U.S.C. 98h-5 specifies a "base" conflict period, followed by a three-year period for the replenishment or replacement of all munitions, combat support items, and weapon systems and related essential civilian and industrial requirements after the conflict period.

GLOBAL FOOTPRINT

Allies and Partners

The United States maintains robust relationships with its allies and partners to support the deeper integration of defense and essential civilian supply chains. This engagement also is a core recommendation of the report delivered pursuant to E.O. 13817, A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals. Under this strategy, the United States entered into broad interagency critical minerals collaboration engagements coordinated via diplomatic channels with Canada and Australia, and other countries have requested similar agreements with the U.S. Government. Unfortunately, the onset of the COVID-19 pandemic severely disrupted the interagency's ability to advance these action plans.20

CANADA

Canada is a member of the National Technology and Industrial Base (NTIB) under 10 U.S.C. 2500. Canadian companies and persons are the only non-U.S. entities and persons who are considered a "domestic source" for the purposes of the DPA (50 U.S.C. 4500 et seq.). Both of these factors reflect the deeply integrated nature of the U.S. and Canadian economies and the very strong security relationship between the United States and Canada.

This economic integration leads to Canada being the second-largest import source for those strategic and critical materials for which the United States has net import reliance greater than 50 percent.21 Canadian mining and material processing companies export a variety of strategic and critical materials to the United States, including high-purity aluminum and gallium. The latter, gallium, is gaining more importance due to new Internet-of-Things and semiconductor applications, as well as longstanding applications in integrated circuits, laser diodes, LEDs, solar cells, radar missile defense, and infrared imaging.

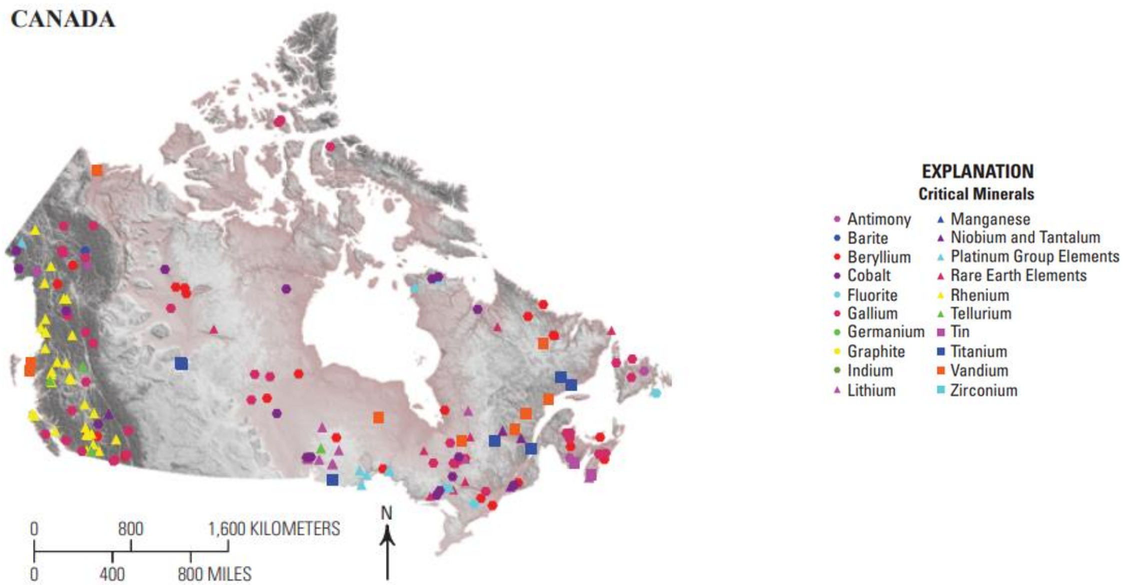
Trade in mineral-based strategic and critical materials between the U.S. and Canada exceeds $76 billion, and Canada is a global hub for mining project finance, including the risk finance that supports junior mining companies exploring for strategic and critical materials and developing the next generation of projects. Canada has substantial resource potential in existing operations and planned projects that could support U.S. needs for cobalt, tantalum, antimony, and twenty additional strategic and critical materials.

---

[20] A discussion of the impact of COVID-19 pandemic on DoD activities in the strategic and critical materials sector is described in U.S. Department of Defense, *Fiscal Year 2020 Industrial Capabilities Report to Congress* (January 2021), https://www.businessdefense.gov/Portals/51/USA002573-20 percent20ICR_2020_Web.pdf?ver=o3D76uGwxcg0n0Yxvd5k-Q percent3d percent3d

[21] U.S. Geological Survey, "*Mineral Commodity Summaries 2021*" (January 29, 2021), https://pubs.usgs.gov/periodicals/mcs2021/mcs2021.pdf

Figure 7: Canadian Strategic and Critical Material Deposits[22]



AUSTRALIA

Australia also is a member of the NTIB. Although Australian entities are not considered a domestic source for the purposes of the DPA, Australian companies have forged several important partnerships with U.S. companies to participate in contracting opportunities related to strategic and critical materials. Key examples of this work include joint ventures related to the processing of light and heavy rare earth oxides through the Industrial Base Analysis & Sustainment (IBAS) program and Title III of the DPA.

As a mineral resource rich country, mining has long been a critical part of the Australia's GDP, as much as 11 percent in 2020.23 Australia also competes with Canada on a roughly equal basis for mining finance, with Australia edging-out Canada with a slightly greater share of global mining exploration expenditures ($1.5 billion versus $1.3 billion) in 2019.24 Australia also holds vast deposits for a variety of mineral-based strategic and critical materials, citing twenty-one of the thirty-five minerals on the "critical minerals" list under E.O. 13817.

The Australian Government has created a Critical Minerals Facilitation Office and expanded the eligibility of Export Finance Australia to support the development of critical minerals projects. Key objectives of this office are enabling and attracting investment, international engagement, project finance, overseeing minerals research, and developing Australia's national strategy for critical minerals. In its recently published Australian Critical Minerals Prospectus 2020, Australia identified dozens of potential projects, ranging from early exploration to "shovel-ready" projects.[25]

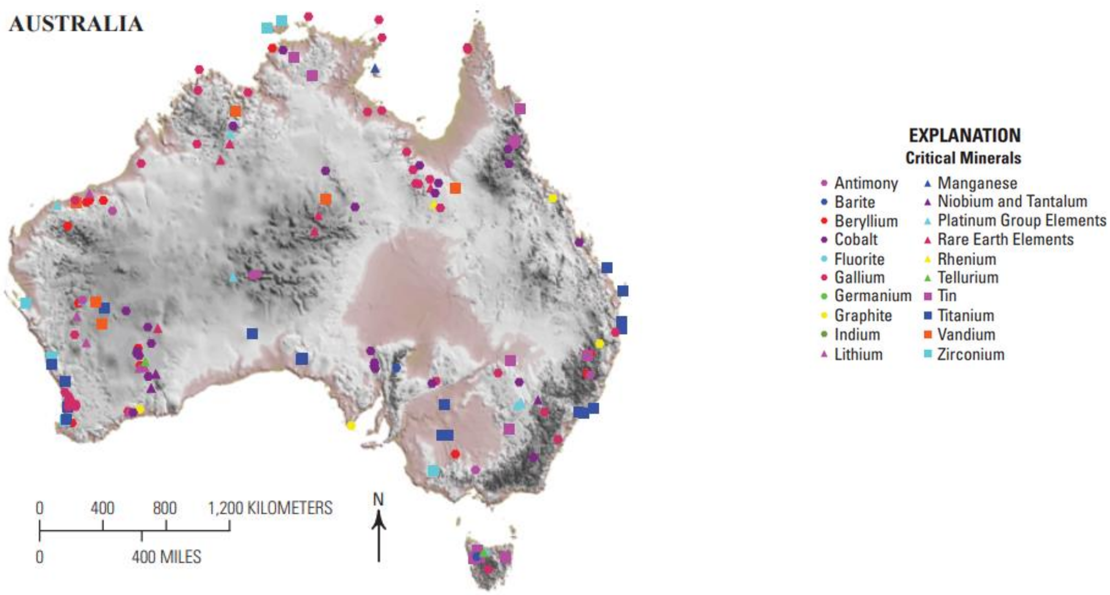
[22] U.S. Geological Survey, *International Geoscience Collaboration to Support Critical Mineral Discovery*, Fact Sheet 2020-3025 (July 2020), https://pubs.er.usgs.gov/publication/fs20203035

[23] Australian Government, *Why Australia: Benchmark Report* (2021), https://austrade.gov.au/benchmark-report/resilient-economy.

[24] Prospectors & Developers Association of Canada (PDAC), *Mineral Finance 2020: Canada Holding Ground* (June 2020), https://pdac.ca/docs/default-source/priorities/access-to-capital/state-of-mineral-finance-reports/pdac-mineral-finance-2020_revised_june-18-2020.pdf?sfvrsn=c9ec9b98_2

[25] Australian Government, *Australian Critical Minerals Prospectus* (October 2020), https://austrade.gov.au/international/invest/opportunities/resources-and-energy

Figure 8: Australian Strategic and Critical Material Deposits[26]



JAPAN

Japan is another important trading partner and U.S. ally in the Asia-Pacific region. Though not a member of NTIB nor eligible as a domestic source under the DPA, Japan is a "qualifying country" for the purpose of the Defense Federal Acquisition Regulation Supplement (DFARS). Qualifying countries have entered into a reciprocal defense procurement agreement with the United States to remove barriers to the purchase of supplies manufactured in or services provided by the other country.[27] Under particular conditions, a "qualifying country" source is considered equivalent to a domestic source in defense procurement procedures.

Independent of this engagement with DoD, Japan is a founding member of trilateral critical materials cooperation with the United States and the European Union (EU), an effort led by the U.S. Department of Energy. The EU-US-Japan Trilateral on Critical Materials is an important platform for experts from all three parties to exchange technical data and approaches to building secure supply chains for critical materials.

Though not necessarily resource-rich, Japan is a vital player in supply chains for strategic and critical materials—as an import destination, a source of project finance, downstream manufacturing, and a materials R&D hub. After 2010, in response to a territorial dispute with China which led to a *de facto* Chinese embargo on rare earth exports, Japan adopted a coordinated, national policy to diversify its rare earth supply chains, combining R&D related to end-of-life recycling, stockpiling thrifting, substitution, and new product development for rare earth elements in over-supply, as well as providing project finance for overseas mining projects.

EUROPEAN UNION

The principal mechanism through which the United States engages the EU on issues related to strategic and critical materials is through the EU-US-Japan Trilateral, although U.S. industry has also been invited to support EU initiatives to assess their import reliance for "critical raw materials," a framework similar to

[26] U.S. Geological Survey, *International Geoscience Collaboration to Support Critical Mineral Discovery*, Fact Sheet 2020-3035 (July 2020), https://pubs.er.usgs.gov/publication/fs20203035

[27] See DFARS 252.225-7001, Buy American and Balance of Payments Program and directly related clauses under DFARS 252.225.

"critical minerals."[28] The European Commission also released an *Action Plan on Critical Raw Materials* in September 2020, which calls for the EU to reduce its dependence on foreign sources throughout the critical materials value chain.[29]

The United States maintains strong, informal communication with the EU via diplomatic channels to ensure a consistent exchange of ideas, as well as extensive communication related to prospective legislation under the European Green Deal framework and new EU regulation on "conflict minerals," a subset of critical minerals on which the United States also has due diligence requirements under the *Dodd-Frank Wall Street Reform and Consumer Protection Act*.

A particularly instructive work for U.S. policy related to strategic and critical materials is the analysis completed by multiple stakeholders across academia, industry, European and non-European governments, and non-governmental organizations through the European Rare Earth Competency Network (ERECON), with some of this work now taken-up by the emerging European Raw Materials Alliance.[30] Noteworthy recommendations from ERECON included:

- Support promising technologies by funding industry-led pilot plants for innovative heavy rare earth element processing;
- Leveling the playing field for European heavy rare earth exploration through co-funding for pre-feasibility and bankable feasibility studies; and
- Making waste management rare earth-friendly through eco-design, incentive schemes for collecting priority waste products, and streamlining policy and waste regulations.31

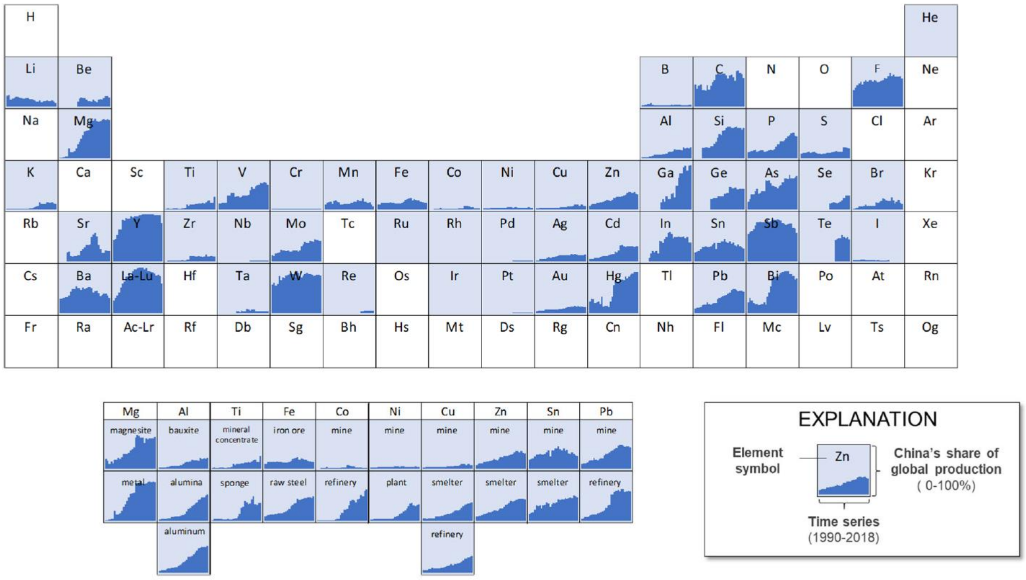
Drivers of Market Demand for Strategic and Critical Materials

Overview – Growth in the Chinese Market

As the world's largest national economies, the United States and China are the world's largest direct and indirect consumers of strategic and critical materials.32,33 The unprecedented growth of the Chinese economy has fueled global growth in strategic and critical material markets, posing a strong incentive to reorient supply chains. Since the end of the Cold War, China's strategic and critical materials industry has expanded many times over (see Figure 9) to meet some of China's domestic demand. Even in cases where other countries conduct the initial beneficiation of a strategic and critical material, China dominates the processing of strategic and critical materials, giving it de facto control over the flow of material through the supply chain.

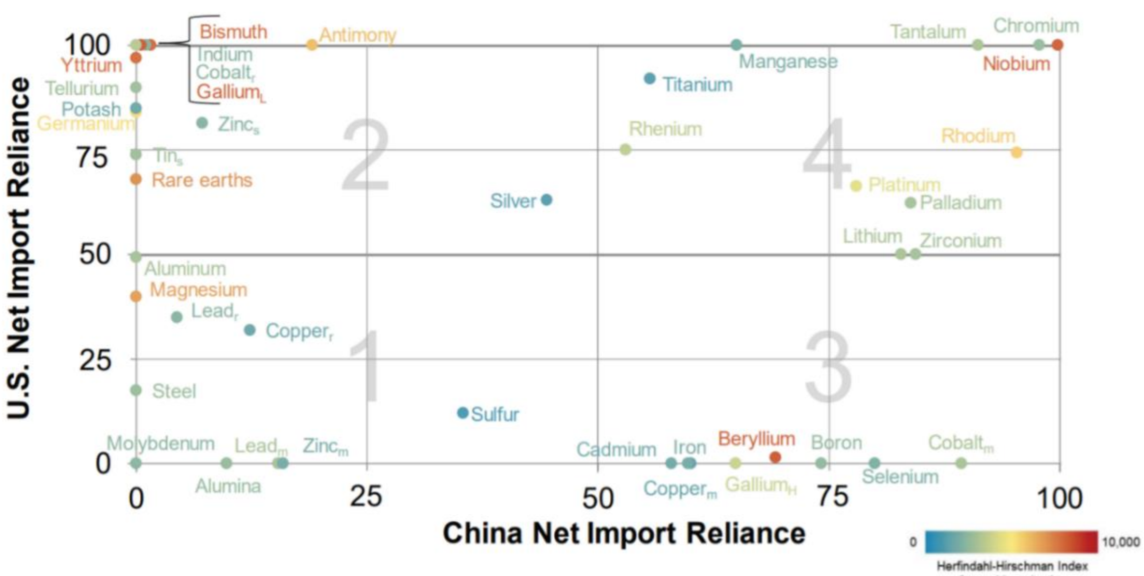
[28] European Commission, *Study on the EU's list of Critical Raw Materials* (September 2020), https://ec.europa.eu/docsroom/documents/42883/attachments/1/translations/en/renditions/native
[29] European Commission, *Critical Raw Materials Resilience: Charting a Path towards Greater Security and Sustainability* (September 2020), https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0474&from=EN
[30] European Commission, *European Rare Earth Competency Network (ERECON)*, https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/erecon_en; European Commission, *European Raw Materials Alliance*, https://erma.eu/
[31] European Rare Earths Competency Network, *Strengthening the European Rare Earths Supply-Chain, Challenges and policy options* (October 2014), https://reinhardbuetikofer.eu/wp-content/uploads/2015/03/ERECON_Report_v05.pdf
[32] The World Bank, "GDP (current US$)", worldbank.org, https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?most_recent_value_desc=true
[33] Jeff Desjardins, "China's Staggering Demand for Commodities," visualcapitalist.com, March 2, 2018, https://visualcapitalist.com/chinas-staggering-demand-commodities/

Figure 9: China's Share of Global Primary Production (1990-2018)[34]



Notwithstanding China's surging domestic production, that production has not kept pace with the rapid expansion of China's economy, from a nominal GDP of $426 billion in 1992 to $14.2 trillion in 2019. This substantial growth has led to an equally substantial increase in China's net import reliance for strategic and critical materials (see Figure 10).35 As China's demand for cobalt, copper, lithium, platinum group metals, and other specialized materials increased, China stepped up its efforts to capture the entire value chain in a variety of modern technologies such as permanent magnets, batteries, and semiconductors.

