# Friendshoring critical minerals: what could the United States and key partners produce?

Bentley Allan, Hannah Jeong, and Cathy Wang

Abstract: This working paper assesses the ability of various friendshoring groups to meet metals demand for clean energy supply chains. The study begins by estimating the amount of various critical minerals needed for solar, wind, and electric vehicle (EV) battery supply chains. These minerals include the copper used in electrical wiring, the nickel and lithium used in many batteries, and the zinc used in protective coatings for solar panels and wind turbines. Demand was indexed to deployment levels in 1.5-degree-Celsius scenarios by the International Renewable Energy Agency and the International Energy Agency. The working paper concludes that while it possible for the world's democracies to friendshore primary production, it would take an unprecedented build-out of clean energy supply chains in order to achieve 2030 goals.

## Introduction

Over three decades of Chinese industrial policy has bolstered its position in clean energy supply chains.[1] China's position is now dominant. It produces 78% of the world's battery cells, 78% of the anode active material, 72% of the refined cobalt, and 61% of refined lithium.[2] It mines 22% of the material needed for its domestic battery production, but refines 66% of the required metal.[3] Concern about this was already heightened when Russia invaded Ukraine. Russia's leverage in the early days of the way, due to Europe's dependence on Russian natural gas, has made the risks of interdependence evident.[4]

---

[1] Allan, Bentley, Joanna I. Lewis, and Thomas Oatley. 2021. Green industrial policy and the global transformation of climate politics. *Global environmental politics*, *21*(4): 1-19.

[2] Bloomberg New Energy Finance. 2021. Energy Storage Trade and Manufacturing. https://csis-website-prod.s3.amazonaws.com/s3fs-public/Energy%20Storage%20Case%20Study%20%20BloombergNEF.pdf?KCOqvXlE3LM6AlBS.lyXF9LnQ7GTk5oc

[3] Moores, Simon. 2021. The global battery arms race: lithium-ion battery gigafactories and their supply chain. Oxford Institute for Energy Studies Forum.

[4] Farrell, Henry and Abraham L. Newman. 2019. Weaponized interdependence: How global economic networks shape state coercion. *International Security 44*(1): 42-79.

In this context, leaders in the U.S., Europe, Canada, and elsewhere have called for "friendshoring" in global value chains.[5] As Secretary Yellen defines it, friendshoring is when countries that share economic values  increase trade with one another in order to reduce dependence on countries that pose geopolitical risks.[6] The friendshoring strategy recognizes that full onshoring within one's borders is not possible and that larger groups of countries must collaborate to forge value chains for clean energy.[7]

Transition metals are an important part of the energy transition. One way to frame the energy transition is that the world is shifting from a world in which oil and gas provide and carry the world's energy to one in which metals are needed to generate and carry energy via turbines, solar panels, and batteries.[8]

Metals play a vital role in net-zero technology, but they are also central to the global and domestic politics of net-zero. Globally, China has secured a strong position in the midstream of the metals supply chain. China processes 61% of the world's lithium and 78% of the world's graphite. Chinese firms also have strong positions in other countries, such as in Indonesia's nickel industry. This creates geopolitical risk for the US and its partners.

China's dominance not only creates dependence on China. It also threatens the ability of other countries to capture domestic economic opportunities in the transition. However, research has shown that the ability of countries to build green industries is a critical component of climate policy and decarbonization potential.[9] Seizing economic opportunities by creating clean energy industries bolsters the green political coalitions that are needed to support long-term decarbonization.

So friendshoring not only aims to increase geopolitical resilience but could also create the economic opportunities that will support long-term decarbonization. In countries like Australia, Canada, Chile, Brazil, Indonesia, and South Africa where mining accounts for 5% or more of GDP, the metals economy is a crucial source of political support for climate action.[10]

---

[5] Kessler, Sarah. 2023. What is 'Friendshoring'? New York Times. https://www.nytimes.com/2022/11/18/business/friendshoring-jargon-business.html

[6] U.S. Treasury. 2023. Treasury Releases Proposed Guidance on New Clean Vehicle Credit to Lower Costs for Consumers, Build U.S. Industrial Base, Strengthen Supply Chains. https://home.treasury.gov/news/press-releases/jy0830

[7] Nahm, Jonas. 2021. Collaborative Advantage. Oxford University Press.

