KRACH INSTITUTE FOR TECH DIPLOMACY AT PURDUE

# Securing Supply Chains of Critical Minerals and Materials for America's Tech Future

**J. Peter Pham**

*Executive Summary*

Among the lessons of the COVID-19 pandemic is that the United States must do more to secure the supply chains for critical goods and materials. President Joseph Biden clearly had this in mind when signing Executive Order 14017, which mandated an accelerated review process with an eye toward creating more secure supply chains, including those for critical minerals essential to high-tech applications including electric vehicles, wind turbines, solar panels, and even smart phones. Many of the consumer products and other crucial clean energy solutions for a low-carbon economy required to meet the Biden administration's ambitious climate action goals rely upon critical minerals for their manufacture or operation. Moreover, irrespective of one's view on the administration's climate agenda, America's future technological innovation increasingly will be dependent upon reliable access to secure supplies of certain key minerals and other strategic materials.

As policymakers continue to craft plans for securing America's supply chains, many have focused on *reshoring*, the process of bringing back home the sourcing of certain materials, rather than depending on foreign imports. While the responsible development of domestic resources where such exists is clearly part of the solution, the idea that it will make a sizable dent in the America's demand for critical minerals is fundamentally flawed given not only geology, but also today's interconnected market dynamics, to say nothing of global politics. It is important for policymakers to understand that most supply chains, like critical materials, simply will not fit into this model, even if it polls well.

It is one thing to call for *securing* the supply chains for critical minerals, but another thing to do it. Policymakers and public officials should bear in mind the following:

- **Critical Minerals Are Today Mostly Imported to the U.S. –** Of the 35 minerals or groups of minerals designated as essential for U.S. economic and national security, imports account for over half of the country's consumption of 31 of these and 100 percent of 14 of them. Today, China produces or processes more than 80 percent of the world's rare earth elements (REEs),[1] the Democratic Republic of the Congo (DRC) possesses half the world's cobalt reserves, and Guinea has the world's largest reserves of bauxite, the primary source of aluminum.

- **For Most Critical Minerals and Materials, Reshoring is Not an Option –** Political support for reshoring upstream suppliers may have reached a fever pitch but meeting all of the current—let alone future—U.S. demand for critical minerals by reshoring is not realistic. Even when U.S. companies can mine critical minerals here at home, they often cannot readily process them domestically due to onerous environmental regulations or local unfavorable political environments. For critical minerals, policymakers should focus less on reshoring and more on solutions that allow U.S. firms and other trusted partners to control more of the mining or manufacturing process. This solution would ultimately help reduce the dependence on China—or any other potential adversary—to meet U.S. needs for critical minerals.

- **Securing the Supply Chain for Critical Minerals is Essential to Meeting U.S. Climate Goals as well as Enabling Future Technological Innovation –** To achieve the goals set out by the Biden administration of a carbon pollution-free power sector by 2035 and a net-zero economy by 2050, the U.S. must increase deployment of solar and wind power and ramp up its fleet of electric vehicles. Making these advances requires critical minerals, since the manufacture of permanent magnets used in wind turbines as well as for electric vehicles, for example, requires rare earth elements such as neodymium, praseodymium, and others. Solar panels require dysprosium, indium, and other elements found only in a handful of countries. Efficient power storage for renewable energy has become a Holy Grail of sorts in recent years and vanadium-based batteries have shown great promise for long life cycles. Currently virtually all of the metal is produced in three countries. In order to achieve America's climate goals and enable future technological innovation, securing reliable supply chains for critical minerals from overseas sources is paramount.

- **Creating a Strategic Reserve Can Help Ensure Critical Materials Are Available When Needed –** Not only can a strategic reserve protect against costly hold ups for manufacturers, but it can also catalyze investments in critical minerals that further protect U.S. supply chains. Through instruments such as offtake agreements and incentives to private companies to supply needed critical minerals, the U.S. can ensure that no one country can cause a market failure for any given mineral or group of materials. In the case of rare earth elements, for

[1] U.S. Department of Interior, U.S. Geological Survey, Rare Earths Data Sheet, Mineral Commodity Summaries 2020, https://pubs.usgs.gov/periodicals/mcs2020/mcs2020-rare-earths.pdf

example, a strategic reserve could help mitigate the risks of the near-total monopoly on processing presently enjoyed by China.

- **Securing the Supply Chain for Critical Minerals Demands a Variety of Approaches –** Multiple approaches may be necessary to create a secure supply chain for critical minerals, including offtake agreements for alternative suppliers; ensuring multiple supply options; diversifying supply geographically so that armed conflict or natural disaster do not knock supplies completely offline; and finding ways to work with diverse multinational suppliers.

*Introduction*

One of the most salient policy lessons in the wake of the COVID-19 pandemic is that supply chains need to be made more secure. From the outset of the pandemic, the United States, like most other countries, found itself overly dependent on imports of personal protective equipment and other essential goods, raising concerns about the disproportionate impact of trade disruptions.

Since coming to office, President Joseph Biden has cast a wider net. In February 2021, he issued Executive Order 14017,[2] which mandated a series of 100-day reviews culminating in a White House report that laid out the goal of securing supply chains across a variety of critical industries, from semiconductors to pharmaceuticals.[3] Importantly, assuring the supply chains for some materials, including the critical minerals used in solar panels, wind turbines, and electric cars, also means moving one step forward towards the president's climate goals. Increasing the nation's electric vehicle fleet, for example, will depend heavily on access to critical minerals. To meet the demand for the buildout and deployment of clean energy technologies, the U.S. relies heavily on the sourcing and processing of critical minerals from foreign countries and companies. Thus, in a globally interconnected economy, what does it mean to secure a nation's supply chains?

To achieve a greener economy, the U.S. will need to rethink how risk is managed up and down far-flung, interconnected supply chains that include friends and foes, as well as market and non-market producers. Much of the political talk in Washington is about *reshoring*, the belief being that upstream suppliers should be brought home to lessen the risk of disruption. While the responsible and sustainable development of domestic mineral resources should be part of the effort to secure supply chains for critical materials, there are limits to how much of a dent that increased mining activity within the United States would make in American demand. Some supply chains, like critical minerals, are especially challenging in this regard since it is often difficult—if not impossible—to relocate the sources of the material in question. For example, the location of a mine is dependent firstly on geology. According to the U.S. Geological Survey, the United States possesses barely 0.7 percent of the global total of extractable reserves of cobalt—an amount so paltry that if the entirety was mined immediately, the resulting stockpile would not even last five years at the current rate of consumption.[4] Even where the resource in question is potentially available domestically, it is often either politically or economically unfeasible to exploit it, as witnessed by Congressional action in late 2021 to block the development of a copper mine in Arizona. The action came despite the record high prices for the metal and the demand for it in green energy projects.[5]

---

[2] President Joseph R. Biden, Executive Order 14017: On America's Supply Chains, February 24, 2021, https://www.whitehouse.gov/briefing-room/presidential-actions/2021/02/24/executive-order-on-americas-supply-chains/.

[3] The White House, *Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Economic Growth*, June 2021, https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf.

[4] U.S. Department of Interior, U.S. Geological Survey, Cobalt Data Sheet, Mineral Commodity Summaries 2022, https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-cobalt.pdf.