Figure 10: China and United States Net Import Reliance (Compared)[36]



[34] U.S. Department of the Interior, *Investigation and Recommendations on our Nation's Reliance on Foreign Sources of Critical Minerals* (September 30, 2020), see Appendix G

[35] The World Bank, "China," worldbank.org, https://data.worldbank.org/country/CN

[36] Gulley, A.L., Nassar, N.T., and Xun, S., "China, the United States, and competition for resources that enable emerging technologies," *Proceedings of the National Academy of Sciences* (April 2, 2018), https://pnas.org/content/pnas/115/16/4111.full.pdf

Meanwhile, China has implemented several policies, such as the Go Out Policy,37 to accelerate its movement into value-added manufacturing sectors. Strategic and critical materials associated with the lithium-ion battery material supply chain have seen significant Chinese Foreign Direct Investment (FDI) flows, typically accompanied by off-take rights.

For example, China's nominal net import reliance for cobalt ores and concentrates is approximately 97 percent (see "Sector 3" of Figure 10). That result obscures the fact that Chinese companies have actively pursued equity positions or outright ownership in cobalt assets in the Democratic Republic of the Congo, Papua New Guinea, and Zambia. Making the conservative assumption that a Chinese company's equity position in a particular asset is the minimum level of off-take it will purchase, then China's Go Out Policy activities in cobalt have decreased China's net import reliance from 97 percent to 68 percent.38 In addition, China dominates downstream processing of cobalt (scoring in "Sector 2" of Figure 10), effectively controlling global material flows for processed cobalt.

Of note, the United States' net import reliance for cobalt ores and concentrates is zero. As indicated elsewhere in this report, the absence of net import reliance does not necessarily indicate the absence of risk. In this case, the United States does not import cobalt ores and concentrates because it has no downstream processing capability; consequently, the U.S. has high net import reliance in high value-added forms of cobalt (i.e., "Sector 2") and cobalt embedded in finished goods (e.g., batteries).

Overview – U.S. Demand

Given their far upstream position relative to the goods and services typically purchased by U.S. consumers, strategic and critical materials impact hundreds of sectors of the U.S. economy, as categorized by the North American Industry Classification System (NAICS).

To capture the relationship between strategic and critical materials to specific industry sectors as well as the inter-dependencies amongst these sectors, DoD uses a combination of input-output and agent-based economic modeling approaches. Due to a combination of statutory requirements (ref: 50 U.S.C. 98h–5) and the intense data requirements to run these models, DoD exercises these models every two years and relies heavily on support from across the Federal Government, including the Departments of Commerce and the Interior, federally-funded research and development centers, U.S. national laboratories, and other Government agencies. DoD also actively engages key domestic and foreign market participants to integrate business proprietary information into these models, to more precisely characterize potential shortfalls to defense or essential civilian requirements during postulated national emergency or peacetime disruption scenarios. The results of this modeling exercise are in Appendix A.

By way of example, the interagency has collected direct demand import statistics for rare earth elements from the Department of Commerce and used agent-based modeling in partnership with a national laboratory to develop estimates of embedded demand in downstream sectors of the U.S. economy. To characterize the economic impact of these materials on the broader U.S. economy, these direct and embedded demand quantities, multipled by market prices, may be compared against manufacturer survey data, also collected by the Department of Commerce.

In the case of rare earth elements (see Figure 11), approximately $613 million in U.S. consumption of rare earth elements unlocks approximately $496 billion in economic activity in essential civilian sectors including

[37] U.S.-China Economic and Security Review Commission, *Going Out: An Overview of China's Outward Foreign Direct Investment* (March 2011), https://uscc.gov/sites/default/files/Research/GoingOut.pdf
[38] U.S. Department of the Interior, *Investigation and Recommendations on our Nation's Reliance on Foreign Sources of Critical Minerals* (September 30, 2020), see Appendix G

petroleum refining, electromedical device manufacturing, automotive manufacturing, and search, detection, and aeronautical instrument manufacturing.

<u>Figure 11: Economic Impact of Rare Earth Imports (by NAICS Code)</u>

NAICS code	NAICS description	Applications	2016 Value Added[1] (million USD)	2016 operating profit margins[2]	2016 expenditure on REE[3] (million USD)	Relative expenditure contribution for each industry by rare earth element[4]											
						La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Er	Yb	Y
324110	Petroleum refineries	Catalyst	$68,758	8.16 percent	$19.6												
325110	Petrochemical mfg.	Catalyst	$27,881	47.65 percent	$0.3												
325130	Synthetic dye & pigment mfg.	Pigments	$3,047	28.13 percent	$5.2												
325211	Plastics material & resin mfg.	Other	$30,379	20.21 percent	$1.4												
325212	Synthetic rubber mfg.	Catalyst	$2,772	19.22 percent	$4.3												
325411	Medicinal & botanical mfg.	Other	$6,970	21.01 percent	$3.9												
325510	Paint & coating mfg.	Other	$13,492	33.42 percent	$1.1												
327110	Pottery, ceramics, & plumbing fixture mfg.	Ceramics	$1,512	26.04 percent	$0.03												
327120	Clay building material & refractories mfg.	Ceramics	$3,441	27.11 percent	$0.1												
327212	Other pressed & blown glass & glassware mfg.	Glass	$2,281	30.38 percent	$1.9												
327910	Abrasive product mfg.	Ceramics	$3,992	49.16 percent	$3.1												
331110	Iron & steel mills & ferroalloy mfg.	Metallurgy	$29,077	18.24 percent	$9.5												
333249	Other industrial machinery mfg.	Magnets	$8,629	13.19 percent	$20.2												
333314	Optical instrument & lens mfg.	Glass	$2,938	4.13 percent	$16.6												
333316	Photographic & photocopying equipment mfg.	Battery, Magnets	$918	19.31 percent	$3.1												
333515	Cutting tool & machine tool accessory mfg.	Ceramics	$3,680	19.55 percent	$0.4												
333611	Turbine & turbine generator set units mfg.	Ceramics, Magnets	$6,421	22.97 percent	$27.2												
333618	Other engine equipment mfg.	Ceramics	$8,451	19.97 percent	$0.1												
333912	Air & gas compressor mfg.	Magnets	$4,593	23.87 percent	$24.4												
333991	Power-driven hand-tool mfg.	Battery	$1,652	21.98 percent	$0.3												
333993	Packaging machinery mfg.	Magnets	$3,569	20.79 percent	$12.3												
334111	Electronic computer mfg.	Magnets, Phosphors	$3,822	20.73 percent	$0.6												
334112	Computer storage device mfg.	Magnets	$3,159	38.05 percent	$77.7												
334118	Computer terminal & other computer equipment mfg.	Phosphors	$4,218	24.37 percent	$0.3												
334210	Telephone apparatus mfg.	Battery, Magnets, Phosphors	$2,582	7.91 percent	$38.3												
334220	Radio & television broadcasting & wireless comm. equip. mfg.	Battery, Magnets, Phosphors, Polishing	$14,998	9.33 percent	$7.8												
334413	Semiconductor & related device mfg.	Ceramics, Polishing	$26,923	22.27 percent	$1.9												
334416	Capacitor, resistor, coil, transformer, & other inductor mfg.	Ceramics	$1,868	10.22 percent	$4.6												
334510	Electromedical & electrotherapeutic apparatus mfg.	Magnets	$17,132	21.17 percent	$38.7												
334511	Search, detection, navigation system mfg.	Magnets, Other	$32,066	29.36 percent	$24.8												
334517	Irradiation apparatus mfg.	Phosphors	$5,082	25.29 percent	$3.8												
334519	Other measuring & controlling device mfg.	Ceramics, Magnets	$6,467	17.93 percent	$8.6												
335110	Electric lamp bulb & part mfg.	Phosphors	$651	17.27 percent	$30.7												
335210	Small electrical appliance mfg.	Battery	$1,849	26.09 percent	$0.4												
33522	Major appliance mfg.	Magnets	$8,724	27.37 percent	$0.9												

[1] Value Added represents each industry's contribution to Gross Domestic Product based on data from the U.S. Census Bureau's Annual Survey of Manufactures (ASM)

[2] Each industry's operating profit margin is calculated as the ratio of its operating profits to its revenues. Operating profits are calculated as the difference between the total value of the industry's shipments and receipts for services (i.e., its revenues) and its operating expenses under the following categories: payroll, fringe benefits (e.g., employee health insurance), cost of materials and energy, rental or lease payments, changes in inventories (including finished goods, work in progress, and materials and supplies), and other operating expenses. Data for each parameter were obtained from the U.S. Census Bureau's ASM

[3] Expenditures are based on the product of consumption quantities and the unit prices for each rare earth element as reported by Argus Media. Consumption quantities include direct (i.e., raw material) and embedded (i.e., those contained in finished and semifinished goods) of rare earth elements as estimated and linked to individual North American Industry Classification System (NAICS) industries.

[4] Color gradient indicates relative expenditure contribution from 0 percent (white) to 100 percent (dark blue) of each rare earth element within an individual industry (i.e., within each row).

335312	Motor & generator mfg.	Magnets	$4,104	19.01 percent	$70.2
335314	Relay & industrial control mfg.	Magnets	$4,939	12.86 percent	$5.3
335911	Storage battery mfg.	Battery, Magnets	$3,582	15.83 percent	$15.8
335921	Fiber optic cable mfg.	Ceramics, Glass, Other	$1,538	22.26 percent	$0.6
335999	All other miscellaneous electrical equipment & component mfg.	Battery	$5,672	15.45 percent	$0.2
336320	Motor vehicle electrical & electronic equipment mfg.	Phosphors	$8,695	11.26 percent	$0.0
336330	Motor vehicle steering & suspension components mfg.	Magnets	$5,190	8.76 percent	$51.3
336350	Motor vehicle transmission & power train parts mfg.	Magnets	$12,283	11.43 percent	$29.0
336390	Other motor vehicle parts mfg.	Battery, Catalyst, Phosphors	$21,280	10.68 percent	$10.5
336412	Aircraft engine & engine parts mfg.	Ceramics	$24,399	26.54 percent	$0.6
336510	Railroad rolling stock mfg.	Magnets	$3,988	4.82 percent	$2.7
336999	All other transportation equipment mfg.	Metallurgy	$2,490	12.06 percent	$14.2
339113	Surgical appliance & supplies mfg.	Battery, Ceramics	$22,009	27.23 percent	$0.3
339115	Ophthalmic goods mfg.	Polishing	$3,625	17.01 percent	$2.0
339999	All other miscellaneous mfg.	Magnets, Metallurgy	$8,995	23.32 percent	$16.8
Total or average			**$496,782**	**17.30 percent**	**$613.4**

Green Energy Demand

To avoid the worst impacts of the climate crisis, the Biden-Harris Administration has committed to 50 percent or more reduction of carbon dioxide (CO2) and non-CO2 greenhouse gas pollution by 2030,1 with a long-term goal to reach net-zerio emissions 2050. Though Federal action is important, consumer and investor demands, combined with private-sector investment, increasingly are aligned around this level of ambition.

The supply chain impact of deploying clean technologies at scale are significant and will require secure, reliable access to strategic and critical materials materials. Examples of mineral-based clean technologies include rare earth elements for permanent magnets in electric vehicles and wind turbines; battery grade cobalt, lithium, manganese, nickel, and graphite for vehicle batteries and grid storage; gallium and many other materials for semiconductors used in LEDs and power electronics used in wind and solar systems; and magnesium and aluminum for vehicle lightweighting.

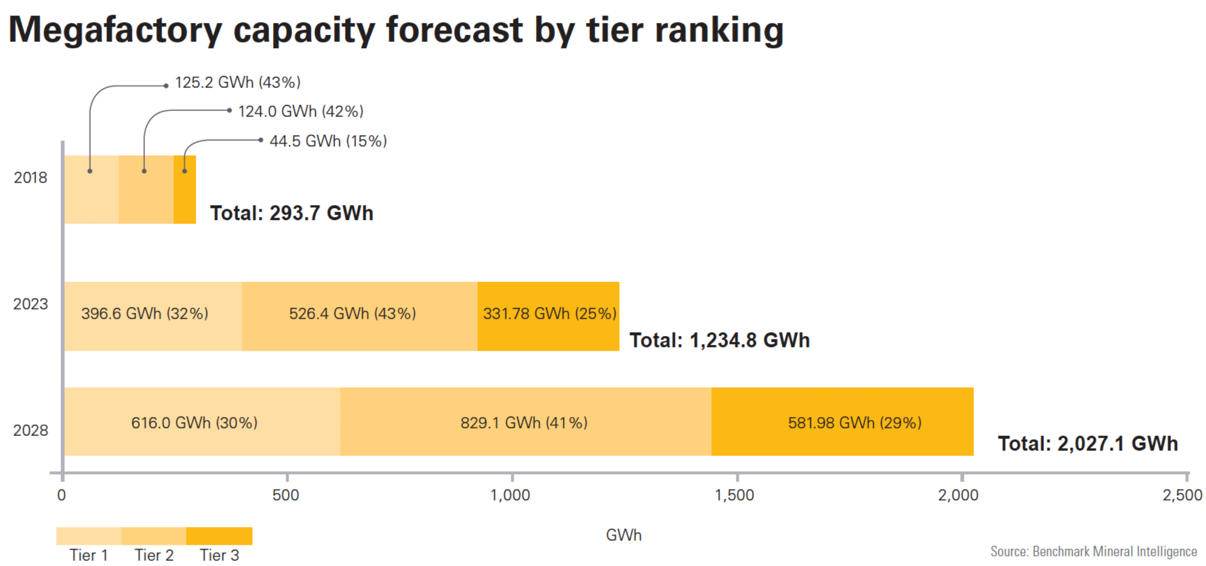
The Department of Energy leads the U.S. Government's evaluation of strategic and critical material demand modeling for green energy and energy conservation technologies through its Critical Materials Strategy.2 Independent of this assessment withheld as Controlled Unclassified Information by the Department of Energy, industry assessments indicate that forthcoming demand for battery-grade nickel, cobalt, and lithium is expected to expand dramatically with global uptake in electric vehicles and stationary storage batteries (see Figure 12). The projected demand for electric vehicles also is expected to drive demand for the rare earth elements used in the magnets, even more so than is the case today.

The United States can develop secure and resilient supply chains for clean technologies with a broad value-based policy approach, including continuous research, primary production, downstream manufacturing, and recycling. Given the environmental and labor legacy of mining, increased mineral production and reclamation activities must be held to modern environmental standards, require best-practice labor conditions, and consultation with affected communities, including Tribal Nations in government-to-government consultation. In doing so, the United States will make crucial progress towards meeting U.S. economic and climate objectives.

[1] The White House, *Fact Sheet: President Biden Sets 2030 Greenhouse Gas Pollution Reduction Target Aimed at Creating Good-Paying Union Jobs and Securing U.S. Leadership on Clean Energy Technologies* (April 22, 2021), https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/

[2] See Appendix B.