[8] Boer, Lukas, Andrea Pescatori, and Martin Stuermer. 2021. *Energy transition metals*. International Monetary Fund WP/21/243.

[9] Meckling, Jonas, Nina Kelsey, Eric Biber, and John Zysman. 2015. "Winning coalitions for climate policy." *Science* 349, no. 6253: 1170-1171.

[10] Bloomberg New Energy Finance. 2023. Transition Metals Outlook 2023. https://about.bnef.com/blog/transition-metals-become-10-trillion-opportunity-as-demand-rises-and-supply-continues-to-lag/

In the critical minerals value chain, friendshoring means building mining and processing capacity in areas where China and Russia dominate.[11] The Inflation Reduction Act's (IRA) section 30D, which outlines the requirements for electric vehicle (EV) purchase incentives, includes two powerful friendshoring provisions.[12] First, to receive half of the $7,500 credit, 50 percent (rising to 100 percent in 2029) of the battery components must be produced in North America. Second, to receive the other half of the credit, 40 percent (rising to 80 percent in 2027) of the critical minerals must be sourced in countries that have a free trade agreement with the United States. In addition, the IRA will have a major effect on critical minerals demand by driving deployment of minerals-intensive manufacturing. The viability of the climate agenda embedded within the IRA depends on metals supply chains.

The need to expand supply chains for transition metals has increased the importance of efforts like the Partnership for Global Infrastructure and Investment (PGII) and the Minerals Security Partnership. The PGII was launched at the 2022 G7 meeting to organize U.S. investment and galvanize allied support. The Minerals Security Partnership brings together like-minded mining countries to set standards for producing, processing, and recycling of transition metals.[13] European Commission President Ursula von der Leyen has argued that global partnerships for clean energy supply chain inputs are a key piece of the EU's industrial strategy.[14] Such efforts build on European efforts to onshore clean energy supply chains through the European Battery Alliance and the Critical Raw Materials Act.

These initiatives are all examples of what we call "joint industrial policy": when states coordinate their industrial strategies at the international level and work together to build supply chains. Joint industrial policy entails states collaborating to create markets in support of net-zero industries at home and secure supplies of needed technologies abroad.

The push for collaborative strategies for critical minerals raises important questions: how much critical minerals could the United States and its partners produce, and where should they focus efforts to diversify and rebalance clean energy supply chains? This paper argues that given existing reserves, it is possible for the U.S. and its key democratic partners to significantly friendshore the production of critical minerals. However, it would require an unprecedented build-out of the mining industry to achieve clean energy targets for 2030.

[11] Kessler, Sarah. 2023. What is 'Friendshoring'? New York Times. https://www.nytimes.com/2022/11/18/business/friendshoring-jargon-business.html

[12] Inflation Reduction Act of 2022. U.S. Public Law 117-169, 136 Stat. 4188. https://www.congress.gov/bill/117th-congress/house-bill/5376/text; U.S. Treasury. 2023. Treasury Releases Proposed Guidance on New Clean Vehicle Credit to Lower Costs for Consumers, Build U.S. Industrial Base, Strengthen Supply Chains. https://home.treasury.gov/news/press-releases/jy1379

[13] U.S. State Department. 2022. Minerals Security Partnership. https://www.state.gov/minerals-security-partnership/

[14] European Commission. 2023. Special Address by President von der Leyen at the World Economic Forum. https://ec.europa.eu/commission/presscorner/detail/en/speech_23_232

The next section lays out the methodology of the study in detail. The following section lays out the findings of two analyses: the reserve analysis and the production analysis. While the conclusions of the reserve analysis are cautiously optimistic regarding the ability of democracies to reshore supply chains, the conclusions of the production study are quite pessimistic. The paper concludes with three implications for joint industrial policy.

## Critical minerals and net-zero supply chains

Our study builds on a number of analyses that have identified a "mining gap."[15] Our study is unique in that it takes a strategic, medium-term perspective focused on democratic countries. First, the potential for friendshoring and other strategic groups has not been specifically modelled. Existing studies focus on world production capability.[16] In the current geopolitical climate, we need to consider subgroups of metal producers.