[5] Ernest Schneyder, "U.S. House Committee Moves to Block Rio Tinto's Resolution Mine," Reuters, September 10, 2021, https://www.reuters.com/world/us/us-house-committee-moves-block-rio-tintos-resolution-mine-2021-09-10/.

Even where the critical mineral might be obtained domestically, the processing itself can become a challenge. This is the case of the REEs[6] mined at the Mountain Pass Mine in southeastern California, which are used in the development of permanent magnets for electric vehicles, among other applications, in part due to concerns over the potential environmental impact of processing. For example, large quantities of sulfuric acid are used to leech REEs in the conventional process of extraction and the ore is shipped to China for refining.[7] Nor can the United States just rely on trade with allies to meet the country's seemingly insatiable demand for critical minerals, whether they are REEs or more abundant metals, like aluminum. Does this mean that these supply chains cannot be secured? Does this mean the U.S. will lack access to the minerals necessary to meet the president's climate goals? And if those supply chains can be secured, how is this to be done?

This paper takes up these questions, starting from the premise that attributes of individual firms need to be given more attention in efforts to secure supply chains. President Biden's executive order on America's supply chains, just like the earlier initiatives upon which it was built, distinguishes producers based on two dimensions: (1) allies versus adversaries; and (2) market versus "non-market" economies. The intuition is that upstream producers in allied, market-based economies are more reliable because their political and economic preferences should typically be in sync with ours. This is a useful first cut, but it is too broad-brush, putting all the action at the *country* level, while ignoring the individual firm. Firm attributes matter too, however, particularly in supply chains, which connect upstream and downstream producers in tight business ecosystems.

If viewed strictly through the lens of a standard country-risk analysis such as the World Bank's recently discontinued Ease of Doing Business rankings,[8] critical minerals are a risky business, to say the least. Many countries from which these materials are sourced, for example, fare

[6] REEs consist of the rare earth metals (REMs) group of the elements with atomic numbers 57 through 71 on the periodic table, also known as the lanthanide series (lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium), as well as the elements scandium (atomic number 21) and yttrium (atomic number 39). Together the REEs play a vital role in modern industry, especially in green technologies, high-tech consumer electronics, medical equipment, and armaments systems. See David S. Abraham, *The Elements of Power: Gadgets, Guns, and the Struggle for a Sustainable Future in the Rare Metal Age* (New Haven, CT: Yale University Press, 2015), 1-17.

[7] Joseph Gambogi, "Rare Earths," in *Mineral Commodity Summaries* (Reston, VA: U.S. Geological Survey, 2021), 132-133, https://pubs.usgs.gov/periodicals/mcs2021/mcs2021-rare-earths.pdf. Recently, the Biden administration announced that the U.S. Department of Defense's Industrial Base Analysis and Sustainment Program awarded MP Materials $35 million in funding to help the company (re)establish the capacity to separate and process heavy rare earth elements at its Mountain Pass, California, facility; see The White House, Fact Sheet: Securing a Made in America Supply Chain for Critical Minerals, February 22, 2022, https://www.whitehouse.gov/briefing-room/statements-releases/2022/02/22/fact-sheet-securing-a-made-in-america-supply-chain-for-critical-minerals/.

[8] World Bank, Ease of Doing Business Rankings, https://www.doingbusiness.org/en/rankings. While the index was not without its flaws and countries often bitterly contested rankings, it provided broadly indicative qualitative assessments. Alas, in September 2021, the World Bank itself discontinued the report following independent audit findings that its leadership pressured experts to manipulate the results in 2018 and 2020 to favor China and several other countries at a time when the Bank was seeking their support for an increase in funding.

poorly on most—if not every—metric. Thus, one needs to *supplement* standard country-risk accounts by looking more closely at the firms that make up these business ecosystems.

These business ecosystems tightly bind together upstream and downstream firms more than typical business-to-business transactions. Take semiconductors, for example. Upstream materials and equipment suppliers work so closely with chip firms on research and development that most of the benefits have historically been captured downstream.[9] An input, like a printed circuit board, can cycle through the semiconductor supply chain, traveling upwards of 25,000 miles before final assembly.[10] On the one hand, this raises concern for disruption, or *hold up*. On the other hand, it means much closer upstream-downstream collaboration, and therefore a larger role for the market to discipline the supply chain. To secure a supply chain, the goal should be to make the whole more than the sum of its parts.

The problem of hold up is an age-old one, whether between countries or in thinking about the need to integrate a firm, horizontally or vertically. As discussed below, hold up can be either intentional or unintentional. The U.S. administration is clearly thinking about intentional hold up when it refers to securing supply chains. The concern is that during conflict or increased tensions, upstream suppliers might withhold vital inputs and bring downstream end users to a halt. The key is thus to make the entire supply chain more responsive to market rather than political incentives by thickening their ties. State-owned enterprises pose unique challenges in this regard, but transparency and best practices in governance and management, for example, can help regardless of the supplier's ownership structure. The point is to strive for increased market-based interdependence, not less.

International partnerships can also help secure supply chains. From rules under commercial agreements to global standards and the conditions included in World Bank loans, supply chains in minerals and materials can be made more responsive to the market, reducing the risk of hold up. In 2019, under Secretary of State Mike Pompeo, the U.S. State Department's Bureau of Energy Resources[11] joined with three other like-minded countries—Australia, Botswana, and Canada—to create the Energy Resources Governance Initiative (ERGI). The ERGI engages resource-rich countries on responsible mining sector governance and fosters resilient energy mineral supply chains to meet the expected clean energy demands.[12]

---

[9] U.S. Congress, Office of Technology Assessment, *Competing Economies: America, Europe, and the Pacific Rim* (Washington, DC: U.S. Government Printing Office, October 1991), https://ota.fas.org/reports/9112.pdf.

[10] Syed Alam, Timothy Chu, Shikrant Lohokare, and Shungo Saito with McKinley Baker, *Global Complexity of the Semiconductor Ecosystem* (New York: Global Semiconductor Alliance & Accenture, 2020), https://www.accenture.com/_acnmedia/PDF-119/Accenture-Globality-Semiconductor-Industry.pdf.

[11] The Bureau of Energy Resources was headed at the time by Assistant Secretary of State Frank R. Fannon, now a Senior Visiting Fellow at the Center for Tech Diplomacy at Purdue.

[12] Despite the emphasis that President Biden has placed on both diplomacy in general and securing supply chains for critical minerals in particular, more than year into the administration he has yet to announce a candidate for Assistant Secretary of State for Energy Resources, much less get the nominee confirmed by the U.S. Senate. The Bureau of Energy Resources is currently

The stakes are great. Building a green economy and meeting the administration's ambitious goals for electric vehicles and for achieving net-zero greenhouse gas emissions by 2050 depends on critical minerals and other materials—as does America's future technological innovation in an ever-increasingly mineral-intensive world. Nearly all of these are imported from China and other countries with which the United States often has tense political relations. It is one thing to call for *securing* these supply chains, and quite another to spell out how to do it. This paper takes up this task.