Figure 12: Expanding Global Lithium-Ion Battery "Megafactories"[3]



Decline in U.S. Production and Processing Operations

Focus on Low-Cost Production

Private sector participants are experts at *seeking global low-cost producers* for strategic and critical materials. A significant driver of this low-cost profile is natural, comparative advantage from unique geologic occurrences or an abundance of related consumables and utilities (e.g., water and power). On the other hand, comparative advantage also may result from negative market interventions, such as a general disregard for worker health and safety, waste-water or hazardous emissions, and forced labor.

For instance, the chemical materials used to manufacture energetic compounds frequently use extraction or synthesis routes that have environmentally harmful waste streams. These waste streams can be controlled only with costly mitigation equipment. Countries whose environmental regulations are relatively lax (or even non-existent) can produce critical materials at a lower price, weakening suppliers where the regulations are more stringent. In addition, government intervention may create a comparative advantage by providing tax incentives and credits, subsidies, and other non-cash benefits. This latter type of economic tradecraft is difficult to challenge, outside of lengthy and sometimes costly enforcement actions using domestic and international trade dispute settlement fora.

Product Differentiation

Strategic and critical materials also operate at two very different product extremes. On the one hand, the primary extraction of many strategic and critical materials occurs as a byproduct or co-product of much larger industrial markets—such as the recovery of rare earth elements from iron ore processing, or germanium from zinc refining. Consequently, producers and consumers generally treat many strategic and critical materials like commodity products, with very little product differentiation among producers.

Counterintuitively, for the exact same strategic and critical materials, their downstream, value-added forms may be so differentiated that the materials are unique and proprietary to a single company. Though thrifting may be possible at upstream supply chain tiers, downstream material forms are not readily substitutable in their end-use application, and market demand is tightly concentrated in only a handful of applications. High performance carbon fibers are an example of this trend. Though many different carbon fibers are available

[3] Benchmark Mineral Intelligence, "The Three Tiers of Battery Megafactories," benchmarkminerals.com (September 13, 2019), https://benchmarkminerals.com/the-three-tiers-of-battery-megafactories/; "Tiers" of production refer to (1) qualification for multinational electric vehicle producers outside of China, (2) qualification to supply Chinese electric vehicle producers or other applications, and (3) no prior history of qualified production.

on the market, the specific carbon fibers suitable for the aerospace sector are limited to a mere handful of sources in the world. For select high temperature, high modulus and high strength applications, only one (non-U.S.) factory in the world is qualified to produce this material.

Permitting of Domestic Strategic and Critical Materials Production

Mining operations—particularly when conducted outside of established governance—can have a significant impact on the environment, including habitat destruction, air and water pollution, hazardous waste generation, and other issues. As such, U.S. mining projects must comply with state and Federal laws, and overseas mining projects must adhere to local laws and global standards designed to mitigate these impacts and protect human health and the environment.

The process of permitting and conducting environmental assessments, environmental impact statements, and related work are a separate time variable, additive to or concurrent with the decade-long development timeline for strategic and critical materials projects. The National Environmental Policy Act (NEPA), the Clean Water Act, and the Clean Air Act are three commonly cited statutes affecting the strategic and critical materials industry. NEPA also requires Federal agencies to consider the environmental impacts of proposed Federal actions and generally provide opportunities the public for input. The mission of the Clean Water Act is "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." Various aspects of the industry potentially influence nearby surface water and groundwater sources, including discharges from initial ore extraction and multiple downstream processing operations (e.g., solvent extraction). The Clean Air Act, first adopted in 1955 and modified in 1970, regulates emission limits on 187 dangerous pollutants. Mine plan of operations approvals by Federal land management agencies under Federal mining regulations are required for mining operations on Federally-managed lands. Mining operations also are subject to State permits and approvals.

Industry and related consulting groups have routinely cited the environmental regulatory process as an impediment to strategic and critical materials production. Behre Dolbear, an industry advisory firm, regularly evaluates the global mining sector using seven criteria relevant to a nation's business climate.4 The United States consistently scores high marks for the stability of its economic and political system, as well as currency stability and active policing of corruption in the sector. But Behre Dolbear reporting also consistently gives the U.S. very low marks related to permitting risk, citing approximately seven to ten years to obtain the relevant permits for full-scale operations.

On the other hand, more recent analysis by the Fraser Institute related to the investment climate for mining exploration indicates that the U.S., on the whole, several U.S. States5, in particular, are among the best jurisdictions in the world.6 Similarly, a Government Accountability Office evaluation of U.S. Government mine plan reviews found that approval processes, including NEPA, took from 1 month to 11 years, with an average time of 2 years.7 This evaluation further identified several key challenges to timely review and approval of mine plans, such as incomplete or vague mine plans, insufficient Federal Government staff to conduct reviews, changes in mine plans after submission, or complex or unusually high potential environmental impacts.

[4] Behre Dolbear, *2014 Ranking of Countries for Mining Investment* (2014), https://dolbear.com/wp-content/uploads/2016/04/2014-Where-to-Invest.pdf

[5] Such as Idaho, Wyoming, Nevada, Utah, Alaska, and Arizona.

[6] Jairo Yunis and Elmira Aliakbari, *Fraser Institute Survey of Mining Companies 2020* (February 23, 2021), https://www.fraserinstitute.org/studies/annual-survey-of-mining-companies-2020

[7] U.S. Government Accountability Office, *Hardrock Mining, BLM and Forest Service Have Taken Some Actions to Expedite the Mine Plan Review Process by Could Do More* (January 2016), https://www.gao.gov/assets/gao-16-165.pdf

China's Non-Market Activities

Whereas the United States is a market economy, the U.S. Department of Commerce classifies China as a non-market economy, meaning China does not "operate on market principles of cost or pricing structures, so that sales of merchandise in such country do not reflect the fair value of the merchandise."[8]

This characterization reflects markedly different policy preferences in commercial markets, made particularly stark for strategic and critical materials. The dwindling U.S. production base for rare earth elements and rare earth-derived products illustrates these differences in policy choices and outcomes.

In the 1990s, the United States largely allowed its domestic rare earth market to operate under market principles, with small carve-outs for defense-specific requirements. Meanwhile, according to the U.S. International Trade Commission, Chinese companies were circumventing various intellectual property rights in their exports of low-cost NdFeB magnets to the U.S. market.[9] In 2003, following acquisition by a conglomerate including a Chinese entity, the United States' leading NdFeB magnet producer ceased operations and relocated its operations to China in 2003.[10] Similarly, in 2015, the United States, Japan, and the EU successfully challenged China's rare earth export quota administration system through the World Trade Organization (WTO) dispute settlement mechanism, which agreed that those export restraints violated WTO rules.[11] Yet, over the course of this period, from 1992 to 2020, the United States lost at least four NdFeB production facilities,[12] and the United States also lost at least three rare earth separation facilities.[13]

By contrast, the Chinese Government has focused on capturing discrete strategic and critical material markets as a matter of state policy. For example, China implemented a value-added tax (VAT) rebate for rare earth exports in 1985, which contributed to the erosion and then elimination of U.S. production in the global market. Figure 13 depicts the growth of China's rare earth exports from the 1960s to the present. In 2002, China's National Development Planning Commission issued the *Interim Regulations on the Management of Foreign Investment in the Rare Earth Industry*, which prohibited foreign investors from establishing rare earth mining enterprises in China and exclusively owning and controlling rare earth smelting and separation projects. In January 2014, China's Ministry of Industry and Information Technology took the lead in forcing the vertical and horizontal integration of Chinese rare earth companies — pushing privately-held rare earth miners out of the market in favor of a handful of national champions. This central planning and active management of the rare earth industrial base continues, with new draft management regulations under review and even more expansion projects underway.

---

[8] See 19 U.S.C. 1677(18)(A)

[9] U.S. International Trade Commission, *In the Matter of Certain Neodymium-Iron-Boron Magnets, Magnet Alloys, and Articles Containing Same*, Investigation No. 337-TA-372, Publication 2964 (May 1996), https://usitc.gov/publications/337/pub2964.pdf

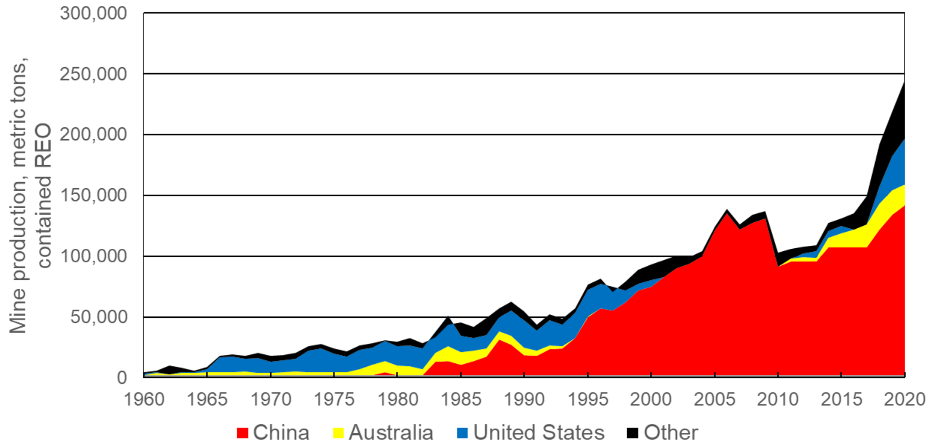
[10] David Moberg, "Magnet Consolidation Threatens both U.S. Jobs and Security," *In These Times* (January 23, 2004), https://inthesetimes.com/article/magnet-consolidation-threatens-both-us-jobs-and-security

[11] World Trade Organization, Dispute Settlement (Summary), DS431, "China – Measures Related to the Exportation of Rare Earths, Tungsten, and Molybdenum" (May 2015), https://wto.org/english/tratop_e/dispu_e/cases_e/ds431_e.htm

[12] Walter T. Benecki, "Magnetics Industry Overview: 2005 – Another Year of Significant Change in the Magnetics Industry," waltbenecki.com (November 2005), https://waltbenecki.com/uploads/Another_Year_of_Significant_Change_in_the_Magnetics_Industry.

[13] Joseph Gambogi, "Rare Earth Data Sheet," in U.S. Geological Survey, *Mineral Commodity Summaries 2020* (January 2020), https://pubs.usgs.gov/periodicals/mcs2020/mcs2020-rare-earths.pdf

Figure 13: Global Rare Earth Production (1960-2020)[14]



RISK ASSESSMENT

Overview

As noted in its reports on the health of the defense industrial base,15 DoD assesses risk in the strategic and critical materials sector in two tiers, at and below the level of armed conflict. DoD models the former set of risk factors on a biennial basis, in accordance with its duties as the National Defense Stockpile Manager under the Strategic and Critical Materials Stockpiling Act of 1979 (50 U.S.C. 98 et seq.).

Though the magnitude of harm from market disruptions during armed conflict is high, the underlying causes of these market disruptions are not new. Instead, the scenario levies a uniquely intense set of requirements upon an already fragile market. This fragility exists today—under conditions well below the threshold of Armed Conflict—and generally results from market forces pushing firms to pursue the most economically efficient or lowest-cost pathway to satisfy demand.

Over the past decade, peacetime supply chain disruptions have increased in frequency and intensity. The COVID-19 pandemic is only the most recent, albeit severe, shock to global supply chains, but private sector companies must also contend with risks ranging from climate-induced power outages to cyber-attacks and disruption of shipping lanes. Core drivers of this absence of resilience in the strategic and critical materials sector include the following risk factors:

- Concentration of Supply
- Single-Source Suppliers
- Price Shocks
- Human Capital Gaps
- Conflict Minerals and Organized Crime
- Forced Labor

Risk Factors below the Level of Armed Conflict

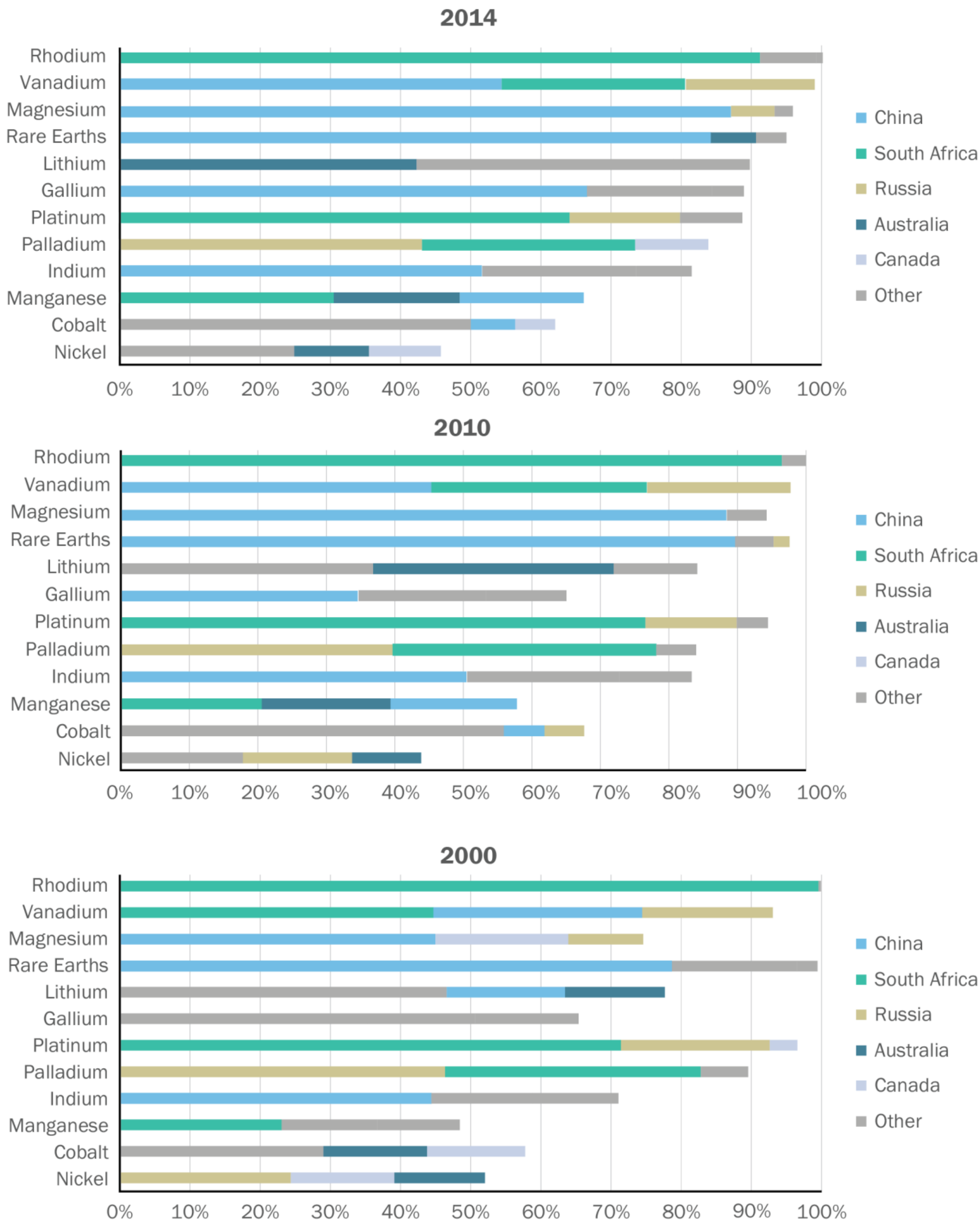
Concentration of Supply

Independent of direct U.S. imports, a significant portion of global production for strategic and critical materials is concentrated in only one or a few countries. This lack of supplier diversity creates not only market challenges for nascent producers, it also means a large portion of global supply is subject to single

[14] Derived from U.S. Geological Survey data.
[15] Department of Defense, *Fiscal Year 2019 Industrial Capabilities Report to Congress* (June 2020), https://www.businessdefense.gov/Portals/51/Documents/Resources/USA000954-20%20RPT%20Subj%20FY19%20ICR%2007092020.pdf?ver=2020-07-10-124452-180

point disruption risk (e.g., natural disasters, shifting industrial or trade policies). Figure 14 shows that, on average, across select strategic and critical materials, supplier diversity decreased from 2000 to 2014.

Figure 14: Market-Share of Largest Global Producers for Select Materials[16]



[16] Department of Energy, "Figure 2-3. Comparison of share of the three largest global producers of select materials (2000, 2010, and 2014)," *Critical Materials Strategy* (February 2019), p 16.