Second, most existing studies are indexed to the metals needed to achieve net-zero by 2050.[17] However, clean energy technologies and their supply chains are rapidly changing. This will alter metals demand beyond 2030 significantly. For example, cobalt has long been a bottleneck metal in the battery supply chain. Innovators and carmakers conducted concerted efforts to reduce reliance on cobalt, including widespread shifts from NMC 3-3-3 to NMC 8-1-1. Over the course of 2022, these efforts hit the cobalt market, which went into surplus.[18] Meanwhile, silver, widely considered to be plentiful, entered a period of long-term structural deficit.[19] Therefore, most 2050 analyses are likely to be overly pessimistic. Basing a strategy on them could lead to overinvestment. It is important that we model to 2030 in order to understand current needs and support near-term actions to resolve coming bottlenecks.

### Critical minerals demand for 2030 targets

---

[15] Lee, Jordy, Morgan Bazilian, Benjamin Sovacool, Kristen Hund, Simon M. Jowitt, T. P. Nguyen, André Månberger et al. "Reviewing the material and metal security of low-carbon energy transitions." *Renewable and Sustainable Energy Reviews* 124 (2020): 109789; Beylot, Antoine, Dominique Guyonnet, Stéphanie Muller, Stéphane Vaxelaire, and Jacques Villeneuve. "Mineral raw material requirements and associated climate-change impacts of the French energy transition by 2050." *Journal of Cleaner Production* 208 (2019): 1198-1205; Jowitt, Simon M., Gavin M. Mudd, and John FH Thompson. "Future availability of non-renewable metal resources and the influence of environmental, social, and governance conflicts on metal production." *Communications Earth & Environment* 1, no. 1 (2020): 13; Valero, Alicia, Antonio Valero, Guiomar Calvo, and Abel Ortego. "Material bottlenecks in the future development of green technologies." *Renewable and Sustainable Energy Reviews* 93 (2018): 178-200; Watari, Takuma, Keisuke Nansai, and Kenichi Nakajima. "Review of critical metal dynamics to 2050 for 48 elements." *Resources, Conservation and Recycling* 155 (2020): 104669.

[16] Valero (2018), for example, does not break down findings by individual countries.

[17] Lee et al 2020, supra note 15.

[18] Desai, Pratima. 2022. Surpluses for battery material cobalt stretch into horizon. Reuters. https://www.reuters.com/article/cobalt-surplus/surpluses-for-battery-material-cobalt-stretch-into-horizon-idUSKBN2ST1B3

[19] Reuters. 2022. Silver heads for biggest deficit in decades, Silver Institute says. https://www.reuters.com/markets/commodities/silver-heads-biggest-deficit-decades-silver-institute-says-2022-11-18/

In this study, we analyze the amount of accumulated demand for critical minerals necessary to achieve 2030 targets on a 1.5 degrees 2050 pathway, as modelled by IRENA and the IEA.[20] Table 1 shows the installed capacities of wind turbines, solar panels, and EV batteries necessary to meet those 2030 targets.

Table 1. 2030 accumulated demand for wind, solar, and batteries on a 1.5-degrees pathway

| | |
|---|---|
| Onshore Wind (GW) | 2,240 |
| Offshore Wind (GW) | 355 |
| Solar (GW) | 4,470 |
| Batteries (GWh) | 27,080 |
| Vehicles (millions) | 338,500 |

Source: IRENA 2022 and IEA 2022.

The next step of the analysis was to assess the critical minerals that would be needed to produce the technologies outlines in table 1. We built a technology-specific demand schedule based on a review of studies for metals needs in the three supply chains (Table 2).

Table 2. Critical minerals needs for 2030 deployment

| | Wind (t/GW) | Solar (t/GW) | Batteries (t/GWh) | EVs (t/vehicle) | Global 2030 Needs (t) | Democratic 2030 Needs (t) |
|---|---|---|---|---|---|---|
| Boron | 1.9 | | | | 4,969 | 2,683 |
| Chromium | 505 | | | | 1,311,708 | 708,322 |
| Cobalt | | | 46 | | 1,245,680 | 672,667 |
| Copper | 2242 | 3970 | | 69.5 | 40,247,958 | 21,733,897 |
| Graphite | | | 1114 | | 30,180,660 | 16,297,556 |
| Lithium | | | 107 | | 2,884,020 | 1,557,371 |
| Manganese | 786 | | 43 | | 3,205,278 | 1,730,850 |
| Molybdenum | 105 | 5 | | | 296,105 | 159,896 |
| Nickel | 363 | 1 | 368 | | 10,914,172 | 5,893,653 |
| Selenium | | 0.5 | | | 2,123 | 1,147 |
| Silver | 126 | | | | 326,970 | 176,564 |
| Tellurium | | 7.7 | | | 34,575 | 18,671 |
| Tin | | 494 | | | 2,209,655 | 1,193,214 |
| Zinc | 5500 | | | | 14,272,500 | 7,707,150 |

Source: IRENA 2022; Valero 2018; Argonne National Laboratory 2019.