***The Challenge***

On his very first day in office, President Biden signed the instrument bringing the United States back into the Paris Agreement on climate change. The administration subsequently unveiled an ambitious agenda for a clean energy revolution that aspires to have America achieve a carbon pollution-free power sector by 2035 and a net-zero economy by 2050.[13] This matches the aims of the European Union (EU) to have a climate-neutral economy by the same date, according to the European Commission's first-ever proposed European Climate Law to legally codify the net-zero gas emission goal. To get there, the United States will need access to an unprecedented amount of critical minerals like cobalt, lithium, and aluminum, the vast majority of which it imports. Therein lies the challenge: to build a green economy, the United States will have no choice but to depend on supply chains that, at the country level, are fraught with risk.[14]

The scope of the challenge is breathtaking. Executive Order 13817, signed by President Donald Trump early in his presidency, tasked the Secretary of the Interior with identifying, in coordination with the Secretary of Defense, "critical minerals," which were defined as "(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."[15] Eventually 35 minerals or groups of minerals were

headed by a career Foreign Service Officer serving as "Senior Bureau Official" in the absence of a Senate-confirmed Assistant Secretary. In August 2021, Secretary of State Anthony J. Blinken also appointed Amos J. Hochstein, whom President Barack Obama nominated to be Assistant Secretary in 2015—though the Senate did not act on the nomination—to be the State Department's Senior Advisor for Energy Security.

[13] The White House, Fact Sheet: President Biden Takes Executive Actions to Tackle the Climate Crisis at Home and Abroad, Create Jobs, and Restore Scientific Integrity Across Federal Government, January 27, 2021, **https://www.whitehouse.gov/briefing-room/statements-releases/2021/01/27/fact-sheet-president-biden-takes-executive-actions-to-tackle-the-climate-crisis-at-home-and-abroad-create-jobs-and-restore-scientific-integrity-across-federal-government/**.

[14] Andy Home, "U.S. Infrastructure Bill Targets Critical Minerals Supply," Reuters, August 12, 2021, https://www.reuters.com/article/us-critical-minerals-ahome-idUSKBN2FD1GU.

[15] President Donald J. Trump, Executive Order 13817: A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals, December 20, 2017, https://www.govinfo.gov/content/pkg/DCPD-201700922/pdf/DCPD-201700922.pdf.

designated as essential for U.S. economic and national security.[16] Imports account for over half of the country's consumption of 31 of these, and 100 percent of 14 of them. Executive Order 13953, issued toward the end of the Trump administration, noted that U.S. dependence on China for REEs is "particularly concerning" [17]—an observation that is even more salient because they are crucial to the Biden administration's goal of having electric vehicles (EVs) account for half of all U.S. new car sales by 2030.[18] In fact, the 100-day review ordered by President Biden found that "China has positioned itself as a market leader in the [battery] manufacturing supply chain through the practice of questionable environmental policies, price distortion, state-run entities that minimize competition, and large subsidies."[19]

To meet this goal, for example, Tesla, which made about 500,000 vehicles in 2020, the last year for which statistics are currently available,[20] would have to produce 20 million automobiles per year. This is easier said than done given the volume of REEs and other metals needed. Beginning with REEs, to produce those 20 million vehicles, Tesla would consume 40 percent of the current global output of permanent magnets to make the majority of its motors and need 165 percent of the world's current production of cobalt to manufacture its batteries. Beyond REEs and exotic materials, Tesla would also use 30 percent of the world's current nickel production (the company's models average about 45 kilograms of nickel a piece).[21] And one should not forget that battery electric vehicles demand almost four times more copper than conventional automobiles operating on an internal-combustion engine (83 kilograms versus 23 kilograms).[22]

---

[16] U.S. Department of the Interior, Office of the Secretary, Final List of Critical Minerals, May 17, 2018, https://www.govinfo.gov/content/pkg/FR-2018-05-18/pdf/2018-10667.pdf. The minerals identified were aluminum (bauxite), antimony, arsenic, barite, beryllium, bismuth, cesium, chromium, cobalt, fluorspar, gallium, germanium, graphite (natural), hafnium, helium, indium, lithium, magnesium, manganese, niobium, platinum group metals, potash, the rare earth elements group, rhenium, rubidium, scandium, strontium, tantalum, tellurium, tin, titanium, tungsten, uranium, vanadium, and zirconium.

[17] President Donald J. Trump, Executive Order 13953: Addressing the Threat to the Domestic Supply Chain From Reliance on Critical Minerals From Foreign Adversaries and Supporting the Domestic Mining and Processing Industries, September 30, 2020, https://www.govinfo.gov/content/pkg/FR-2020-10-05/pdf/2020-22064.pdf.

[18] The White House, Fact Sheet: President Biden Announces Steps to Drive American Leadership Forward on Clean Cars and Trucks, August 5, 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/08/05/fact-sheet-president-biden-announces-steps-to-drive-american-leadership-forward-on-clean-cars-and-trucks/.

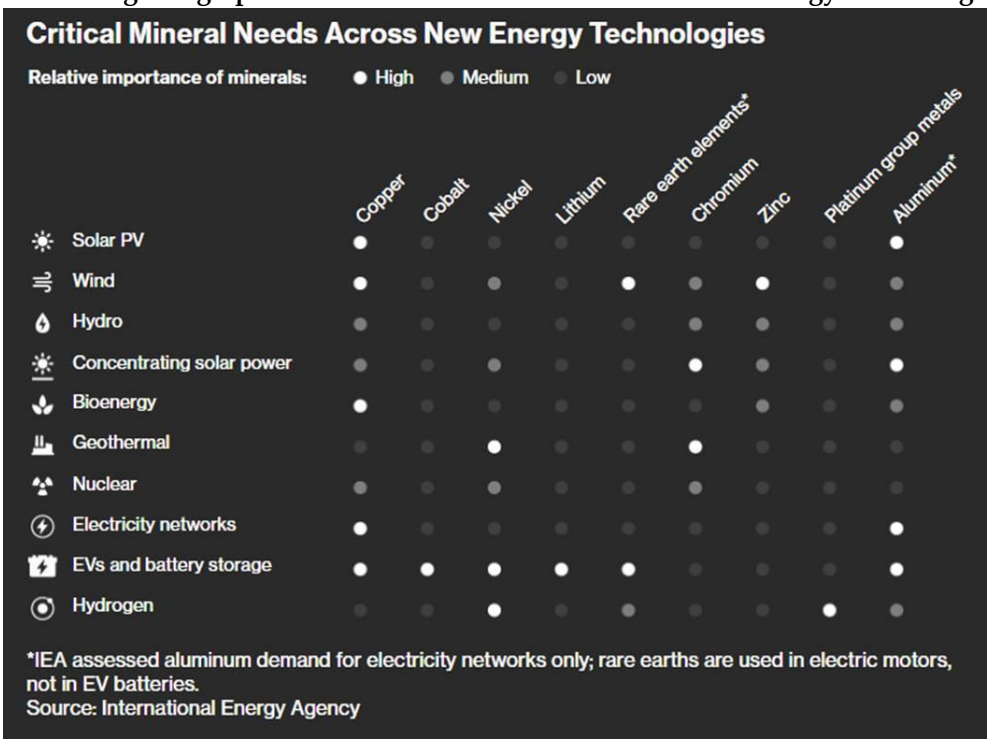
[19] The White House, *Building Resilient Supply Chains*, *op. cit.*

[20] Brian Dean, "Tesla Revenue and Production Statistics for 2022," Backlinko.com, January 6, 2022, https://backlinko.com/tesla-stats.

[21] Frik Els, "All the Mines that Tesla Needs to Build 20 Million Cars a Year," Mining.com, January 27, 2021, https://www.mining.com/all-the-mines-tesla-needs-to-build-20-million-cars-a-year/.