When a particular country's share of global production exceeds half of global production for a particular strategic and critical material, that country is considered a "foreign market dominator" for the purposes of DoD's input-output or agent-based economic modeling.[17] Figure 15 displays a list of 37 shortfall strategic and critical materials (see the section, *Risk Factors at the Level of Armed Conflict*) that exhibit this foreign market dominator criterion.

Figure 15: Strategic & Critical Materials Subject to a Foreign Market Dominator

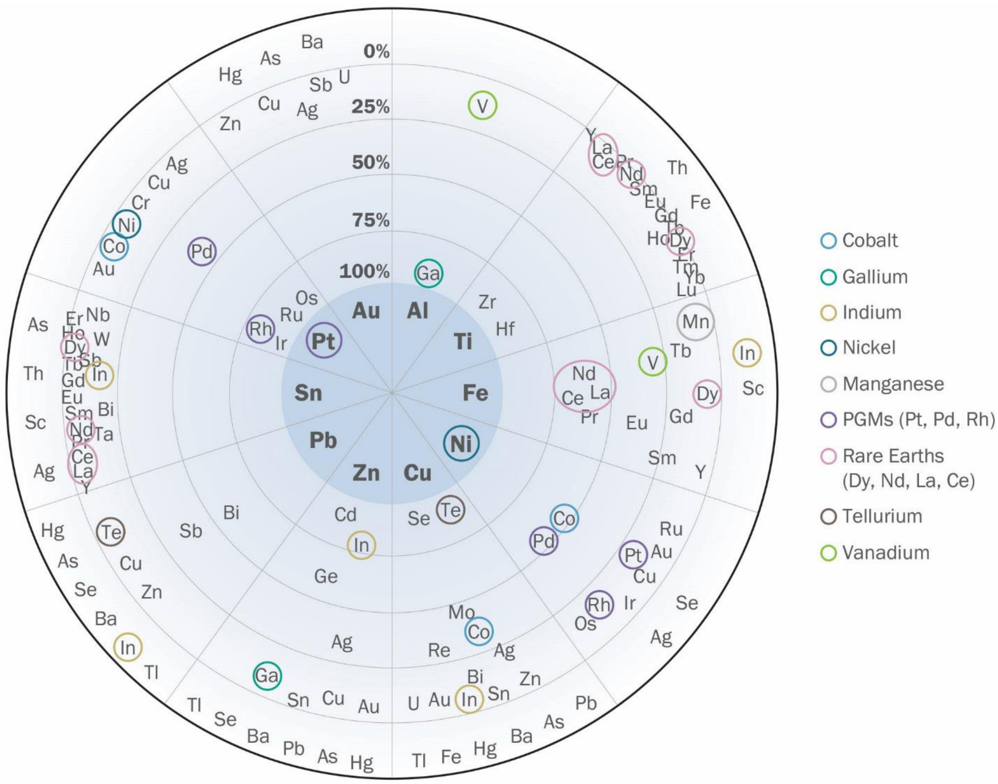
Aluminum, high purity	Manganese metal, electrolytic
Arsenic, molecular beam grade	Neodymium
Barium	Niobium
Beryllium metal	Praseodymium
Beryllium ore, beryl ore	Rare earth permanent magnets, NdFeB types
Bismuth	Rare earth permanent magnets, Samarium Cobalt types
Carbon-Carbon (multiple)	Samarium
Cerium	Scandium
Erbium	Steel, 1080 grade ultra-high strength cable tire cord
Energetic Materials[18]	Steel, grain oriented electrical steel silicon-based
Europium	Strontium
Fluorspar, acid grade	Tin, low alpha
Graphite, iso-molded civilian grade	Tungsten, ammonium paratungstate
Graphite, iso-molded defense grade	Tungsten, ores and concentrates
Lanthanum	Yttrium oxide
Lithium metal	Zirconium
Magnesium metal	

Byproduct and Coproduction Dependency

Byproduct production of strategic and critical materials can add significant value to an existing production operation and improve the business case for a nascent producer. However, some strategic and critical materials are derived exclusively from byproduct production, which means a fairly small market depends on the prevailing dynamics of a separate but much larger commodity market. A mapping of this dependence is shown in Figure 16.

[17] The computation of the fraction of world supply that a specific country provides is made before any of the conflict-related decrements are applied to its supply level.
[18] Multiple types, see Appendix H.

Figure 16: Co-Production Dependency[19]



Single Source Production

In some cases the concentration of supply can be so extreme that U.S. or global production is concentrated in a single source. Current domestic sole-source, or single points of failure, in shortfall strategic and critical material supply chains (see *Risk Factors at the Level of Armed Conflict*) are shown in Figure 17.

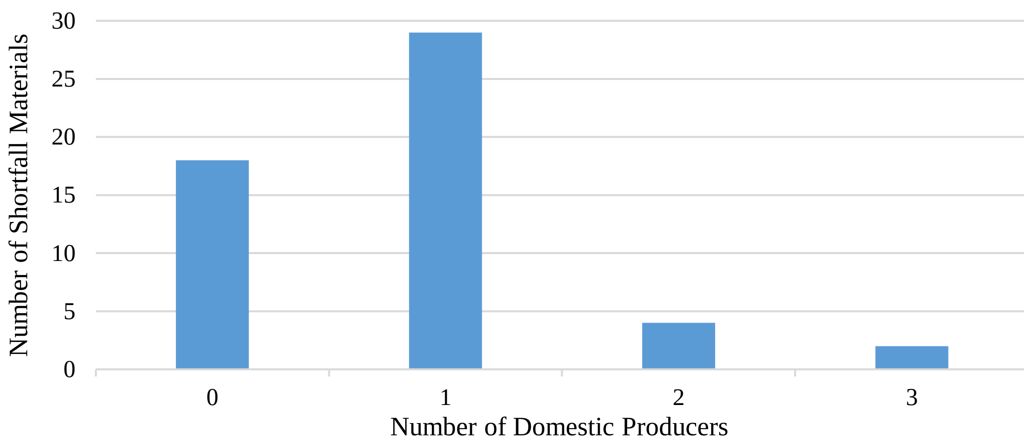
Figure 17: Select Domestic Sole-Source Strategic and Critical Materials

Aluminum, high purity	Magnesium metal
Aluminum-lithium alloys	Manganese, ferromanganese
Barium	Rare earth permanent magnets, SmCo types
Beryllium metal	Steel, grain oriented electrical steel silicon-based
Beryllium ore, beryl ore	Strontium
Boron powder	Tantalum
Boron-10 Isotope[20]	Tin, low alpha
Energetic Materials[21]	

[19] N. T. Nassar, T. E. Graedel and E. M. Harper, "By-product metals are technologically essential but have problematic supply," *Science Advances* (2015), https://advances.sciencemag.org/content/1/3/e1400180. This figure demonstrates the relationship between critical materials that are produced as by-products of primary products. This figure does not provide a complete picture of all minerals on the Federal List of Critical Minerals, 2018, https://federalregister.gov/documents/2018/05/18/2018-10667/final-list-of-critical-minerals-2018.
[20] Note: the Department of Defense has run only a limited number of isotope supply chains through its modeling process for the National Defense Stockpile program. The Department of Energy maintains robust monitoring of and participation in the isotope market, and at-risk materials are covered in Appendix D and Appendix E
[21] See Appendix A and Appendix H

More generally, in DoD modeling of strategic and critical materials under national emergency conditions, a domestic sole-source provider exists for 29 of the 53 unclassified shortfall materials, and 18 materials have no domestic production at all. Figure 19 illustrates U.S. reliance on single domestic producers for 83 percent of shortfall materials for which domestic production exists. Outside of this assessment of strategic and critical material supply chains, other DoD surveys have found that approximately 75 percent of energetic materials used in defense supply chains are sole-source products (see Appendix H).

Figure 19: Domestic Producers for Unclassified Shortfall Materials



Skills and Human Capital Development Gaps

DoD's *Fiscal Year 2020 Industrial Capabilities Report to Congress* highlighted the vulnerability of a "shrinking workforce" in advanced manufacturing. There is a mismatch between the skill needs of advanced manufacturers *vis-à-vis* the training programs available. Programmatic responses to education and training needs still focus on four-year STEM-based[22] programs rather than on digital industrial skills on the factory floor. The Department of Commerce has summarized the real, yet seldom recognized, challenge to U.S. economic competitiveness from labor shortfalls in the strategic and critical materials sectors as follows:

> The entire U.S. critical minerals supply chain faces workforce challenges, including aging and retiring personnel and faculty; public perceptions about the nature of mining and mineral processing; and foreign competition for U.S. talent. Unless these challenges are addressed, there may not be enough qualified U.S. workers to meet domestic production needs across the entire critical minerals supply chain.[23]

For more than 35 years, the number of colleges and universities with mining and extractive metallurgy production programs has steadily decreased. A number of major colleges and universities have eliminated their mining departments altogether. Others have reduced their emphasis in mining and minerals engineering.24 Former colleges of mining engineering have downsized to the point where they now exist as smaller departments under a university's college of engineering. A principal reason for this decline in education and knowledge is the reduced U.S. demand for mining engineers and technicians.

---

[22] STEM stands for Science, Technology, Engineering, and Mathematics.

[23] U.S. Department of Commerce, *A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals* (June 4, 2019), https://commerce.gov/sites/default/files/2020-01/Critical_Minerals_Strategy_Final.pdf

[24] J. Harrison Daniel, "The Circumstances, Events and Politics Leading the Closure of the U.S. Bureau of Mines: Was It the Correct Decision?" *Mining Engineering,* Vol. 62, No. 4 (April 2010): p 20, https://me.smenet.org/abstract.cfm?preview=1&articleID=436&page=20

With the elimination of these types of colleges and university departments, ostensibly for lack of funding or demand or both, now only a handful of mining and mineral-related degree-granting university programs are left in the United States. This decline follows the defunding of the Bureau of Mines (USBM) 25 years ago, which issued educational grants and assisted university programs across the country. By way of comparison, China has 39 universities granting mineral processing and metallurgy degrees, thousands of undergraduate and graduate students.

Many other downstream manufacturers continue to struggle to recruit and retain skilled workers, according to a recent survey of small and medium-sized manufacturers (i.e., those with fewer than 500 employees) by the Manufacturing Institute's Center for Manufacturing Research. When asked to identify the skills most difficult to fill, 77 percent identified manufacturing and production skills, followed by maintenance, repair and installation (42 percent), and engineering (39 percent).[25]

Other evidence indicates hiring difficulties are concentrated among roughly one-quarter of U.S. manufacturers, suggesting the skills challenge in U.S. manufacturing is manageable and amenable to targeted policy action.26 Forging and incentivizing better structured connections between community and technical colleges and manufacturers for well-defined industrial skills pipelines is needed to address shortages of skilled labor in the United States. In one survey, most U.S. manufacturers reported that, though they were aware of a community college in their region, only about half reported that they had conversations with the college regarding skill issues and only about a quarter actually used a community college for hiring new employees or training incumbent workers.[27]

Insufficient domestic workforce capabilities also represents a significant economic loss for the United States. For example, during the last available reporting period, China's rare earth mining industry and smelting industry employed 4,000 and 40,600 people, respectively. These industries also generated $1.1 billion and $10.5 billion in revenue over the same period, for a revenue to employment ratio of approximately $265,000 and $258,000 per employee.28 Of note, rare earth mining and smelting operations are concentrated in non-urban provinces in which the average annual mining salary is less than $9,500 per year.[29]

Conflict Minerals, Forced Labor, Organized Crime, and Related Vulnerabilities

The production and trade of strategic and critical materials may involve a range of chain-of-custody risks at the mine site and at each subsequent node. Human rights violations, including forced or child labor, profiteering by non-state actors, environmental pollution, the role of organized crime, and corruption are increasingly concerning factors for minerals and materials supply chains. In response, modern consumers, market economies, and even some non-market jurisdictions are increasingly demanding that private sector supply chains conduct extensive due diligence and achieve higher productions standards. This dynamic is playing out across many different types of supply chains, from clothing to chocolate, and critical minerals and materials are no exception.

It is important to note that many of these issues are often associated with artisanal and small-scale mining when addressing mining at the source. Those valid issues notwithstanding, large-scale mining also carries many of these same issues and concerns.

---

[25] The Manufacturing Institute, *The Manufacturing Institute–BKD Small and Medium-Sized Manufacturers Survey, February 2021: The 'New Normal' and Post-Pandemic Workforce Challenges* (February 2021), https://themanufacturinginstitute.org/wp-content/uploads/2021/02/BKD-MI-Survey-Feb2021.pdf

[26] Andrew Weaver and Paul Osterman, "Skill Demands and Mismatch in U.S. Manufacturing," *Industrial and Labor Relations Review*, Vol. 70, No. 2 (March 2017), https://journals.sagepub.com/doi/10.1177/0019793916660067

[27] Paul Osterman and Andrew Weaver, "Community Colleges and Employers: How Can We Understand their Connection?" *Industrial Relations*, Vol. 55, No. 4 (October 2016), pp 523-545, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2835733

[28] Data derived from the China Economic Census and National Bureau of Statistics of China for the 2013 reporting period.

[29] Data derived from China's National Bureau of Statistics.

The Department of Labor issues three regular assessments30 on international child and forced labor that serve as a valuable resource for corporate responsibility and law enforcement to prevent and eliminate labor abuses in global supply chains. Though each has a distinct mandate, collectively they document the current situation for child labor, forced labor, and force child labor around the globe. As of the latest release in September 2020, the List of Goods Produced by Child Labor or Forced Labor includes 32 goods and 13 goods, respectively are produced using child labor or forced labor in the mining and quarrying sector. Strategic and critical materials on this list include cobalt, tin, tantalum, and tungsten.

Conflict Minerals

The United States' effort to break the connection between armed groups and profit from valuable minerals was established through Section 1502 of the Wall Street Reform and Consumer Protection Act of 2010—also known as Dodd-Frank 1502. Dodd-Frank 1502 defines "conflict minerals" cassiterite, columbite-tantalite, wolframite, gold, or their derivatives, which include tin, tantalum, tungsten (3TG)31 and requires those companies who manufacture products or contract to have products manufactured that contain 3TG that are necessary to the functionality or production of those products to have certain reporting requirements to the Securities and Exchange Commission (SEC). If a company reasonably believes the 3TG they use may have originated in the Democratic Republic of the Congo (DRC) or its adjoining neighbors, the company is expected to file a conflict-minerals report with the SEC describing its supply chain due diligence efforts aimed at the source and chain of custody of those minerals.

Section 1502 also provides the Secretary of State with the authority to designate additional conflict minerals beyond 3TG, based on a determination that such minerals are financing conflict in the DRC or an adjoining country. In addition, as of January 2021, the EU is implementing a similar regulation covering EU importers of these same minerals when importing from an undefined list of conflict-affected and high-risk areas. The United States and the EU actively support and promote private sector application of the Organization for Economic Co-operation and Development (OECD) Supply Chain Due Diligence for minerals as the key tool for companies to understand their supply chains.

Approximately 1,200 companies provide annual conflict minerals reports to the SEC on their efforts to describe the source and chain of custody of conflict minerals in their supply chains. Given active U.S. reporting requirements and the EU's emerging requirements, the consumer electronic, automotive, aerospace, jewelry, and medical industries — which comprise the bulk of industries most reliant on 3TG — have largely adapted to the resulting culture of supply chain due diligence.

Forced and Child Labor

The Trafficking Victims Protection Reauthorization Act of 2005 (Public Law 109-317) the Department of Labor (DoL) to produce a biannual list of goods it has reason to believe are produced by child or forced labor (TVPRA list). The 2020 TVPRA list features 155 goods in 77 countries. The list includes tin ore, tantalum ore (coltan), and tungsten ore (wolframite) mined with forced labor, including forced child labor, from the Democratic Republic of the Congo (DRC); and gold produced with forced labor, including forced child labor, from Burkina Faso and the DRC. E.O. 13126 on the *List of Products Produced by Forced or Indentured Child Labor* is intended to ensure that Federal agencies do not procure goods made by forced or indentured child labor, and Section 307 of the Tariff Act of 1930 (19 U.S.C. §1307) prohibits importing any product that was

[30] U.S. Department of Labor, "Findings on the Worst Forms of Child Labor", https://www.dol.gov/agencies/ilab/resources/reports/child-labor/findings; U.S. Department of Labor, "List of Goods Produced by Child Labor or Forced Labor", https://www.dol.gov/agencies/ilab/reports/child-labor/list-of-goods; U.S. Department of Labor, "List of Products Produced by Forced or Indentured Child Labor", https://www.dol.gov/agencies/ilab/reports/child-labor/list-of-products

[31] Separate from the reporting requirement under Dodd-Frank 1502, Congress also has adopted new procurement restrictions on DoD procurement of end items and materials containing tantalum and tungsten metal products, as well as two forms of rare earth permanent magnets. These procurement restrictions are implemented in 10 U.S.C. 2533c.

mined, produced, or manufactured wholly or in part by forced labor, including forced or indentured child labor.