[20] IRENA. 2022. World Energy Transitions Outlook. https://www.irena.org/publications/2022/mar/world-energy-transitions-outlook-2022; IEA. 2022. Net-Zero by 2050. https://www.iea.org/reports/net-zero-by-2050.

To estimate demand for each of the friendshoring groups, we simply multiplied global demand by the percentage of global GDP that group represents. For example, Table 2 shows that since all democratic countries comprise 54% of global GDP, we can expect them to need 54% of global totals.

In our model, wind turbines generate demand for boron, chromium, copper, manganese, molybdenum, nickel, silver, and zinc.[21] The body of a wind turbine is made up of blades, a tower, a hub, and a nacelle, requiring steel, fiberglass, and iron. Solar panels generate demand for copper, molybdenum, nickel, selenium, tellurium, and tin.[22] A standard solar panel consists of a layer of silicon cells, a metal frame, a glass casing, and wiring to direct current flow. In these applications, nickel is used in steel, copper is used in electrical wiring, silver is prized for its conductivity and longevity, tin is used in solder to create electrical connections, and zinc is used in protective coatings.

Silicon solar cells, including crystalline silicon (c-Si) and amorphous silicon (a-Si) type cells, have been around for decades. They have lower costs, because the primary materials involved are silicon and copper. Two other major thin-film photovoltaic semiconductors on the market are cadmium telluride (CdTe) and copper indium gallium diselenide (CIGS). CdTe has a higher theoretical efficiency level due to tellurium's semiconductor properties alloyed with cadmium's high absorption property. CdTe also outperforms traditional silicon cells under harsh climate conditions. However, it is also worth noting the environmental concerns of CdTe panels, as cadmium is a highly toxic product. CIGS cells, on the other hand, are relatively non-toxic. CdTe cells currently comprise 5% of the world's solar panel fleet.[23] We modelled 2030 demand using a fleet comprised of 95% c-Si and 5% CdTe cells. We did this as a conservative estimate to test the easy case for tellurium.

Batteries create demand for lithium, nickel, manganese, cobalt, iron, phosphate, copper, aluminum, and graphite in our model.[24] There are many types of battery chemistries, but we can simplify them into two dominant commercial groups: nickel-rich cathodes and lithium-iron-phosphate (LFP) batteries. While nickel-rich cathodes are prized for their longer ranges, LFP batteries are much cheaper as they use abundant minerals. However, LFP's market share is growing as previous weaknesses have been alleviated. In China, LFP batteries already account for half the EV market.[25] Ford and Tesla have both announced that they will partner with CATL, the Chinese battery giant, to make LFP batteries in the United States.[26] To capture this dynamic and

---

[21] For wind metals needs, we used, Gielen, Dolf. 2021. Critical Materials for the energy transition. IRENA. https://www.irena.org/-/media/Files/IRENA/Agency/Technical-Papers/IRENA_Critical_Materials_2021.pdf

[22] For solar metals needs, we used the metal requirements from Valero et al (2018), supra note 15.

[23] Department of Energy. 2022. Cadmium Telluride Solar Panels. https://www.energy.gov/eere/solar/cadmium-telluride

[24] We used Argonne National Laboratory's BatPac 4.0 model. https://www.anl.gov/cse/batpac-model-software.

[25] Shanghai Metals Market. 2023. CPCA: LFP Batteries Account for 55.6% of Market Share in 2022. https://news.metal.com/newscontent/102075553/cpca-lfp-batteries-account-for-556-of-market-share-in-2022

[26] South China Morning Post. 2023. Tesla in talks with CATL, China's leading EV battery maker, on building plant in the US. https://www.scmp.com/business/companies/article/3215488/tesla-talks-catl-chinas-leading-ev-battery-maker-building-plant-us

keep needs for nickel and cobalt conservative, our model uses a simple 50% nickel-manganese-cobalt (8-1-1) and 50% LFP battery fleet.