[22] "The Electric Vehicle Market and Copper Demand," International Copper Association, June 2017, https://copperalliance.org/wp-content/uploads/2017/06/2017.06-E-Mobility-Factsheet-1.pdf.

**Bloomberg Infographic – Critical Mineral Needs Across New Energy Technologies**[23]




Where do these REEs and other metals come from? In aggregate, China produces upwards of 80 percent of the world's REEs, including the neodymium used in permanent magnets.[24] Even this figure may understate the situation. For example, Europe sources 98 percent of its REEs from China.[25] Other examples are just as eye-opening. Half of the world's cobalt reserves are found in the Democratic Republic of the Congo.[26] At present, the country accounts for about 70 percent of global production,[27] and Chinese companies have largely cornered that sector, either owning or financing 15 of the 19 cobalt-producing mines in the country.[28] The government of President Félix Tshisekedi,

[23] "There's a Fortune to Be Made in the Obscure Metals Behind Clean Power," Bloomberg, By Andrew Janes, David Stringer and Adrian Leung, September 21, 2021, https://www.bloomberg.com/graphics/2021-materials-silver-to-lithium-worth-big-money-in-clean-energy/.

[24] Adam Isaak, "A Rare Metal Called Neodymium Is in Your Headphones, Cellphone and Electric Cars like Tesla's Model 3—and China Controls the world's supply," CNBC.com, October 19, 2018, https://www.cnbc.com/2018/10/18/neodymium-china-controls-rare-earth-used-in-phones-electric-cars.html.

[25] European Commission, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on Critical Raw Materials Resilience: Charting a Path to Greater Security and Sustainability, September 3, 2020, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0474&from=EN.

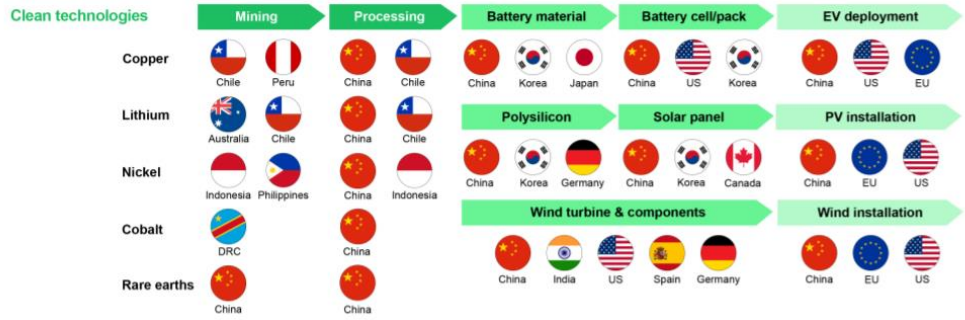
[26] M. Garside, "Cobalt Reserves Worldwide as of 2020, by Country," Statista, February 16, 2021, https://www.statista.com/statistics/264930/global-cobalt-reserves/.

[27] "Profiling the World's Eight Largest Cobalt-Producing Countries," NS Energy, February 22, 2021, https://www.nsenergybusiness.com/features/top-cobalt-producing-countries/.

[28] Eric Lipton, Dionne Searcey, and Michael Forsythe, "Race to the Future: What to Know About the Frantic Quest for Cobalt," *The New York Times*, November 20, 2021, https://www.nytimes.com/2021/11/20/world/china-congo-cobalt-explained.html.

who took office in 2019, however, is currently reviewing many of the contracts awarded by his Chinese-educated predecessor, reportedly with support from the United States.[29] As for aluminum, the United States mostly imports from Canada, while Canada is entirely dependent upon imports of bauxite, the main ingredient in aluminum, adding a layer of risk to one of America's most secure supply chains. Tight supplies had already caused prices to rise steadily when, in September 2021, a coup d'état in Guinea, which has the world's largest reserves of bauxite, sent the price per ton of aluminum to the metal's highest level in more than a decade.[30] In addition to the need for cobalt, nickel, and lithium for electric vehicle batteries, the automotive sector leads demand for platinum and palladium for use in catalytic converters—found in hybrid vehicles. Palladium reserves, however, are found in and production predominantly takes place in South Africa, Russia, and Canada, whereas U.S. reserves for palladium and production are at significantly lower levels.

**International Energy Agency: The transition to a clean energy system brings new energy trade patterns, countries, and geopolitical considerations into play**[31]




Notes: DRC = Democratic Republic of the Congo; EU = European Union; US = United States; Russia = Russian Federation; China = People's Republic of China. Largest producers and consumers are noted in each case to provide an indication, rather than a complete account.

Looking to the future, the search for an efficient power storage with long life cycles for energy from renewable sources has become something of a modern-day quest for the Holy Grail. Vanadium-based "redox flow" batteries have shown great promise with their ability to be recharged thousands of times—potentially retaining their value for decades. Currently, 90 percent

[29] Stanis Bujakera Tshiamala, "RDC-Chine: contrats miniers contre infrastructures, des annonces…à la réalité," *Jeune Afrique*, September 15, 2021, https://www.jeuneafrique.com/1232674/economie/rdc-chine-contrats-miniers-contre-infrastructures-des-annonces-a-la-realite/.

[30] "Soaring Aluminium Hits $3,000 for First Time since 2008," Reuters, September 13, 2021, https://www.reuters.com/article/global-metals/metals-soaring-aluminium-hits-3000-for-first-time-since-2008-idUSL1N2QF0PY.

[31] "The Role of Critical World Energy Outlook Special Report Minerals in Clean Energy Transitions," International Energy Agency, May 2021, https://iea.blob.core.windows.net/assets/24d5dfbb-a77a-4647-abcc-667867207f74/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf.

of all the vanadium produced comes from just three countries: China, Russia, and South Africa—with China alone accounting for about 55 percent of the total.[32]

Moreover, the dominance of any one country over a supply chain can over time undermine the ability of the market to rebalance. For example, with respect to REEs, Chinese firms, with varying degrees of state coordination and support, waged a price war that—coupled with local environmental activists concerned about radioactivity in the minute quantities of thorium associated with some rare earth oxides—drove the last major European processor, the French chemical firm Rhône-Poulenc, whose factory in La Rochelle once produced 50 percent of the purified REEs in the world, out of the business altogether.[33] The risk of possible hold ups to supply chains will only increase with China's recently announced plans for a strategic consolidation of the SOEs that already dominate the production and processing of rare earths.[34] Thus, any eventual alternative supply chain will have to contend not only with the challenge to obtain access to the raw resources,[35] but also sustainment through what is anticipated to be a fierce effort to defend dominance. Offtake agreements for alternative suppliers would contribute to addressing the issue of dependence on imports from China in the short and intermediate term, even as research is pursued in technologies to recycle REEs or develop alternatives.