To help mitigate these risks of child labor and forced labor in supply chains, including in the extractive sector, DoL developed *Comply Chain: Business Tools for Labor Compliance in Global Supply Chains*. Comply Chain provides practical, step-by-step guidance on critical elements of social compliance and is designed for companies that do not have a social compliance system in place or those needing to strengthen their existing systems.

Transnational Organized Crime (TOC)

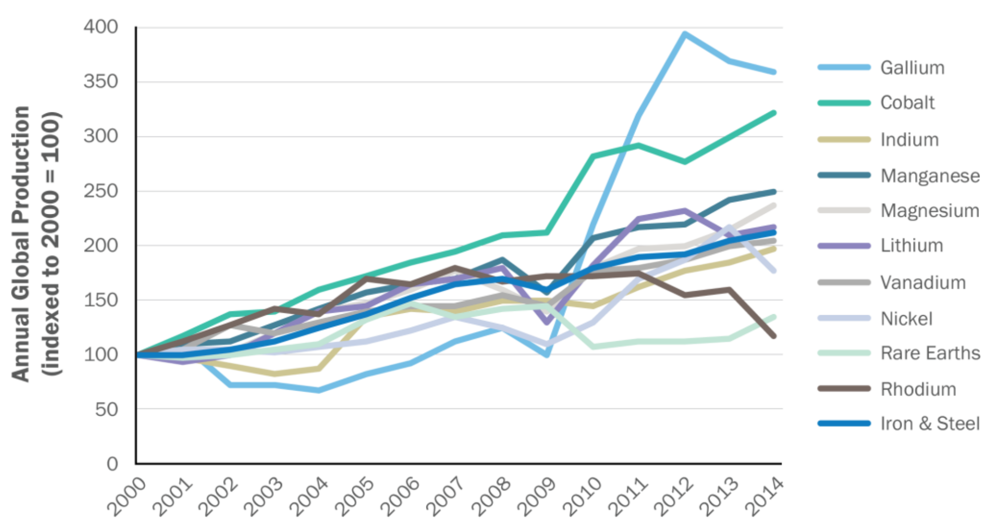
TOC groups, including drug traffickers and insurgent groups, use illegally mined gold and other materials to reap billions in illicit profits. They also use gold trafficking to launder profits from other illicit activities. Though gold is not a strategic and critical material, government policy in this area is highly instructive for strategic and critical materials more generally. The United States does not have criminal laws to investigate commodities that have been illegally mined in other jurisdictions, and so U.S. law enforcement organizations increasingly have relied on Federal money laundering statutes to address this illicit activity.

Working with the Organization of American States, for example, the State Department has established a regional enforcement system to combat illegal mining financial structures. This project builds the capacity of authorities in Brazil, Colombia, Ecuador, Guyana, Peru, and Suriname responsible for combatting illegal gold mining in order to increase investigations and convictions for crimes related to illegal mining and increase the quantity and value of seized and confiscated assets linked to illegal mining criminal networks in all targeted countries.

Market/Economic Shocks

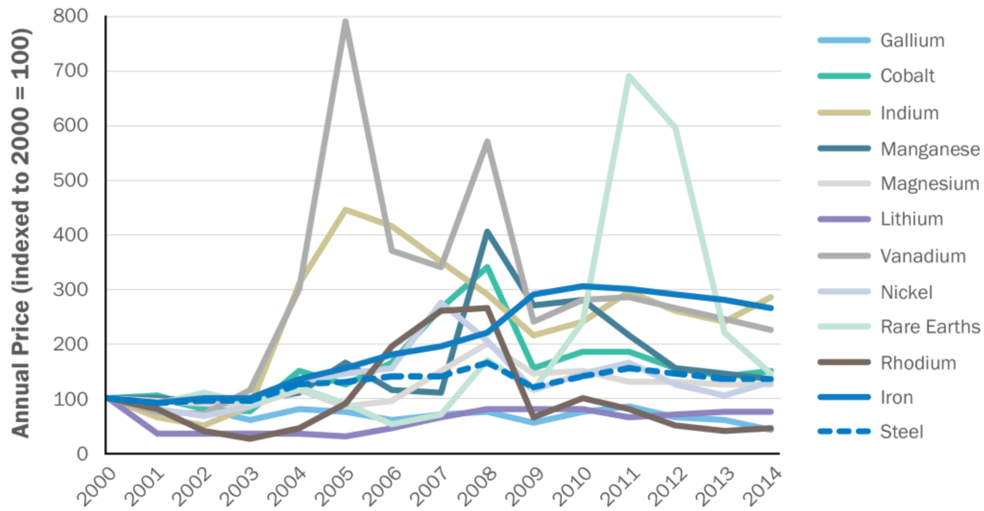
Strategic and critical materials markets are often very small and, because efforts to increase production are complex project finance undertakings, supply is relatively inelastic in the short-run. Recent data collected by the Critical Minerals Subcommittee of the National Science and Technology Council (NSTC), shows aggregate supply for several strategic and critical materials slowly rising over the long-term. Over the same period, however, this NSTC subcommittee found significant short-run price volatility for many of the same strategic and critical materials (see Figure 19 and Figure 20).

Figure 19: Annual Global Production (Select Materials, 2000-2014)[32]



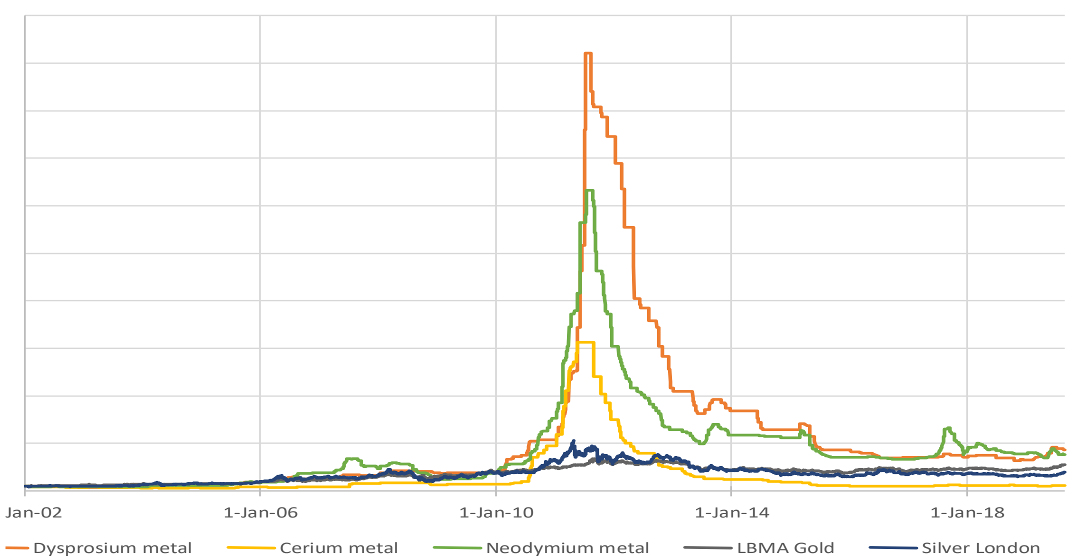
[32] Derived from National Science and Technology Council, *Assessment of Critical Minerals: Updated Application of Screening Methodology* (Washington, DC: NSTC, February 2018), https://trumpwhitehouse.archives.gov/wp-content/uploads/2018/02/Assessment-of-Critical-Minerals-Update-2018.pdf

Figure 20: Indexed Annual Price (Select Materials, 2000-2014)[33]



Perhaps the best-known case of significant price volatility in the strategic and critical materials market was the massive shift in prices for rare earth elements over the course of 2010 and 2011 (see Figure 21). In short, the combined effects of changes in the administration of China's rare earth export policies, a territorial dispute between Japan and China in the East China Sea, and capricious enforcement of Chinese customs led to exponential increases in rare earth prices. Anecdotally, price quotes for select rare earth materials were available to U.S. buyers for only a few hours, before the pledged materials (at that price) would be taken by other consumers. The price spike set-off a wave of R&D, substitution, and some supply-side investments, but by the time the rare earth prices returned to "normal" after 2014, the market pressure to diversify supply chains had waned.

Figure 21: Prices for Select Rare Earth Elements, Benchmarked (2002-2019)



Unfair Foreign Trade Practices

Another risk to critical material supply chains involves unfair foreign trade practices that distort global prices and affect the competitiveness of U.S. producers. These include but are not limited to export restrictions

[33] *Ibid.*

that incentivize domestic production and processing; theft of intellectual property, particularly related to processing technology; and export subsidies. The United States enforces a range of U.S. trade laws to address such trade practices both in the United States and at the World Trade Organization (WTO), often in coordination with other trading partners that are similarly affected.

The United States has brought 23 cases against China since its accession to the WTO. Of those, eleven cases were decided in favor of the United States, nine settled via consultation, and the balance are outstanding. Some of these cases have rolled back discriminatory governmental trade practices that provided preferences for China's domestic industry at the expense of foreign buyers, but problematic trade practices persist, including dumping.

"Dumping" generally refers to the practice of exporting a product at a price that is less than the comparable price of a like product in the domestic market. Though costly and data-intensive, several U.S. industry segments have obtained favorable findings under anti-dumping investigations for strategic and critical materials, including duties greater than 140 percent on Chinese magnesium metal exports. China produces about 78 percent of global magnesium, and the United States has a sole-source domestic producer of primary magnesium metal. Magnesium alloys help to reduce the weight of cars, and magnesium-rare earth alloys are essential for certain rotary- and fixed-wing aircraft castings. The former is especially important for traditional, internal combustion engine vehicles to meet increasingly stringent fuel economy standards.

As of April 2021, the United States has more anti-dumping and countervailing duty orders against China than any other nation—215 of 576 orders.[34] Of note, almost 60 percent of these antidumping and countervailing duty orders cover chemicals, steel products, and other metals and minerals.

Other foreign practices also can unfairly depress the prices of strategic and critical materials, thus harming the competitiveness of U.S. producers and their commercial viability. Unfair competitive advantages include lax enforcement of environmental or worker health and safety regulations, as well as government intervention (e.g., sales or purchases) to support national champions. Though China is often cited as a quintessential culprit of unfair trade practices, other countries that produce strategic and critical materials also have pursued such unfair advantages.

Risk Factors at the Level of Armed Conflict

National Defense Emergency Scenario Modeling

As the National Defense Stockpile Manager, DoD undertakes regular economic and scenario-based modeling of strategic and critical material supply chains. The Defense Logistics Agency Strategic Materials (DLA SM) leads this work, offering detailed insights into strategic and critical material markets, and relevant dependencies, under national emergency conditions. The *Strategic and Critical Materials 2021 Report on Stockpile Requirements*[35] is the most recent and final edition, due to the repeal of this reporting requirement pursuant to Section 1061 of Public Law (P.L.) 114-328.

Per the Stockpiling Act, each edition includes alternative, more stressful scenarios in addition to a "base case" military conflict scenario. Given the impact of the COVID-19 pandemic across the global economy, DLA SM included an "alternative case" pandemic study in the 2021 report.

Of the 283 materials monitored or formally assessed for this report, DLA SM identified unclassified base case shortfalls for 53 materials. During a national emergency, the United States is likely to face inadequate supply of these materials due to an inability to access foreign sources, among various other factors. Foreign supply sources include 84 different countries that produce at least one shortfall material:

- 27 countries each produce exactly 1 shortfall material;

[34] U.S. International Trade Commission, *Antidumping and Countervailing Duty Orders in Place as of April 14, 2021* (April 2021), https://usitc.gov/trade_remedy/documents/orders.xls

[35] This report, including key assumptions related to shipping losses, war damage, and other factors covered by 50 U.S.C. 98h-5, are included in Appendix A.

- 20 countries each produce 2 shortfall materials;
- 16 countries each produce between 3 and 5 shortfall materials;
- 11 countries each produce between 6 and 10 shortfall materials;
- 7 countries each produce between 11 and 20 shortfall materials; and
- 3 countries each produce more than 20 shortfall materials.

Figure 22 contains a list of the 53 unclassified base case shortfall materials, with selected important U.S. application areas or critical infrastructure sectors. Of note, the absence of a shortfall is not necessarily indicative of the absence of supply chain risk. Instead, the zero shortfall result may indicate that (1) DoD was unable to generate sufficiently reliable data to produce modeling results; or (2) the U.S. industrial base may have so atrophied that no U.S. manufacturer is purchasing said strategic and critical materials.

Figure 22: Shortfall Materials and Application Areas

Shortfall Material	**Major Application Areas**
Aluminum, high purity	Commercial Aircraft Combat Vehicles and Tactical Wheeled Vehicles
Aluminum lithium alloys	Commercial Aircraft
Antimony	Pressure Blasting Applications Plastics Storage Batteries Synthetic Rubber
Arsenic, molecular beam grade	Semiconductors and Other Electronic Components
Beryllium ore, beryl ore	Beryllium Hydroxide, Alloys, Oxides, Metals
Beryllium metal	Search, Detection, and Navigation Equipment
Bismuth	Medicinal Chemicals and Botanical Products Pharmaceutical Preparations Primary Aluminum
Boron-10 (boron isotope)[36]	Nuclear Power
Carbon-Carbon (different types)	Defense applications
Cerium	Motor Vehicle Parts Petroleum Refineries Glass and Glass Products, Except Containers Miscellaneous Manufacturing Broadcast and Wireless Communications Equipment
	Explosives and Propellants

[36] The Department of Defense has run only a limited number of isotope supply chains through its modeling process for the National Defense Stockpile program. The Department of Energy maintains robust monitoring of and participation in the isotope market, and at-risk materials are covered in Appendix D and Appendix E

Shortfall Material	Major Application Areas
Energetic Materials[37]	Ammunition Primers and Tracers Demolition and Fuses
Erbium	Optical Instruments and Lenses
Europium	Miscellaneous Manufacturing
Fluorspar, acid grade	Fluorocarbon Air Conditioning
Gadolinium	Pharmaceuticals and Medicines Transportation Equipment Miscellaneous Manufacturing
Graphite, iso-molded civilian grade	Semiconductor machinery Industrial molds
Graphite, iso-molded defense grade	Industrial molds Industrial furnace and oven manufacturing Other defense applications
Lanthanum	Petroleum Refineries Motor Vehicle Parts
Lithium metal	Alloys Batteries Pharmaceuticals
Magnesium metal	Transportation
Manganese metal, electrolytic	Metal Containers, Packaging, Shipping Materials Construction and Building Products Motor Vehicle Parts Electrical and Communications Equipment
Manganese, ferromanganese	Construction and Building Products Motor Vehicle Parts Oil and Gas
Neodymium	Computer Storage Devices Miscellaneous Manufacturing Non-Metallic Mineral Products Transportation Equipment Electronic Components Motors and Generators

[37] Multiple types, see Appendix A and Appendix H

Shortfall Material	Major Application Areas
Niobium	Oil and Gas Motor Vehicle Parts Aerospace Products and Parts
Praseodymium	Synthetic Dyes and Pigments Miscellaneous Manufacturing Non-Metallic Mineral Products Computer Storage Devices Motor Vehicle Parts
Rare earth permanent magnets, Neodymium Iron Boron (NdFeB) types	Industrial Motors Motor Vehicle Parts Magnetic Resonance Imaging (MRI)
Rare earth permanent magnets, Samarium Cobalt (SmCo) types	Electric Motors Medical Devices Consumer Electronics
Rubber, natural	Tire Manufacturing (except retreading)
Samarium	Electromedical and Electrotherapeutic Apparatus
Scandium	Fuel Cells
Steel, 1080 grade ultra-high strength cable tire cord	Tire Belts and Bead Wire
Steel, grain oriented electrical steel silicon-based	Transformer Laminations
Tantalum	Electronic Capacitors Explosively-formed projectiles, warheads
Tin, low alpha	Solders for Electronic Components
Titanium sponge	Aerospace, Commercial
Tungsten	Metalworking Machinery Electric Lighting Equipment
Yttrium	Miscellaneous Manufacturing Electric Lamp Bulbs and Parts Aircraft Engines and Engine Parts
Yttrium (multiple other types)	Semiconductors and Other Electronic Components

Non-Availability of Domestic Stockpiles

U.S. industry maintains some buffer stocks and other work-in-progress inventories that may offset the impact of a limited supply chain interruption. However, the Federal Government generally has not collected data on these inventories outside of mandatory assessments by the Bureau of Industry and Security (BIS) at the Department of Commerce, pursuant to Title VII of the DPA.