### Critical Mineral Reserves in Democratic Countries and other friendshoring groups

The final step in the analysis was to compare 2030 metals needs with existing reserves in democratic countries. To provide a clear, independent definition of democracies, we categorized democratic countries into liberal democracies (LD, LD-, LD+) and electoral democracies (ED, ED-, ED+) according to V-Dem's classification measures (see Appendix A for the whole list).[27] A minus sign indicates uncertainty, meaning that the country could belong to the lower category, while the plus sign indicates that the country could belong to the higher category.

We used data on current global mineral reserves from the U.S. Geological Survey's Mineral Commodity Summaries.[28] We then calculated the total reserves of three groups of countries: all democracies, stable democracies (which excludes LD-, ED, ED-), and free trade countries under the Inflation Reduction Act (IRA). For the latter, we used the official list of countries from the Treasury guidance.[29]

The core test of this study is whether existing reserves in friendshoring groups are sufficient to meet accumulated demand in the 1.5-degree 2030 scenario from Table 2. This is an easy test for two reasons. First, reserves are the portion of mining resources that are considered economically viable. However, the viability of mineral resources changes based on commodity prices and demand forecasts. Indeed, empirical research on reserves indicates that for most metals, reserves stay constant.[30] This reflects the steady conversion of resources to reserves over time. Mineral resources beyond reserves certainly exist. Second, many of the metals in this study have competing applications. Thus, even if clean energy demand does not use up the reserves, other applications could.

We simplify the complexities of demand in other sectors, following Valero et al, by assuming that material demand in other sectors will remain constant, and this production will be covered by the steady conversion of resources in reserves.[31] Thus, the logic of the test here is that existing reserves must be able to cover the additional demand that will be imposed by a 1.5-degree compatible deployment of clean energy technologies. This would cover the worst case scenario

---

[27] V-Dem Institute. 2022. Democracy Report 2022. https://v-dem.net/media/publications/dr_2022.pdf

[28] USGS. 2022. Mineral Commodities Summaries. https://pubs.er.usgs.gov/publication/mcs2022. For aluminum, cement, and magnesium, there is no available reserve data because there is sufficient supply. We dropped them from the analysis.

[29] As at May 1, 2023. This includes Japan, but not the EU. U.S. Treasury. 2023. Treasury Releases Proposed Guidance on New Clean Vehicle Credit to Lower Costs for Consumers, Build U.S. Industrial Base, Strengthen Supply Chains. https://home.treasury.gov/news/press-releases/jy1379

[30] Jowitt, S.M., Mudd, G.M. & Thompson, J.F.H. 2020. Future availability of non-renewable metal resources and the influence of environmental, social, and governance conflicts on metal production. Commun Earth & Environment 1(13) https://doi.org/10.1038/s43247-020-0011-0

[31] Valero et al 2018, supra note 15.

in which no new reserves are established beyond those needed to cover existing demand. This easy test allows us to identify which metals are likely to be subject to shortfalls, but should not be considered as providing a precise estimate of metals availability.

Recycling is an important part of the metal economy. However, large volumes of recycled metals will not be available until after 2035. Vehicles have an average life of 12 years, so recycled batteries will only be available 12 years after vehicle sales.[32] This lag means that it will take time for recycled metals to significantly impact demand. Materials from wind and solar installations will also be important, but their lifespans are even longer. Recycling volumes are highly unlikely to match new extraction before 2040. For this study, which is indexed to 2030 targets, we did not consider recycling.

## Findings: Reserves analysis

This study finds that reserves in all democratic countries cover both democratic and global 2030 deployment needs. Table 3 compares the mining reserves of all democratic countries to democratic and global demand. There are ample reserves to meet 2030 targets in all but one metal: tellurium, which is a key input for innovative American solar panels.