In this respect, the response of Japan to the unofficial—but, nonetheless, very real—embargo of access to REEs to which it was subjected following a maritime dispute with China in 2010 is illuminating. Realizing the need to secure an alternative supply chain for rare earths, the Japanese government teamed up with Japanese businesses to support the mining of REEs in western Australia's Mount Weld. The mining is led by Lynas, an Australian company that through the process has become the world's second largest producer of neodymium and praseodymium, two light REEs which together form the magnet in many consumer electronics, including the iPhone.[36] Lynas currently processes the REEs in Malaysia, although its Japanese backers have recently provided financing to move the operations closer to the mine in Australia; in exchange, the Japanese

[32] U.S. Department of Interior, U.S. Geological Survey, Vanadium Data Sheet, Mineral Commodity Summaries 2020, https://pubs.usgs.gov/periodicals/mcs2020/mcs2020-vanadium.pdf. This particular U.S. Geological Survey report also highlights another challenge policymakers face: access to up-to-date reliable information. The report on vanadium lists just five countries as having *any* reserves: China, Russia, South Africa, Brazil, and the United States—the latter with a paltry 0.2 percent of the total global reserves. Missing from the list is Norway, where the Anglo-Norwegian exploration company Norge Mining has discovered a world-class reserve in three areas.

[33] Guillaume Pitron, *The Rare Metals War: The Dark Side of Clean Energy and Digital Technologies*, trans. Rebecca Jacobsohn (London: Scribe Publications, 2020), 63-69.

[34] Tom Daly, "Minmetals Unit Flags China Rare Earths Restructuring," Reuters, September 23, 2021, https://www.reuters.com/world/china/minmetals-unit-flags-china-rare-earths-restructuring-2021-09-23/.

[35] Currently there are only three mines for REEs located outside of China: Mountain Pass in California, operated by the eponymous company; Mount Weld in western Australia, operated by Lynas; and Gakara in Burundi, operated by Rainbow Rare Earths.

[36] Mary Hui, "Lynas is Shaking Up the Supply Chain for Rare-Earth Metals," *Quartz*, March 6, 2021, https://qz.com/1980445/lynas-wants-to-shake-up-the-rare-earths-supply-chain/.

will have preferential access to the production through the end of this decade at least.[37] For Japan, the partnership with the Australian firm has already paid off: it has cut its dependence on the import of Chinese REEs by almost half since the 2010 crisis.

In addition, geographically far-flung supply chains raise the risk of hold up, meaning that an upstream producer intentionally or unintentionally prevents the sale of inputs to downstream end-users. The classic example of intentional hold up is political conflict, like war. In terms of unintentional hold up, think natural disaster. To plan for a natural disaster, downstream end-users might look to diversify the geographies from which they source, hoping to work around a flood, for example. But what about conflict and war? The Trump administration's executive order declared that "[i]t shall be the policy of the Federal Government to reduce the Nation's vulnerability to disruptions in the supply of critical minerals which constitutes a strategic vulnerability for the security and prosperity of the United States." Yes, but how?

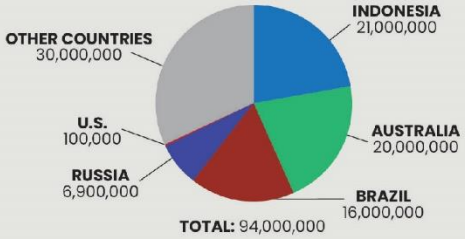
[37] Cecilia Jasmasmie, "Japan Secure Rare Earth Supply for Longer through Lynas Funding," *Mining.com*, June 27, 2019, https://www.mining.com/japan-secures-rare-earth-supply-for-longer-through-lynas-funding/.

# Nickel, Cobalt, and Platinum Group Metals – Top Countries for Reserves Supply and Production

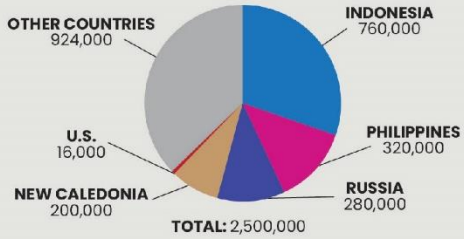
*The Impossibility of Reshoring Critical Minerals Production to the U.S.*

## Nickel

RESERVES – TOP COUNTRIES



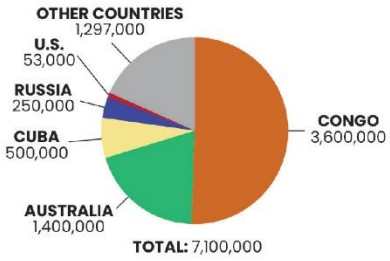

MINE PRODUCTION IN 2020 – TOP COUNTRIES



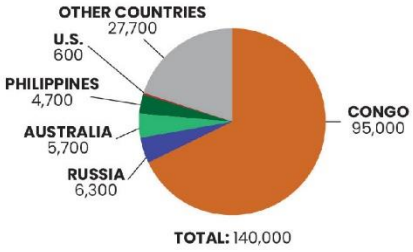

Source: U.S. Department of the Interior, U.S. Geological Survey, Mineral Commodities Summary 2021, Nickel Summary, page 112: https://pubs.usgs.gov/periodicals/mcs2021/mcs2021.pdf