DoD maintains a stockpile of strategic and critical materials through the NDS, authorized pursuant to the Strategic and Critical Materials Stockpiling Act of 1979 (50 U.S.C. 98 et seq.). Of note, the NDS is a strategic stockpile, not an economic stockpile. As such, the NDS has a deliberately conservative posture and is intended to offset supply chain risk to defense and essential civilian industry from a national emergency event. By contrast, China's State Reserve Bureau is an economic stockpile and is more interventionist in markets, actively combatting price volatility or supporting particular industry segments.

Currently, the NDS Program maintains inventories for 55 materials, with a total value of approximately $1 billion (Figure 23). DoD funds the operations of the NDS Program from a revolving fund known as the NDS Transaction Fund. As noted in the President's Budget Request for Fiscal Year (FY) 2021 and FY 2020, the NDS Transaction Fund will exhaust all of its resources by FY2024 or FY2025, dependent on (1) the pace at which the NDS Program acquires new materials to mitigate current shortfalls; and (2) the proceeds from the sale of existing stocks.

Figure 23: NDS Program Inventories as of September 30, 2020

Antimony	Lithium Ion – LCO
Beryl	Lithium Ion – LNCA
Beryllium Metal Hot Pressed Powder	Lithium Ion – MCMB
Beryllium Metal Rods	Electrolytic Manganese Metal
Beryllium Metal Vac Cast	Manganese Ferro High Carbon
Beryllium Structural Powder	Manganese Metallurgical Grade Ore
Cadmium Zinc Telluride Substrates	Mercury
Carbon Fibers - PAN	Nickel Alloys
Chromium - Ferro High Carbon	Platinum Group Metals-Iridium
Chromium - Ferro Low Carbon	Platinum Group Metals-Palladium
Chromium Metal	Platinum Group Metals-Platinum
Cobalt	Platinum Group Metal Alloy / Wire
Cobalt Alloys	Platinum Group Metal Compounds - Iridium Alloy
Columbium Metal Ingots	Quartz Crystals
Ferroniobium Low-Alloy-Steel Grade	Silicon Carbide Fibers
Ferroniobium Vacuum Grade	Tantalum Columbium Concentrate
Ferroniobium Stainless-Steel Grade	Tantalum Metal
Dysprosium	Tantalum Alloy
Ferrodysprosium	Tin
Europium Oxide (4N)	Titanium Alloys
Europium Oxide (5N)	Energetic Materials (Multiple Types)
Europium (SEG)	Tungsten Ores & Concentrates

Germanium Metal – Intrinsic	Tungsten Metal Powder
Germanium Wafer	Tungsten Alloys
Germanium Scrap (Coated) (Uncoated)	Tungsten-Rhenium
Iron Alloys	Zinc

The funding deficit for the NDS Transaction Fund is driven by a combination of growing shortfall requirements and legislatively-mandated disbursements from the NDS Transaction Fund to other programs (see Figure 24). From FY2003 to FY2018, Congress diverted 89.8 percent of the proceeds from NDS Program activities, measured in real dollars, to other defense and non-defense programs, such as the Operations & Maintenance accounts of the Military Services, construction of the World War II Memorial, and the Federal Supplementary Medical Trust Fund.

Figure 24: National Defense Stockpile Transaction Fund Distributions

Distribution Type	Total Amount (FY03→FY18) (Real $2018)	Average Annual Cash Flow (Real $2018)	Sample Activities / Accts.
To National Defense Stockpile Transaction Fund	$ 417.3M	$ 26.0M	• Material acquisitions • Qualification of new sources • Metallurgical R&D
To Non-Defense Accts.	($ 998.6M)	($ 62.4M)	• General Treasury Acct. • American Battle Monuments Commission (World War II Memorial) • Hospital Insurance Trust Fund • Federal Supplementary Medical Trust Fund
To Other Defense Accts.	($ 2,701.5M)	($ 168.8M)	• Foreign Military Sales Treasury Acct. • Electromagnetic spectrum program • Defense Health Program • MILSVC Operations & Maintenance accts.
Net Cash Flow to National Defense Stockpile Transaction Fund	($ 3,282.8M)	($ 205.1M)	

In addition to this inadequacy of funding, the NDS once held many of the materials currently identified in shortfall. For example, the Department of Commerce recently concluded an investigation into titanium sponge under Section 232 of The Trade Expansion Act of 1962, and the interagency Titanium Sponge Working Group is evaluating options to mitigate vulnerabilities in the titanium sponge supply chain, including new stockpile purchases. Unfortunately, the NDS liquidated its stocks of titanium sponge during the post-Cold War sell-off, and now, to the extent possible within existing funding, the NDS Program is increasing its stocks of titanium by recycling it from end-of-life weapon systems. Similarly, the NDS formerly contained approximately 14,000 metric tons of rare earth materials, equivalent to about 7 percent of today's global market. DoD has submitted legislative requests to acquire rare earth materials for the NDS, but Congress has not authorized these purchases.

OPPORTUNITIES & CHALLENGES

Challenges to Future Domestic Production

Transparency

Individual strategic and critical materials markets are often small, with incomplete information on trade flows, production, prices, or inventories. This lack of transparency can involve even the most basic level of information, such as a material's country of origin. For example, sintered NdFeB magnets are the highest value segment of the rare earth market, with a value of about $10 billion and an estimated production of 160,000 metric tons.38 The word "estimated" is emphasized because producers and consumers do not report production or consumption data; and although third-party pricing data exists, there is little or no certainty that market participants close their business deals at the published prices. Further, rampant smuggling and illegal mining and processing leaves many market participants unable to trace the origins and chain-of-custody for rare earth materials.

By contrast, the global crude steel market is far larger: approximately 1.8 billion metric tons in 2020.[39] The World Steel Association collects and publishes statistics on the global steel market, and the provision of data is usually a requirement for membership. Similarly, aluminum prices are benchmarked to a global, publicly-available exchange, with local market premiums. Data on production, trade, and price for steel and aluminum is, therefore, highly transparent.

Asymmetric Information

Due to the small dollar value and the overall product volumes for many strategic and critical material markets relative to other bulk commodities, the number of market participants tends to be very small. This leads to asymmetric information between market participants and outside observers, in which one part of the market obtains an advantage from better or more information than does another part of the market. This asymmetry of information is typified by the volume of press releases and opinion-editorial articles on strategic and critical materials immediately following reported supply chain disruptions. These reports, though well-intended, generally include information on only one aspect of a supply chain, or they are unaware of important developments by government or industry stakeholders.

Asymmetric information is not a lack of information. Rather, the disconnect between actual market activities and the appearance of market activity delays the deployment of private capital to profitable or promising strategic and critical materials projects, resulting in inefficient use of capital. The consequences of asymmetric information can include criminal enterprises convincing investors to buy physical rare earth metal inventories.40 Rare earth metals are highly illiquid and essentially worthless to private individuals. The perpetrators failed to disclose this risk and leveraged media attention for personal gain.

Elastic Demand and Inelastic Supply

The operating tempo in strategic and critical materials markets also varies dramatically based on a participant's position in the supply chain. For downstream manufacturers and individual buyers, response times for price fluctuations can be measured from months to a few years. For upstream producers, however, the time to respond can range from years to decades. This gap between elastic demand and inelastic supply in the short-run encourages a very conservative, risk-averse posture in the mining and mineral processing sector.

---

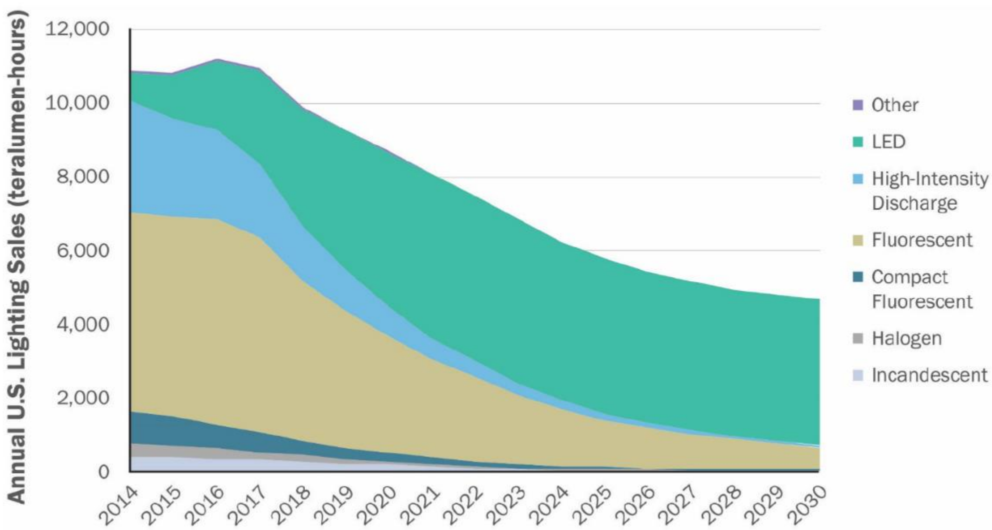
[38] Adamas Intelligence, *Rare Earth Magnet Market Outlook to 2030* (August 2020), https://adamasintel.com/report/rare-earth-magnet-market-outlook-to-2030/

[39] World Steel Association, "Global crude steel output decreases by 0.9 percent in 2020," worldssteel.org (January 26, 2021), https://worldsteel.org/media-centre/press-releases/2021/Global-crude-steel-output-decreases-by-0.9--in-2020.html

[40] Crown Prosecution Service, "Money Launders Jailed for Role in Rare Earth Metal Scam worth 1 Million Pounds," cps.gov.uk (September 30, 2019), https://cps.gov.uk/cps/news/money-launderers-jailed-role-rare-earth-metal-scam-worth-ps1million

Exemplifying this disconnect is the U.S. lighting industry's transition from tungsten filament lighting products to compact fluorescent, and then to LED products. For decades U.S. tungsten producers enjoyed steady growth — until the emergence of compact fluorescent bulbs. As new homes and offices shifted to this more energy-efficient offering, the U.S. tungsten industry went into decline, including the value-added manufacturing skills needed for wire drawing. Compact fluorescent lighting relies on heavy rare earth elements, such as yttrium and europium. As prices climbed due to tight supply and in anticipation of future growth, producers increased production. However, the same price increases also incentivized the lighting industry to transition from florescent technology to LEDs, which require lesser quantities of heavy rare earth elements. The arrival of new producer capacity, after downstream industry had transitioned to a new technology platform, has contributed to depressed prices for select heavy rare earth elements intended for use by the lighting market, such as yttrium and europium.

Figure 25: U.S. Lighting Sales by Type (2015-2030)[41]



Small Defense Requirements Relative to Commercial Markets[42]

Even though the U.S. Armed Forces have vital requirements for strategic and critical materials, the essential civilian sector would likely bear the preponderance of harm from a disruption event. This finding is consistent across every modeling excursion by DoD since 2009. The NdFeB magnet market provides an effective illustration of this finding.

A key assumption within DoD modeling of the strategic and critical materials under national emergency conditions is that the U.S. Government will make maximum use of allocation and prioritization authorities pursuant to Title I of the DPA. In brief, if there were a threatened disruption of NdFeB supply, the DoD model assumes that NdFeB materials would be diverted from civilian markets to the defense industrial base. This is similar to the recent diversion of health resources from private sector buyers to Federal Government contracts during COVID-19 pandemic response. Both the Department of Health and Human Services and the Federal Emergency Management Agency deploy these DPA, Title I authorities, respectively, to (1) prioritize direct Federal contracts over private sector and state/local/tribal government purchases of health resources; and (2) require authorization with respect to exports of health resources.

[41] U.S. Department of Energy, *Energy Savings Forecast of Solid-State Lighting in General Illumination Applications* (August 2014), https://energy.gov/sites/default/files/2015/05/f22/energysavingsforecast14.pdf

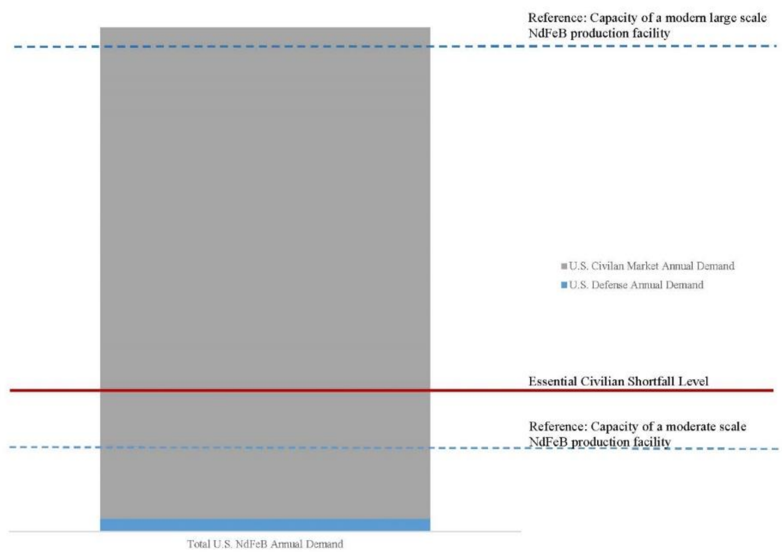
[42] For more detail on this section, see Appendix A.

As regards the NdFeB supply, DoD currently has all necessary authority to place priority ratings, using DPA, Title I, on strategic and critical materials through the Defense Priorities and Allocations System (DPAS) regulation administered by the Department of Commerce. Both the DPAS regulation and the delegation of authority to DoD specifically note that placing priority ratings for stockpiling purchases is permitted, so to the extent that DoD needs to place priority ratings under the DPAS for strategic and critical materials—either for NDS purchases or operational requirements—it has the ability to do so.

The disruption of global supply chains from the scenario and, to a far lesser extent, diversion of supply under DPAS actions is expected to produce very large essential civilian shortfalls — more than ten times DoD's annual peacetime consumption. Even if DoD limited all of its peacetime NdFeB procurement,

direct and embedded, to a single domestic producer, that arrangement would not be sufficient to hedge the risk to essential civilian industry (see Figure 26), nor would it be sufficient to support even a "moderately" sized NdFeB production facility.

Figure 26: Peacetime Civilian and Defense NdFeB Demand, versus Essential Civilian Shortfalls



Further, a key difference between the essential civilian market and the defense market is in the form of their respective imports. Both sectors rely on imports, but approximately two-thirds of DoD consumption of NdFeB magnets occurs as *direct demand* of permanent magnet articles. By contrast, 60 percent of essential civilian demand for NdFeB magnets are *embedded demand* in other intermediate or finished goods. DoD's import posture affords it marginally greater visibility into its foreign reliance compared to other essential civilian sectors, who may not even realize their exposure to an NdFeB magnet disruption since it is several tiers removed from the products they purchase from foreign sources.

Overall, the essential civilian NdFeB shortfall and outsized reliance on embedded demand indicates that a civilian-centric mitigation approach is necessary. DoD and Federal Government activities can act as a catalyst, but absent collaboration with the private sector, government-driven mandates circumscribed to defense procurement will not be sufficient to close the gap between peacetime consumption and postulated national emergency shortfalls.

Balancing the Need for Additional Supply and Environmental Impact

Setting aside modeling shortfalls and significant demand expectations for green energy and energy conservation products, the production of strategic and critical material can have significant physical impact (e.g., open pit mining) as well as intense consumption of strong acids and other hazardous chemicals. Recovery of critical materials from environmental legacy sites impacted by acid mine drainage or impoundments presents an opportunity to pair reclamation efforts with production, turning past industrial waste into the materials needed for green energy products. However, industrial actions often have environmental consequences. In a 2017 report to Congress on the extraction of rare earth elements from coal wastes, the Department of Energy cited six significant environmental challenges:

- Low concentrations lead to processing more material, driving up energy consumption;
- Increased production of fine particular dust, from grinding and crushing operations;
- Potential production of large volumes of liquid and solid wastes;
- The toxic and caustic nature of chemical reagents required for extraction;
- Processing operations may create concentrations of radionuclides; and
- If using current waste piles, extraction of rare earth elements could shift ownership of the long-term environmental liability associated with the waste pile and levy new waste management standards not otherwise applicable if the waste pile is left undisturbed.[43]

The Department of Energy is addressing the environmental concerns identified in this 2017 report, and their research efforts have demonstrated the technical feasibility for producing critical materials from unconventional sources, optimizing many of the challenges cited in this prior work. Continued research in this area is essential to minimize the environmental impact of using unconventional sources or particularly in regions that are economically distressed, affected by energy transitions, or harmed by adverse environmental impact from the strategic and critical materials industry. More specific waste characterization and business case analysis also will be required as this bench-scale test work advances into pilot studies.