Table 3. Critical Minerals Potential in All Democratic Countries

| | Democratic Countries' Reserves (kt) | 2030 Global Demand, 1.5° Scenario (kt) | Surplus or Deficit (kt) | 2030 Democratic Demand, 1.5° Scenario (kt) | Surplus or Deficit (kt) |
|---|---|---|---|---|---|
| Boron | 79,000 | 5 | 78,995 | 3 | 78,997 |
| Chromium | 213,620 | 1,312 | 212,308 | 708 | 212,912 |
| Cobalt | 2,302 | 1,246 | 1,056 | 673 | 1,629 |
| Copper | 1,235,800 | 23,568 | 1,212,232 | 12,727 | 1,223,073 |
| Graphite | 75,200 | 30,181 | 45,019 | 16,298 | 58,902 |
| Lithium | 17,255 | 2,884 | 14,371 | 1,557 | 15,698 |
| Manganese | 1,338,000 | 3,205 | 1,334,795 | 1,731 | 1,336,269 |
| Molybdenum | 6,876 | 296 | 6,580 | 160 | 6,716 |
| Nickel | 60,000 | 10,914 | 49,086 | 5,894 | 54,106 |
| Selenium | 32 | 2 | 30 | 1 | 31 |
| Silver | 388 | 327 | 61 | 177 | 211 |
| Tellurium | 11 | 35 | **-24** | 19 | **-8** |
| Tin | 2,330 | 2,210 | 120 | 1,193 | 1,137 |
| Zinc | 129,900 | 14,273 | 115,628 | 7,707 | 122,193 |

[32] Bureau of Labour Statistics. 2022. Average Age of Automobiles and Trucks in Operation in the United States. https://www.bts.gov/content/average-age-automobiles-and-trucks-operation-united-states

Note: Democratic countries included are Argentina, Armenia, Australia, Austria, Belgium, Bhutan, Bolivia, Brazil, Bulgaria, Canada, Chile, Finland, France, Georgia, Germany, Ghana, Iceland, Indonesia, Japan, Mexico, Mongolia, Nigeria, Norway, Peru, Poland, Portugal, Senegal, Sierra Leone, South Africa, South Korea, Spain, Sri Lanka, Sweden, Ukraine, and the United States.

Source: Johns Hopkins University's Net Zero Industrial Policy Lab and the U.S. Geological Survey

However, table 4 shows that when countries coded as fragile democracies are removed from the friendshoring group, significant shortfalls emerge in graphite, silver, and tin. The key countries with large reserves affecting these outcomes are Argentina, Brazil, Bolivia, Indonesia, Mexico, Peru, Poland, and South Africa.

Table 4. Critical Minerals Potential in Stable Democratic Countries

| | Stable Democratic Countries' Reserves (kt) | 2030 Demand, 1.5° Scenario (kt) | Surplus or Deficit (kt) | 2030 Democratic Demand, 1.5° Scenario (kt) | Surplus or Deficit (kt) |
|---|---|---|---|---|---|
| Boron | 75,000 | 5 | 74,995 | 3 | 74,997 |
| Chromium | 13,620 | 1,312 | 12,308 | 708 | 12,912 |
| Cobalt | 1,620 | 1,246 | 374 | 673 | 947 |
| Copper | 1,050,800 | 23,568 | 1,027,232 | 12,727 | 1,038,073 |
| Graphite | 600 | 30,181 | **-29,581** | 16,298 | **-15,698** |
| Lithium | 14,960 | 2,884 | 12,076 | 1,557 | 13,403 |
| Manganese | 283,000 | 3,205 | 279,795 | 1,731 | 281,269 |
| Molybdenum | 4,196 | 296 | 3,900 | 160 | 4,036 |
| Nickel | 23,000 | 10,914 | 12,086 | 5,894 | 17,106 |
| Selenium | 16 | 2 | 14 | 1 | 15 |
| Silver | 142 | 327 | **-185** | 177 | **-35** |
| Tellurium | 7 | 35 | **-27** | 19 | **-11** |
| Tin | 560 | 2,210 | **-1,650** | 1,193 | **-633** |
| Zinc | 87,100 | 14,273 | 72,828 | 7,707 | 79,393 |

Notes: Countries classified by the Varieties of Democracy (V-Dem) Institute as fragile democracies are not included. The stable democratic countries included are Australia, Belgium, Bhutan, Canada, Chile, Finland, France, Germany, Ghana, Iceland, Japan, Norway, Portugal, South Korea, Senegal, Spain, Sweden, and the United States.