## Cobalt

RESERVES – TOP COUNTRIES

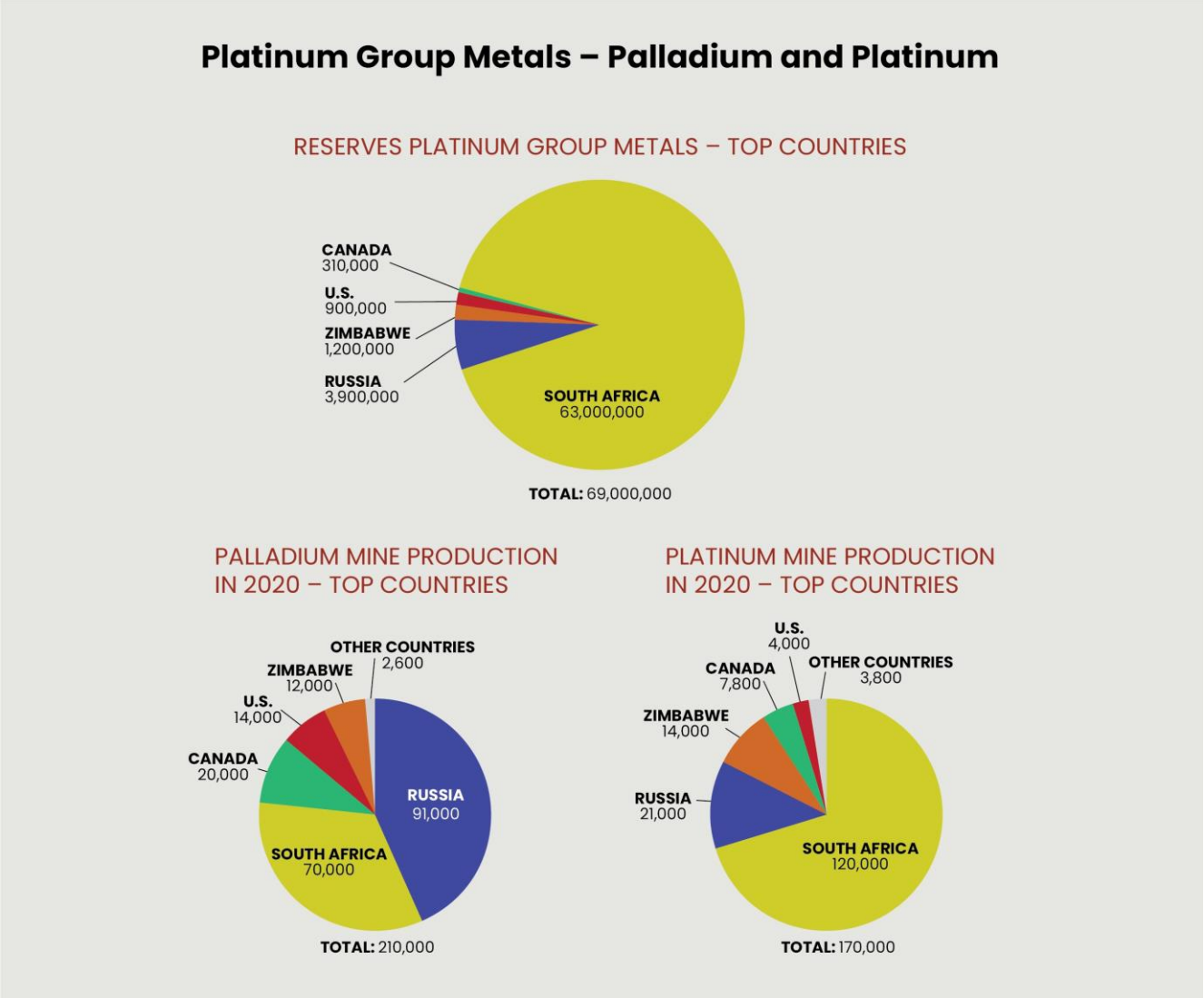



MINE PRODUCTION IN 2020 – TOP COUNTRIES




Source: U.S. Department of the Interior, U.S. Geological Survey, Mineral Commodities Summary 2021, Cobalt Summary, page 113: https://pubs.usgs.gov/periodicals/mcs2021/mcs2021.pdf

*Figures are in million tons




Source: U.S. Department of the Interior, U.S. Geological Survey, Mineral Commodities Summary 2021, Platinum Group MetalsSummary, page 125: https://pubs.usgs.gov/periodicals/mcs2021/mcs2021.pdf

*Figures are in million tons

To address these concerns as well as to help meet President Biden's decarbonization goals, strategically realigning the nation's goals for sourcing critical minerals is crucial. As noted earlier, Tesla and other EVs consume a significant proportion of the world's current nickel production, and China is the top country involved in the processing of nickel—absorbing the lion's share of top producer Indonesia's mining output. In 2020, Chinese imports of Indonesian nickel pig iron for processing and refining were quadruple the volumes notched in 2018, even as its purchases of refined product declined.[38] Meanwhile, Russia has some of the world's largest reserves of nickel

[38] Andy Home, "China's 2020 Refined Nickel Imports Slump to 6-Year Low," Reuters, February 11, 2021, https://www.reuters.com/article/us-china-nickel-ahome/column-chinas-2020-refined-nickel-imports-slump-to-6-year-low-andy-home-idUSKBN2AB1RW.

and is the third-largest producer of the metal, mining some 280,000 tons annually.[39] Virtually all of Russia's proven nickel reserves are controlled by Norilsk Nickel (also known as Nornickel), a London Stock Exchange-listed multinational corporation with trading offices in the United States that is the world's largest producer of battery-grade nickel. This is an example of the point made earlier about mitigating risks to supply chains by distinguishing between potential suppliers: generally speaking, a Russian non-state-owned multinational firm presents less of a long-term strategic threat of hold up than a Chinese state-owned enterprise. The United States produces about 18,000 metric tons of nickel a year, almost all of it at a single mine in the Upper Peninsula of Michigan, which is then shipped to Canada for processing. At the same time, American industry requires 210,000 metric tons of the metal annually.[40] Thus, notwithstanding the conflict in Ukraine, while no one in the Biden administration has been so crass as to say it in as many words, importing Russian nickel from a publicly-traded company can be viewed as preferable to dependence on processed nickel controlled by the Chinese state—which probably is why Norilsk Nickel has, thus far, not appeared on the sanctions lists of the United States or its allies.[41]

[39] "Profiling the Top Six Countries with the Largest Nickel Reserves in the World," NS Energy, February 11, 2021, https://www.nsenergybusiness.com/features/nickel-reserves-countries/.

[40] U.S. Department of Interior, U.S. Geological Survey, Nickel Data Sheet, Mineral Commodity Summaries 2022, https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-nickel.pdf.

[41] Alistair MacDonald, "This Russian Metals Giant May Be Too Big to Sanction," *Wall Street Journal*, March 7, 2022, https://www.wsj.com/articles/this-russian-metals-giant-might-be-too-big-to-sanction-11646559751.

# The Global Production of Nickel, Cobalt, and Platinum Group Metals

*The following countries are among the top producers of nickel, cobalt, and platinum group metals.*


| ■ NICKEL PRODUCTION | | ● COBALT PRODUCTION | | ▲ PALLADIUM PRODUCTION | | ◆ PLATINUM PRODUCTION | |
|---|---|---|---|---|---|---|---|
| Indonesia: | 760,000 | Congo: | 95,000 | Russia: | 91,000 | South Africa: | 120,000 |
| Philippines: | 320,000 | Russia: | 6,300 | South Africa: | 70,000 | Russia: | 21,000 |
| Russia: | 280,000 | Australia: | 5,700 | Canada: | 20,000 | Zimbabwe: | 14,000 |
| New Caledonia: | 200,000 | Philippines: | 4,700 | United States: | 14,000 | Canada: | 7,800 |
| Australia: | 170,000 | Canada: | 3,200 | Zimbabwe: | 12,000 | United States: | 4,000 |
| United States: | 16,000 | United States: | 600 | | | | |

Source: U.S. Department of the Interior, U.S. Geological Survey, Mineral Commodities Summary 2021, Nickel Summary, page 112: https://pubs.usgs.gov/periodicals/mcs2021/mcs2021.pdf; Cobalt Summary, page 113: https://pubs.usgs.gov/periodicals/mcs2021/mcs2021.pdf; , Platinum Group Metals Summary, page 125: https://pubs.usgs.gov/periodicals/mcs2021/mcs2021.pdf

*Figures are in million tons

***Thinking About Solutions***

For most critical minerals and materials, reshoring is *not* an option. Even if it is possible to mine some of these at home, processing is often done abroad because of environmental regulations. EU countries, for example, mine lithium but cannot process it domestically because of legal restrictions as well as an unfavorable political climate. This adds a layer of risk to the supply chain. The same is true in California with the REEs mined at Mountain Pass which, as mentioned earlier, ironically, have been shipped to China for processing for years.

Since autarky is *not* realistically in the cards, "[t]he United States recognizes the continued importance of *cooperation on supply chain issues with international partners and allies*," the Trump administration's Executive Order 13953 noted. This opens the door to trade, even if it does not offer much guidance on securing supply chains that include friend and foe alike. In fact, other than suggesting that tariffs and quotas can be used on China and "other non-market foreign adversaries," the document is silent on risk mitigation strategies with respect to particular countries.

A 2020 European Commission report offers a slightly different perspective worth considering.[42] It explains that critical minerals and materials are key to Europe's Green Deal, that COVID-19 demonstrated the fragility of supply chains, and that policy should focus on "strengthening rules-based open trade in raw materials and removing distortions to international trade." This is a useful reminder that risk mitigation strategies can involve the disciplining effect of global institutions and the markets they govern, not just country-specific approaches or measures.