In-process and post-consumer recycling of strategic and critical materials often supplement primary production, and recycling is a key component of the U.S. Government's approach to mitigating strategic and critical materials risk. For example, DoD has consistently sought to identify and then mature promising technologies for NdFeB magnet collection and uptake. From 2016 to the present, DoD has invested approximately $30.7 million in NdFeB magnet recycling, first through Small Business Innovation Research (SBIR) awards, followed by scale-up capital from Title III of the DPA.

Through this process, DoD and our non-defense agency partners, who assist with program management reviews, have identified several challenges to increased recycling of strategic and critical materials:

- Like coproduct or byproduct dependency, recycling of strategic and critical materials often depends on the recovery of another metal with high intrinsic value, such as gold;
- Take-back and collection schemes for end products containing strategic and critical materials are highly variable, ranging from non-existent to completely closed systems in which end items must be returned to the original manufacturer;
- End products often are not designed for recycling (e.g., use adhesives and other proprietary fastening devices, lack of labeling for processing and consumer awareness of recyclability, and use of hazardous materials or materials that become hazardous waste at EOL) increase the cost of recycling; and
- State and local regulations for take-back and collection of end-items (e.g., consumer electronics) containing strategic and critical materials are highly variable.

Opportunities to Resume Strategic and Critical Materials Production

In support of this assessment, DoD posted a *Federal Register* Notice of Inquiry, soliciting public comments from any interested stakeholders. DoD received over 100 comments, supplemented by business proprietary

[43] U.S. Department of Energy, *Report on Rare Earth Elements from Coal and Coal Byproducts* (January 2017), https://www.energy.gov/sites/prod/files/2018/01/f47/EXEC-2014-000442 percent20- percent20for percent20Conrad percent20Regis percent202.2.17.pdf

data submissions as well as bilateral and multilateral engagements with U.S. allies, partners, and other foreign governments.

DoD also participated in small group discussions with key participants representing upstream and downstream industry, large and small businesses, environmental justice advocates, academia, and consultants to U.S. and foreign industry leaders. DoD held some of these discussions under "Chatham House Rule" in an effort to solicit a frank exchange of views on the challenges in the strategic and critical materials sector and possible approaches to mitigating them.

In the course of DoD's stakeholder engagements, there is a clear—if not unanimous—consensus that environmental-social-governance (ESG) reporting and low-carbon strategic and critical materials production is a real and strengthening market force. However, there also is a consensus that the strategic and critical materials market does not yet place a premium on a "sustainably produced" strategic and critical material, with limited exceptions.

Sustainability, as a value proposition to support production and post-consumer recycling, has the potential to structurally change strategic and critical material markets which, heretofore, have largely focused on cost — be it the cost of production or imposing trade barriers to increase the cost of imports. Moreover, numerous industry groups and non-governmental organizations already have set a strong foundation for responsible sourcing of strategic and critical materials. Each of these standards differ, participation is voluntary, and implementation is uneven within specific strategic and critical material markets and across jurisdictions.

Taken together, this untapped market demand for sustainably-produced strategic and critical materials presents an opportunity for the U.S. Government to reward "good" behavior, while relying on natural market forces to push bad actors towards improvement or exiting the market. Ultimately, the approach implemented by the Federal Government will be bespoke to the particular challenges associated with each strategic and critical material and its market, with a sample included in Appendix C.

RECOMMENDATIONS

Reliable, secure, and resilient supplies of key strategic and critical materials are essential to the U.S. economy and national defense. The United States needs an "all of the above" comprehensive strategy to increase the resilience of strategic and critical material supply chains that both expands sustainable production and processing capacity and works with allies and partners to ensure secure global supply. We recommend a strategy centered on the following:

1. Developing and Fostering New Sustainability Standards for Strategic and Critical Material-Intensive Industries.

As detailed in this report, the global race to the bottom in search of lowest-cost production has led to the proliferation of critical mineral extraction, processing, and recycling operations in locations with weak environmental regulations, labor standards, and governance. As the world-leading developed economy, the United States can drive global market change towards the value of environmentally and socially responsible production.

The private sector and Federal agencies that purchase strategic and critical materials and end-items containing these materials generally do not evaluate the complete environmental, social, and related risks associated with unsustainable production practices. The U.S. Government, working in partnership with the private sector and other stakeholders, should encourage the development of new sustainability standards for designated strategic and critical materials to conduct due diligence, eliminate sources of unsustainable production, and accelerate Federal and commercial purchasing of sustainable products. A recognized sustainability standard, potentially backed by legislation, and coordinated with trading partners, would encourage private sector investment in sustainable sources and increase supply chain resilience.

- *Develop Sustainably-Produced Content Standards for Strategic and Critical Material-Intensive Industries*

  The U.S. Government should work with key stakeholders from the private sector, labor, and non-governmental organizations (NGOs) to develop easy to understand sustainability metrics for designated critical minerals and other critical materials. In the near term, this initiative should begin as a public-private partnership focused on a handful of materials essential to the U.S. economy. Over time, the Executive Branch should work with Congress to provide the authority to develop and promulgate regulations that would support the use of "sustainably produced" strategic and critical materials from domestic and foreign sources.

  Sustainability standards should be particularly applicable to those sectors that drive U.S. consumption, particularly automotive and aerospace products, fuel production, power generation and distribution, and electrical and electronic products. New products and materials should be added as necessary to conserve and promote the sustainability of strategic and critical materials.

  The definition of "sustainability" should be developed through a collaborative process between the Administration and other interested stakeholders. The scope of "sustainability" should ensure strong environmental standards throughout the mining lifecycle; corruption prevention; worker health and safety; the strength of local governance; consultation with potentially impacted tribal and indigenous communities; eliminating forced, indentured, or child labor; and transparency. Within the Federal Government, responsibility for the technical development of this standard should be co-led by the Department of Energy and the Environmental Protection Agency, with support from other relevant agencies (such as the Departments of Commerce, Interior, and Transportation) and external stakeholders as appropriate.

  As uniform product labelling is essential to informed consumer choice, an element largely absent in strategic and critical material markets today, the U.S. Government should encourage a clear and uniform labelling standard for sustainably produced critical minerals and materials. The U.S. Government should also work with allies and partners, including through international standards-setting bodies, to promote international adoption of sustainability standards for designated strategic and critical materials.

- *Establish U.S. Government Procurement as a Sustainability Leader*

  Though Department of Defense and other U.S. Government purchases will not be sufficient to serve as an "anchor" customer for most sustainably-produced end-items, adoption of a sustainability requirement for U.S. Government purchasing will act as an important signal to the market. Upon development of a "sustainably produced" standard, the U.S. Government should direct the Federal Acquisition Regulatory Council to publish a rule for public comment that would establish a preference or requirement for the selection of products with higher sustainably-produced content.

2. Expanding Sustainable Domestic Production and Processing Capacity, Including Recovery from Secondary and Unconventional Sources and Recycling

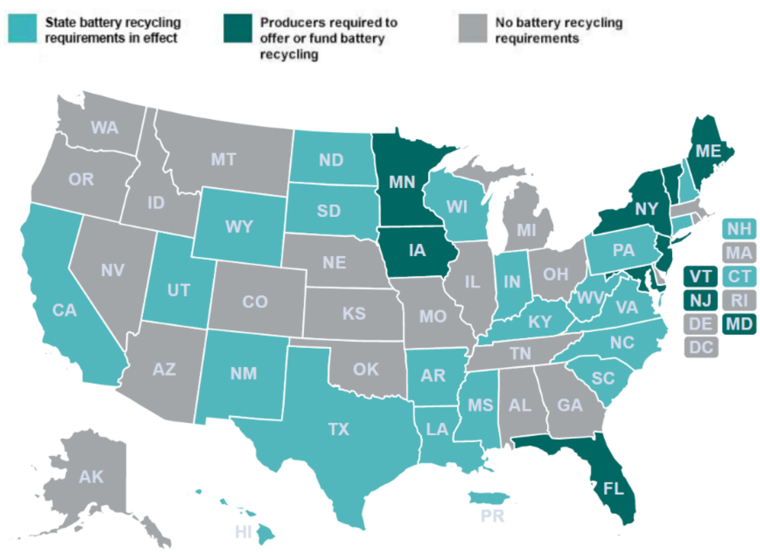
As identified in this report, the United States faces weaknesses in both the production and the processing of a range of strategic and critical materials. In addition to demand-side commitments, the U.S. Government should incentivize domestic and foreign production, processing, and recycling of strategic and critical materials, ensuring that they adhere to strong environmental standards, meaningful community consultation including government-to-government consultation with Tribal Nations, and strong labor standards. Expanding U.S. production and processing capacity will require investments in mining, including in non-traditional types of mining, in processing, and in recycling. To the greatest extent possible, new processing and recycling investments should prioritize locations with economic development and high-quality job creation opportunities for communities impacted by mining and the transition to a low-carbon economy.

- *Build a Foundation for Accelerated Growth in Strategic and Critical Material Recycling*

Recycling is one of the original green technology industries in the United States. There is tremendous opportunity for the private sector to grow strategic and critical material recycling as hybrid-electric and full electric vehicles, as well as other emerging technologies, reach end-of-life (EOL). This could include strategic and critical materials in lithium-ion batteries (nickel, cobalt, lithium, others) and electric motors (rare-earth elements).

The Federal Government, particularly the Environmental Protection Agency, should play a foundational role in decreasing market barriers to recycling in the United States by providing recommendations and guidance to State and local governments to create uniform collection procedures for EOL items containing strategic and critical materials, such as electric vehicle batteries. Developing a strong, uniform national standard for end of life recycling would be a no-cost approach to supporting the development of closed-loop recycling processes (see Figure 27 for the variance in State recycling laws related to batteries). The Administration should work with Congress to develop legislation to unify collection procedures for these EOL items.

Figure 27: U.S. Battery Laws by State[44]



There are multiple other areas in which the Federal Government should support recycling opportunities. For example, the Federal Government should encourage key industry sectors (e.g., consumer electronics) to adopt industry standards related to designing products to be more readily recyclable. A second area of support should include R&D support to develop technologies that isolate and increase concentrations of strategic and critical materials in EOL waste streams. Department of Defense and the Department of Energy should continue to provide R&D incentives for industry to develop, pilot, and deploy technologies that automate removal of rare earth magnets and other strategic and critical material-containing components from EOL items, such as hard disc drives, cell phones, and other small devices.

The Federal Government should work with industry through public-private partnerships to establish standards for the requalification of strategic and critical materials and related components for reuse. This would enable like-for-like reinsertion into the supply chain or "down-cycling" to other supply chains, if reclaimed materials do not maintain sufficient performance in the original end-item.

[44] Call2Recycle, "Recycling Laws By State" (2021), call2recycle.org, https://call2recycle.org/recycling-laws-by-state/

The Federal Government should also lead by example by establishing a government-wide recycling program to reclaim strategic and critical materials. For example, the U.S. Government operates more than 4,000 data centers, which represent a near-term opportunity to leverage Federally-funded R&D to recycle rare earth permanent magnets from hard disk drives.[45]

- *Collaborate with the States, Tribal Nations, and Non-Governmental Organizations on Reclamation of Mining Waste*

  The Federal Government has a long history of working with States, Tribal Nations, and NGOs on mine remediation, reclamation and restoration. However, these efforts center on individual projects; there is no unified national strategy to accelerate and coordinate these efforts, nor do these efforts evaluate potential resources within mine wastes at abandoned or other active mining sites.

  As part of a material-by-material strategy to secure a domestic supply, secondary and unconventional sources should be prioritized to provide new, near-term sources of supply and reduce the need for new conventional extraction. The U.S. Geological Survey's Energy, Minerals, Environmental Health, and National Land Imaging programs and partners have identified several recommendations to support the development of such a strategy, while helping resource management agencies weigh the benefits and risks of reprocessing, reclaiming, and restoring mine waste sites. These include:

  - Accelerating development of a national mine waste inventory by the U.S. Geological Survey, other Department of Interior offices, U.S. Department of Agriculture, Environmental Protection Agency, and State agencies, including site prioritization and coordination of data collection, and grants to universities and States;

  - Supporting demonstration projects to reprocess, reclaim, remediate and restore abandoned mine wastes; and

  - Creating and staffing a Federal Advisory Committee (FAC) to bring together Federal, State, Tribal, and private sector actors and, in tandem, create a Federal interagency body that works with the FAC to understand and focus efforts on the environmental and community impacts of mine wastes and effective remediation and reclamation strategies, including opportunities for reprocessing, economic development, and workforce opportunities for former mine workers and mining communities.

- *Identify and Spotlight U.S. Sustainable Resource Production Opportunities*

  The United States' non-fuel mineral resources are significantly under-mapped relative to those of other developed nations; only 12 percent of U.S. territory has modern high-resolution geophysical surveys of the subsurface, and only 35 percent is covered by detailed geologic mapping of the surface and near-surface.

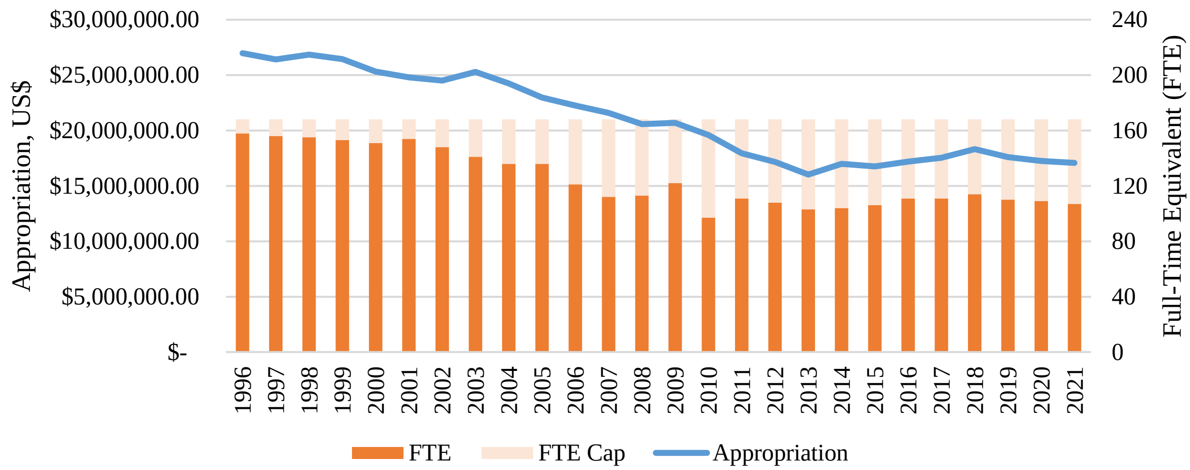
  By statute, the U.S. Geological Survey's National Minerals Information Center within the Mineral Resources Program collects information on mining and mineral processing, through to metal and alloy production. These data on the "above-ground" portion of the nation's mineral resource base provide a foundation for significant bodies of analysis on supply chain risks, but significant gaps in information still exist.

  Moreover, the Department of the Interior should seek expanded funding and full staffing for the U.S. Geological Survey's Mineral Resources Program, including the National Minerals Information Center (NMIC). NMIC funding has declined by 37 percent in real dollars over the past 25 years, notwithstanding its outsized contributions to economic modeling and geological assessments by the

[45] U.S. Government Accountability Office, *Data Center Optimization, Continued Agency Actions Needed to Meet Goals and Address Prior Recommendations* (May 2018), https://www.gao.gov/assets/gao-18-264.pdf

U.S. Government. Furthermore, though NMIC is authorized 168 full-time equivalents (plus contractors), available funding has never enabled NMIC to staff-up to full strength (see Figure 28).

Figure 28: Appropriations and Staffing for Department of the Interior's USGS National Minerals Information Center ($2021)



The Geological Survey and the major U.S. public lands agencies, the Department of the Interior and the Department of Agriculture, also should establish a new interagency task force to develop a material-by-material plan to identify specific locations of key strategic and critical materials in the United States that could be sustainably produced domestically. This task force should include the Environmental Protection Agency and consult with other key stakeholders, to ensure that such resources can be extracted while meeting the highest environmental, Tribal Nation consultation, and labor standards.

3. Deploy the DPA and Other Programs

Title III of the DPA gives the President the authority to issue grants, loans, loan guarantees, and other economic incentives to establish industrial capacity, subsidize markets, and acquire materials. Though DoD executes investments under the authority of Title III of DPA consistent with its duties as the DPA Fund Manager,[46] any Federal Agency responsible for a critical infrastructure[47] sector may request the use of DPA to mitigate current or estimated shortfalls to national defense.[48]

As highlighted multiple times throughout this report, the essential civilian sectors of the U.S. economy bear the brunt of risk and vulnerability related to potential supply disruptions of strategic and critical materials. The use of DPA and other authorities also has the potential to spark private sector investment and send a strong signal to market participants.

The Departments of Energy, Commerce, Interior, and Defense should use DPA and other existing authorities and funding to incentivize production across the supply chain, including downstream, high value-added manufacturing such as new magnet capabilities and advanced electric motor designs.

---

[46] White House, E.O. 13603 *National Defense Resources Preparedness* (March 16, 2012), https://obamawhitehouse.archives.gov/the-press-office/2012/03/16/executive-order-national-defense-resources-preparedness

[47] As established by White House, *Presidential Policy Directive – Critical Infrastructure Security and Resilience* (February 12, 2013), https://obamawhitehouse.archives.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil

[48] "National defense" is defined in 50 U.S.C. 4552 to mean: programs for military and energy production or construction, military or critical infrastructure assistance to any foreign nation, homeland security, stockpiling, space, and any directly related activity. Such term includes emergency preparedness activities conducted pursuant to title VI of The Robert T. Stafford Disaster Relief and Emergency Assistance Act [42 U.S.C. 5195 et seq.] and critical infrastructure protection and restoration.

Agencies also should use DPA, Title III and similar programs to support proven R&D capacities and emerging technologies, particularly those developed by small businesses through the SBIR and Small Business Technology Transfer (STTR) programs The Department of Defense's work to develop, mature, and scale rare earth magnet recycling capabilities with a U.S. small business and engineering studies related to heavy rare earth oxide separation through the IBAS program demonstrate this commitment to bridge the "Valley of Death" from late-stage research to full-rate production.

DoD has recently used DPA, Title III authorities to make investments in domestic strategic and critical material processessing operations, specifically in rare earth elements. Similarly, the Deparment of Energy operates two loan programs, pursuant to the Energy Policy Act of 2005 (Public Law 109-58) and the Energy Independence and Security Act of 2007 (Public Law 110-140), which can support domestic production of critical minerals.[49]

DPA, Title III and similar authorities should be used to support domestic production in sustainable production and processing operations, like the greenhouse gas reduction, financial, and end-use requirements of the Department of Energy loan program. When the Federal Government is responsible for incentivizing domestic production, the Government should take additional measures (beyond complying with sustainability standards) to ensure that the mining occurs in an environmentally and socially protective manner over the entire mining lifecycle through reclamation and closure. Initial recommendations include:

- Conditioning economic incentives to applicants with strong past performance on environmental compliance at current or previous operations or applicants bringing environmental best-practices to legacy operations;

- Providing incentives only for applicants that can demonstrate up-front financial assurance for full site reclamation and closure.

- Providing incentives only for mines in U.S. states that have strong mining environmental regulations and enforcement and compliance programs.

- Ensuring regular environmental inspections in the course of awardee performance, to validate compliance with Federal permits and approvals.

- Requiring strong labor protections, including prevailing wage requirements, use of Project Labor Agreements and community hire on construction projects, union neutrality policies for employers, and a ban on mandatory arbitration agreements, as relevant to the proposed scope of work.

- Requiring goods and materials to be made in the United States and shipped on U.S.-flag, U.S.-crewed vessels.

4. Convene Industry Stakeholders to Expand Production

Title VII of the DPA provides authorities that the interagency can deploy today to support requirements generation and definition, such as the mandatory survey authority of the Department of Commerce in 50 U.S.C. 4555. Non-availability of data remains a significant constraint to effective mitigation programs in the strategic and critical materials sector, and so those agencies with information collection requirements, such as

[49] Loans Program Office (Department of Energy), "Notice of Guidance for Potential Applicants Involving Critical Minerals and Related Activity," *Federal Register* 85 No. 231 (December 1, 2020), 77202-77203, https://www.federalregister.gov/documents/2020/12/01/2020-26407/notice-of-guidance-for-potential-applicants-involving-critical-minerals-and-related-activity

mining production surveys by the Geological Survey or industrial base analyses by DoD, should engage the Department of Commerce to deploy this authority to mitigate data gaps.

Title VII of the DPA also authorizes the Federal Government to convene industry, with protection from civil and criminal anti-trust law, to coordinate business activities and form plans of action that satisfy a national need (50 U.S.C. 4558). The U.S. Government should use these authorities to convene a government-industry working group to identify opportunities to expand sustainable domestic production, and explore opportunities to create consortiums or public-private partnerships for sustainable domestic processing of key strategic and critical materials.

5. Promote Interagency Research & Development to Support Sustainable Production and a Technically-Skilled Workforce

Though significant research and development efforts have been underway to address critical and strategic material supply chain risks over the past decade, these have been largely limited to early-stage research and development past the stage of mining. The Energy Act of 2020, as incorporated into the Consolidated Appropriations Act, 2021 (Public Law 116-260) provides additional authorization for the Department of Energy to expand critical material R&D efforts to include demonstration and commercialization. Congress should fully fund and resource these programs.

A coordinated interagency approach to R&D should prioritize the laboratory-to-market transition for emerging technologies in the area of sustainable production. The Departments of Defense and Energy and other Federal agencies should signal their commitment and interest in U.S. innovation by establishing stronger links between early stage research, DPA, Title III grants, loans and incentives, as well as non-competitive awards through SBIR and STTR Phase III legislative authority for commercialization. DPA, Title III, when evaluating applicants, gives preference to small businesses.

Similarly, multiple agencies invest substantial resources in workforce training. This includes, but is not limited to, the Departments of Education, Labor, Defense, Veterans Affairs, and the National Science Foundation, with supporting investments with universities in R&D. Timely investments by such agencies in technical training and education will be essential to ensure that all other investment-driven recommendations can be implemented—from mine engineering to sustained research in ecologically sustainable modes of production.

The Departments of Education and Energy, in coordination with other agencies as appropriate, should conduct a joint study with a federally-funded R&D center to evaluate the development and programmatic operationalization of a fully-integrated education and R&D center, consistent with fiscal law, for sustainable strategic and critical materials development. This will enable more efficient transfer and execution and linkage of R&D, education, and workforce training funds from across the interagency to address whole-of-nation needs.

6. **Strengthen U.S. Stockpiles**

National stockpiles can play a key role in supply chain resilience by providing a buffer against short-term supply disruptions or bridging the gap between peacetime and full industrial mobilization. However, U.S. stockpile authorities and funding have not kept up with needs.

As noted in this report, Congress diverted approximately $3.3 billion (2018) and approximately $1 billion (2018) of NDS Program revenue to other defense and non-defense programs. Although Congress has ceased those transfers, the NDS Program will exhaust all of its current resources within the Future Years Defense Program (FYDP). To sustain operations, the NDS is compelled to sell currently stockpiled materials for which the Department of Defense and essential civilian industry have shortfall requirements. More generally, due to a lack of available funding, less than 10 percent of postulated wartime material shortfalls are estimated to be mitigated.

DoD's flagship authority for the evaluation of risk in strategic and critical materials supply chains flows from the Strategic and Critical Materials Stockpiling Act (50 U.S.C. 98 et seq.). Though Congress has made small adjustments to the statute since the end of the Cold War[50], the last overarching review and reform occurred in 1979, and in the intervening years, delegations of authority from the President to DoD have not kept pace with the reorganization of the Office of the Secretary of Defense.[51] Many of the recommendations from the last systemic review of DoD stockpiling activities—more than two decades ago—have not been implemented.[52]

First, the President should issue an E.O. delegating existing authority for the release of NDS materials for use, sale, or other disposition, pursuant to 50 U.S.C. 98f. Notwithstanding congressional authorization for this delegation through Public Law 112-239, no such delegation has been made.

Further, DoD should seek new legislation to recapitalize and modernize the NDS Program, including the following actions:

- Obtain new appropriations for the NDS, totaling not less than $1 billion over the next FYDP to sustain operations;

- Reinstate the reporting requirement for biennial modeling and simulation of strategic and critical material supply chains under national emergency conditions (50 U.S.C. 98h–5);

- Grant the NDS the authority to purchase strategic and critical materials currently identified in shortfall (e.g., rare earth elements);

- Grant the NDS the authority to "loan" material from Federal Government stocks to U.S. private industry, DoD Components, or other Federal agencies to mitigate peacetime disruption risk;

- Grant the NDS the authority to purchase strategic and critical materials, for actions less than $50M, without congressional authorization; and

- Obtain appropriate direct-hire authority or other relevant authorization for the recruitment, retention, and incentive pay for highly-qualified personnel to staff the NDS program and related national emergency preparedness and mobilization programs, such activities under the DPA.

7. Work with Allies and Partners and Strengthen Global Supply Chain Transparency

Though increasing U.S. production is a key part of a resilient strategic and critical materials supply chain, the United States also must work with allies and partners to strengthen collective resilience. The United States should pursue several steps to do this:

- *Engage Trading Partners and Emerging Markets to Ensure Reliable Supplies and Improve Governance*

  Through the Department of State and the Office of the U.S. Trade Representative, the United States should engage with like-minded foreign producers of strategic and critical materials to promote a value-based approach as they consider approaches to sustainability—rather than one focused on cost-imposition—and encourage alignment of U.S. and foreign product sustainability standards.

  The Department of State should use government-to-government fora and related collaborative networks, such as the Energy Resources Governance Initiative (ERGI)[53] or the Extractive Industries

---

[50] Such as the addition of "single point of failure" analysis via P.L. 104-201.
[51] Ronald Reagan, E.O. 12626, "National Defense Stockpile Manager," February 25, 1988, https://archives.gov/federal-register/codification/executive-order/12626.html
[52] U.S. Government Publishing Office,"Proposed Reconfiguration of the National Defense Stockpile," *Hearing before the Readiness Subcommittee of the Committee on Armed Services, (U.S. House of Representatives*, July 23, 2009, https://govinfo.gov/content/pkg/CHRG-111hhrg52723/pdf/CHRG-111hhrg52723.pdf
[53] Founding members of ERGI include the United States, Australia, Botswana and Peru.

Transparency Initiative (EITI), to build foreign capacity to implement and oversee sustainable practices in the strategic and critical materials sector. The Department of Energy-led trilateral agreement between the United States, Japan, and the EU, as well as bilateral engagements with Canada and Australia via the Department of State, are model examples for international cooperation on strategic and critical materials. These efforts should continue and, as appropriate, additional engagements should be undertaken.

ERGI, led by the Department of State, promotes sound mining sector governance and resilient energy mineral supply chains. This initiative brings countries together to advance governance principles, share best practices, and encourage a level playing field for investment. The Founding Partners of ERGI also have developed an online toolkit, free and open to the public, as a unique resource for governments interested in sound governance and regulation of their extractive industry sector.

The Initiative for Responsible Mining Assurance (IRMA) is an international coalition of businesses, nongovernmental organizations, labor unions, mining operators, and other stakeholders that has developed a Standard for Responsible Mining and established a system for independently certifying mines worldwide that adhere to that standard. IRMA may provide a method for U.S. companies and the federal government to ensure that minerals are being sourced from mines with robust environmental, social, and financial responsibility policies, and also could provide a model for responsible development of additional mines in the United States.

- *Incentivize Sustainable Production by Allies and Partners*

  Multiple agencies of the U.S. Government can support the sustainable production and processing of critical minerals and other materials in U.S. allies and partners. The Export-Import Bank of the United States (EXIM) should provide loans or loan guarantees to support the export of U.S. mining equipment and engineering services. The U.S. International Development Finance Corporation (DFC) is uniquely positioned to invest in bankable projects in the strategic and critical materials sector in emerging markets with its debt, equity and political risk insurance products, and should pursue such opportunities.

  This type of financing support, implemented in accordance with strong, internationally recognized environmental and social standards, should improve local development of strategic and critical materials extraction and value-added manufacture in accordance with sustainability goals and ease the path to compliance for developing nations. Materials experts across the U.S. Government should provide technical guidance to EXIM and DFC to assist them in assessing a potential project's sustainability and benefits to supply chain resilience.

- *Support Increased Transparency in Materials Supply Chains*

  Supply chain transparency for strategic and critical materials, including critical minerals, is of great importance for U.S. objectives. Responsible mineral supply chains should be transparent in their methods and origins, traceable, and pursue best practices with respect to labor and human rights, the environment, and other criteria. The United States has continued to work on a variety of initiatives that support these complex and reinforcing areas of commerce. We recommend deepening and expanding U.S. policy efforts in these areas by the actions outlined below:

  - The Department of State should recommit the United States to the EITI. Though the United States maintains strong financial support for EITI, a public recommitment to its objectives will have an important impact on producing states.

  - The SEC should review compliance with Dodd-Frank 1502 and the rule promulgated thereunder, issuing enforcement actions as appropriate. The Department of State develop a spend plan to fully-resource its supply chain transparency and governance initiatives. Section

1502 drove a global movement in minerals supply chain transparency by forcing an entire market to map supply chains for conflict minerals to try to break the link between armed groups and these materials in the Democratic Republic of the Congo and the African Great Lakes Region.

- The Department of State should seek new authority from Congress to expand Section 1502 beyond the African Great Lakes Region to other conflict-affected and high-risk areas. This expansion would mirror global compliance trends, such as those planned in the EU.

- The Department of Treasury, Department of Homeland Security, and the Department of State, with collaboration from other Federal agencies as appropriate, should build a coalition of stakeholders, financiers, and practitioners to develop innovative solutions to increase transparency throughout supply chains from mining to finished product delivery in materials with a high risk for human rights abuse and corruption.

- The Department of State, the Department of Justice, the Department of Homeland Security, and the Department of the Treasury should develop a spend plan to (1) fully-resource and staff their activities to trace strategic and critical material supply chains, investigate money laundering, corruption, links to organized crime, and human rights abuses; and (2) implement the appropriate mix of civil, criminal, and administrative enforcement actions.

- The President should direct the Attorney General and the Secretaries of State, Treasury, Homeland Security, Department of Labor to provide periodic updates to the National Security Council and the National Economic Council on strategic and critical material due diligence laws, industry best-practices, and recommendations—to include new legislation—to reduce the impact of forced labor, organized crime, and other human rights abuses in strategic and critical material supply chains.

ABBREVIATIONS

BIS - Bureau of Industry and Security, Department of Commerce
USBM - Bureau of Mines, a now-closed component of the Department of Interior
DFARS - Defense Federal Acquisition Regulation Supplement
DLA SM - Defense Logistics Agency Strategic Materials, Department of Defense
DPAS - Defense Priorities and Allocations System, under Defense Production Act
DPA - Defense Production Act
DRC - Democratic Republic of the Congo
DoD - Department of Defense
EOL - End-of-Life
ERGI - Energy Resources Governance Initiative
ESG - Environmental Social Governance
EU - European Union
ERECON – European Rare Earth Competency Network
E.O. - Executive Order
EXIM - Export-Import Bank of the United States
EITI - Extractive Industries Transparency Initiative
FAC - Federal Advisory Committee
FY - Fiscal Year
FDI - Foreign Direct Investment
FYDP - Future Years Defense Program
GDP - Gross Domestic Product
IBAS - Industrial Base Analysis & Sustainment
IRMA - Initiative for Responsible Mining Assurance
IEA - International Energy Agency
LEDs - Light Emitting Diodes
MRI - Magnetic Resonance Imaging
NDS - National Defense Stockpile
NEPA - National Environmental Policy Act
NMIC - National Minerals Information Center
NSTC - National Science and Technology Council
NTIB - National Technology and Industrial Base
NdFeB - Neodymium Iron Boron
NiMH - Nickel Metal Hydride
NGO - Non-Governmental Organization
OECD - Organization for Economic Cooperation and Development
R&D - Research and Development
SEC - Securities and Exchange Commission
SBIR - Small Business Innovation Research
STTR - Small Business Technology Transfer
SMART - Strategic Materials Assessment and Risk Topography
SOFC - Solid Oxide Fuel Cell
TREO - Total Rare Earth Oxide
TVPRA - Trafficking Victims Protection Reauthorization Act list
VAT - Value-Added Tax
WTO - World Trade Organization
YSZ - Yttrium-stabilized zirconia
3TG - Tin, Tantalum, and Tungsten