A landmark World Trade Organization (WTO) dispute, commonly known as *China-Rare Earths*, is a case in point.[43] In 2012, the United States complained about Chinese export restrictions on the REE tungsten, which has a variety of industrial as well as military applications, and molybdenum, which is used primarily to improve the strength and resilience of steel alloys. In 2014, the WTO ruled in favor of the United States, and China removed these offending policies by 2015. The case was unusual in that China invoked an exception to WTO rules concerning non-renewable resources, and lost because the country's efforts at conservation applied only to foreign, not domestic use. This is precisely the kind of distortion the EU is seeking to prevent.

[42] European Commission, Critical Raw Materials Resilience, *op. cit.*

[43] World Trade Organization, *DS 431: China—Measures Related to the Exportation of Rare Earths, Tungsten and Molybdenum*, https://www.wto.org/english/tratop_e/dispu_e/cases_e/ds431_e.htm.

More broadly, the EU may have in mind something like the agreement at the beginning of the pandemic between New Zealand and Singapore to eliminate tariffs, export restrictions, and nontariff barriers on covered products in key medical supply chains.[44] This model deserves more attention. The agreement was struck amidst a spike in the number of global import and export restrictions on protective personal equipment, and ran against the grain by opening markets rather than closing them.

Importantly, the EU also considers firm attributes, insisting that Brussels ought to influence the practices of foreign suppliers by helping them improve local governance structures and sharing "responsible mining practices." These mining practices will invariably mirror EU preferences and could prove costly for developing countries to implement. This is where global standards can help.

In its recent strategy for supporting critical minerals and materials supply chains, the U.S. Department of Energy suggests that the International Organization of Standardization (ISO) is starting to take a leading role in setting standards on critical minerals and materials.[45] Two ISO Technical Committees stand out in this regard: ISO/TC 298 on Rare Earth Elements and ISO/TC 333 on Lithium. In the case of REEs, for example, the technical panel, which includes Australia, Canada, China, India, Japan, Korea, the United States, and 22 "observing" countries, is set to work on naming conventions, quality control systems for packaging, and recycling, among other issues. The standards that result from these efforts will set "best practices" for suppliers around the world. U.S. leadership in drafting these standards should thus be a priority.

Now, which firm attributes are likely to matter most in securing global supply chains? President Trump's Executive Order 13953, which focuses on non-market economies, defines them under U.S. law as countries that do not "operate on market principles of cost or pricing structures."[46] Arguably, a non-market economy responds more to *political* than economic incentives. This exposes suppliers to the foreign policy whims of their government, making them more of a supply chain risk, and likely tougher to compete with, given favorable explicit and implicit industrial and trade policies that follow from the government's involvement in the economy. Of course, not even all non-market economies are the same. The 2020 Executive Order explicitly worries about

[44] Declaration on Trade in Essential Goods for Combatting the COVID-19 Pandemic, April 15, 2020, https://perma.cc/WWG4-JRAC.

[45] U.S. Department of Energy, *Critical Minerals and Materials: U.S. Department of Energy's Strategy to Support Domestic Critical Minerals and Materials Supply Chains (FY2021-FY2031)*, January 20, 2021, https://www.energy.gov/sites/prod/files/2021/01/f82/DOE%20Critical%20Minerals%20and%20Materials%20Strategy_0.pdf.

[46] Wayne M. Morrison, "China's Status as a Nonmarket Economy (NME)," Congressional Research Service, January 10, 2019, https://sgp.fas.org/crs/row/IF10385.pdf.

"certain" ones. Given that the Department of Commerce lists 11 countries as non-market economies for purposes of antidumping and countervailing duties provisions under U.S. law,[47] the implication would seem to be that some, even among these, are more market-oriented than others.

An interesting case is that of what is now the Anglo-Russian EN+ Group, the largest aluminum producer outside of China. The company was sanctioned by the U.S. Department of Treasury's Office of Foreign Assets Control (OFAC) in 2018, along with three dozen other Russian entities, in response to alleged Russian government interference with U.S. elections as well as involvement in conflicts in Ukraine and Syria. In order to remove the OFAC sanctions, EN+ Group committed to what the Peterson Institute for International Economics described as "a series of important reforms that heightened the firm's corporate accountability and drastically revised its governance"[48]—effectively resulting in its removal from the sanctions list by the U.S. Treasury Department. The Treasury Department acknowledged that the group, now traded on the London Stock Exchange and led by a board comprised of a majority of U.S. government-approved directors, had "agreed to unprecedented transparency."[49]

What about enforcement? If U.S. foreign direct investment (FDI) is involved, one option is to use dispute settlement mechanisms provided under bilateral investment treaties (BITs). The "Model BIT" published by the U.S. Trade Representative,[50] for example, has useful provisions on market-based "performance requirements" in Article 8, giving investors private standing to challenge cases of intentional hold up as *de jure* or

[47] U.S. Department of Commerce, Countries Currently Designated by Commerce as Non-Market Economy Countries, https://www.trade.gov/nme-countries-list. The 11 countries are Armenia, Azerbaijan, Belarus, China, Georgia, Kyrgyzstan, Moldova, Tajikistan, Turkmenistan, Uzbekistan, and Vietnam.

[48] Gary Clyde Hufbauer, "Some Sanctions Against Russia Actually Achieve Their Foreign Policy Goals," *Real Clear Energy*, April 26, 2021, https://www.realclearenergy.org/articles/2021/04/26/some_sanctions_against_russia_actually_achieve_their_foreign_policy_goals_774497.html.

[49] U.S. Department of the Treasury, "OFAC Delists EN+, Rusal, and EuroSibEnergo," January 27, 2019, https://home.treasury.gov/news/press-releases/sm592. More recently, the resignations of Lord Barker, a former British Minister of State for Energy and Climate Change, as the chairman of the board of the EN+ Group and of another British independent director of the company in response to political pressures in the United Kingdom following the Russian invasion of Ukraine ironically underscored the effectiveness of the OFAC supervision. Barker's resignation did not have immediate effect, but rather, as the company noted in a regulatory news statement filed with the London Stock Exchange, in "continued compliance with the terms agreed to with the U.S. Office of Foreign Asset Control," involved a short period during which he would assist with the transition of the senior independent director, former acting U.S. Under Secretary of State for Management Christopher Bancroft Burnham, into the chairman's role. See "EN+ Announces Directors' Resignations," March 7, 2022, https://www.londonstockexchange.com/news-article/ENPL/en-announces-directors-resignations/15355467.

[50] U.S. Trade Representative, 2012 U.S. Model Bilateral Investment Treaty, https://ustr.gov/sites/default/files/BIT%20text%20for%20ACIEP%20Meeting.pdf.

*de facto* expropriation. The United States should negotiate more BITs to better secure critical supply chains.

More generally, some FDI recipients have sought to tie their own hands as a way to signal their commitment to swearing off intentional hold up. Mongolia, for example, offers international arbitration under a 2017 law based on recommendations of the United Nations Commission on International Trade Law.[51] The United States needs to do more to assist in capacity building in resource-rich countries to follow Mongolia's lead. In fact, the Energy Resource Governance Initiative (ERGI) would be an excellent vehicle for such an effort. Alas, more than one year after taking office, President Biden has yet to even nominate an assistant secretary of state for energy resources.

Even if U.S. FDI is not involved, domestic and international forums can still provide formal and informal business-to-business and business-to-government dispute settlement. Local trade associations, as well as transnational ones like the International Center for the Settlement of Investment Disputes (ICSID), part of the World Bank Group, and the International Chamber of Commerce (ICC), for example, can help perform these functions. In addition to its sponsorship of the International Court of Arbitration, the ICC provides a variety of dispute resolution services as an alternative to commercial litigation. Given the comprehensive reach of the ICC, it can be a particularly attractive forum.

***Conclusions and Recommendations***

As the United States emerges from the COVID-19 pandemic, the tensions with China, far from showing any sign of relenting, seem to be intensifying. Thus, securing supply chains will not only be the talk of Washington's policymakers, but, for both the public and private sectors, very much a strategic preoccupation well beyond the news cycle or even the 2022 midterm elections. In this context, a few points are worth bearing in mind:

- ***Reshoring is, for the most part, not a viable option.*** Political support for the *notion* of reshoring upstream suppliers may have reached a fever pitch, but as far as critical minerals and materials are concerned, very little can in *reality* be reshored, let alone in a timely and cost-effective manner. Either the geology is such that the resources are not available domestically in commercially exploitable quantities, if at all, such as with cobalt, or the development of the resources is politically difficult, as has been the case with several recent efforts to build copper mines in

[51] "International Arbitration in Mongolia," Aceris Law, March 22, 2021, https://www.acerislaw.com/international-arbitration-in-mongolia/.

the western United States. Alternatively, the resource is found and extracted in the United States, but the commercial processing involves potential environmental risks so that refining operations face difficult regulatory and political hurdles.

- ***More nuance is required in differentiating between foreign firms in the critical supply chain.*** As part of the wide-ranging interagency reviews of supply chains mandated by recent executive orders, the U.S. government should establish criteria for partnering with foreign countries and companies that recognize the subtle—but significant—difference between state-owned enterprises and multinational corporations, as noted above. Among the latter, there needs to be a distinction between those that have adopted governance structures that substantially lower risk from those that have not. Moreover, building resilient supply chains will also require engaging with appropriate corporate partners, even in countries with which the United States may have significant political differences, but not on issues related to the extraction, processing, and sale of critical minerals. And even in those exceptional cases where the potential trading partner is not especially well-governed, one needs to distinguish between those actors in a position to threaten a hold up of the supply chain for a vital material and those who are unable or unlikely to do so.

- ***The creation of a strategic reserve is needed to ensure the availability of critical minerals and materials.*** A reserve not only helps protect against hold ups in the supply chain, whether intentional or unintentional, but by signaling U.S. demand for select critical materials, it can also serve as a catalysis of investment from appropriate countries and companies that will provide further protection for U.S. supply chains. As President Biden noted in Executive Order 15051, signed as he hosted the Summit on Global Supply Chain Resilience with the European Union and 14 like-minded countries on the sidelines of the G20 meeting in Rome in October 2021, "[a] critical component of safeguarding supply chain resilience and industrial base health is ensuring that both the Federal Government and the private sector maintain adequate quantities of supplies, equipment, or raw materials on hand to create a buffer against potential shortages and import dependencies."[52] Moreover, through instruments such as offtake agreements linked to strategic reserves or incentives to private U.S. companies to enter into their own similar deals with appropriate suppliers, the United States can also help solve the problem of market failure typically caused by the dominance of a single

[52] President Joseph R. Biden, Executive Order 15051: Designation to Exercise Authority Over the National Defense Stockpile, October 31, 2021, https://www.federalregister.gov/documents/2021/11/03/2021-24183/designation-to-exercise-authority-over-the-national-defense-stockpile.

country or its firms in the supply chain of any given mineral or group of materials. For example, as discussed above, China's near-total monopoly in the processing of REEs makes the emergence of any alternative supplier exceptionally challenging unless that alternate is given a pathway to surviving the cut-throat and uneven competition.

- ***Develop plans and partnerships for sustainable processing of select critical materials.*** Whether the resource is located at home or abroad, a strategy needs to be developed, engaging both the public and private sectors in partnership, to establish the domestic processing of select critical minerals and materials, notwithstanding the political and other hurdles previously mentioned.[53] This might, for example, involve the importation of partially processed materials for finishing, effectively offshoring some of the more costly or otherwise difficult stages. And where there are hurdles, logistical or political, to developing domestically, this may mean helping partners like the Congo develop their own capacities to capture the value chain. If the whole point of driving electric vehicles and getting power from renewable sources is to mitigate the effects of greenhouse gases on the climate, it makes little sense to ship millions of tons of ore to China when it could be processed in the DRC where, incidentally, the industry can be readily powered by clean renewable energy from hydropower and solar sources.

To achieve goals like the energy transition and to ensure reliable access to critical minerals and other materials upon which future technological innovation depends, the United States will need to rethink how it manages risk up and down far-flung, interconnected supply chains that include friends and foes, as well as market and non-market producers. Today's supply chains are tight business ecosystems. The risk of intentional and unintentional hold up is real. Thus, securing the supply chain for critical minerals must necessarily involve a variety of approaches and multiple lines of effort. It, however, does not mean that, with careful thinking and political will, America cannot proactively and significantly derisk the supply chains for these strategic resources.

[53] Despite the U.S. Senate's 68-32 bipartisan vote to pass the United States Innovation and Competition Act (USICA) in July 2021, the chamber has yet to bring to the floor for a confirmation vote the administration's nominee for Assistant Secretary of Commerce for Industry and Analysis, a position at the center of the interagency process—as well as regional and bilateral dialogues with international partners—on the very supply chain security issues which the legislation sought to address, including technological innovation and manufacturing.

**AMBASSADOR J. PETER PHAM**, a Distinguished Fellow at the Atlantic Council, is a Senior Advisor at the Center for Tech Diplomacy at Purdue. He previously served as United States Special Envoy for the Sahel Region from 2020 to 2021 and as the U.S. Special Envoy for the Great Lakes Region of Africa from 2018 to 2020. Ambassador Pham is a non-executive director of Africell Global Holdings Limited and of Rainbow Rare Earths Limited as well as a strategic advisor to dClimate. In the process of writing of this report, the author gratefully acknowledges the significant insights and contributions of Ambassador Douglas E. Lute, Lieutenant General, U.S. Army (ret.), former U.S. Ambassador to NATO, and Ambassador Frank X. Taylor, Brigadier General, U.S. Air Force (ret.), former Under Secretary for Intelligence and Analysis of the U.S. Department of Homeland Security. Ambassadors Lute and Taylor are also, respectively, a member of the board of directors of the Atlantic Council and a nonresident senior fellow of its Scowcroft Center for Strategy and Security. The final report also benefited from a discussion on "Preparing the United States for a Mineral-Intensive Future," organized by the Atlantic Council's Global Energy Center in February 2022 and moderated by its Deputy Director, Reed Blakemore, at which Senator Lisa Murkowski of Alaska gave the keynote remarks followed by a panel with the author, Ambassador Lute, and Helaina R. Matza, Director of the Office of Energy Transformation at the Bureau of Energy Resources of the U.S. Department of State. Of course, the contents of this report are the product of research by and the personal views of the author and contributors and do not necessarily represent those of any of the organizations with which they are affiliated.

KRACH INSTITUTE FOR TECH DIPLOMACY AT PURDUE