Source: Johns Hopkins University's Net Zero Industrial Policy Lab and the U.S. Geological Survey

The friendshoring group in Table 5 is comprised of U.S. free trade partners, which the IRA EV incentives favor. This friendshoring group faces shortfalls in the same areas as the stable democracies group with one exception. The free trade partners group includes Peru, which helps to alleviate the shortfall in silver.

Table 5. Critical Minerals Potential in Countries with U.S. Free Trade Agreements

| | Free Trade Countries' Reserves (kt) | 2030 Demand, 1.5° Scenario (kt) | Surplus or Deficit (kt) | 2030 Free Trade Countries' Demand, 1.5° Scenario (kt) | Surplus or Deficit (kt) |
|---|---|---|---|---|---|
| Boron | 79,000 | 5 | 78,995 | 2 | 78,998 |
| Chromium | 620 | 1,312 | **-692** | 485 | 135 |
| Cobalt | 1,620 | 1,246 | 374 | 461 | 1,159 |
| Copper | 1,180,800 | 23,568 | 1,157,232 | 8,720 | 1,172,080 |
| Graphite | 3,100 | 30,181 | **-27,081** | 11,167 | **-8,067** |
| Lithium | 14,900 | 2,884 | 12,016 | 1,067 | 13,833 |
| Manganese | 275,000 | 3,205 | 271,795 | 1,186 | 273,814 |
| Molybdenum | 6,626 | 296 | 6,330 | 110 | 6,516 |
| Nickel | 23,000 | 10,914 | 12,086 | 4,038 | 18,962 |
| Selenium | 29 | 2 | 27 | 1 | 28 |
| Silver | 299 | 327 | **-28** | 121 | 178 |
| Tellurium | 7 | 35 | **-28** | 13 | **-6** |
| Tin | 710 | 2,210 | **-1,500** | 818 | **-108** |
| Zinc | 121,400 | 14,273 | 107,128 | 5,281 | 116,119 |

Notes: Countries included are Australia, Bahrain, Canada, Chile, Japan, Mexico, Morocco, Peru, South Korea, and the United States.

Source: Johns Hopkins University's Net Zero Industrial Policy Lab and the U.S. Geological Survey

## Findings: Production analysis

Reserves data tells us whether accumulated demand would eliminate known reserves. But to assess the real-world viability of friendshoring groups, we have to look at actual production. To get at this, we set out to build a measure of annual primary production to a measure of annual demand.[33]

Our measure of annual production draws on the insights of Jessica Jewell work on technology s-curves.[34] By looking at empirical growth rates Jewell's studies give a more realistic sense of whether clean energy technology deployment can happen on the scale necessary to meet climate targets.

[33] Valero 2018, supra note 15. Primary production here includes only the extraction of the minerals; it does not include processing capacity, where China leads the world.
[34] Cherp, Aleh, Vadim Vinichenko, Jale Tosun, Joel A. Gordon, and Jessica Jewell. 2021. "National growth dynamics of wind and solar power compared to the growth required for global climate targets." *Nature Energy* 6, no. 7: 742-754.

In a similar vein, we scaled annual mining production according to observable growth rates from the last commodity supercycle.[35] The last commodity supercycle took place in the 1990s and 2000s, as Chinese demand drove a huge expansion in mining. We used the five-year average from the beginning of the commodity supercycle s-curve (2001-2009) to scale annual production from 2021 levels to a projected 2030 production.

To estimate annual demand, we took the cumulative deployment targets from IRENA and IEA and calculated an annual production ramp, with a linear compound annual growth rate that would achieve the targets. Table 6 compares the 2030 annual production number in this schedule to the 2030 annual projected production.

Table 6. Projected Critical Minerals Production in All Democratic Countries

| | **2021 Production (kt)** | **2030 Projected Production (kt)** | **2030 Democratic Demand 1.5° Scenario (kt)** | **Demand as a percentage of current production** | **Demand as a percentage of projected additional production** |
|---|---|---|---|---|---|
| Boron | 751 | 990 | 0.5 | 0.07% | 0.21% |
| Chromium | 20,300 | 27,223 | 134 | 1% | 2% |
| Cobalt | 13 | 17 | 122 | **936%** | **3040%** |
| Copper | 12,410 | 16,352 | 5,120 | **41%** | **130%** |
| Graphite | 115 | 151 | 2,947 | **2562%** | **8185%** |
| Lithium | 90 | 118 | 282 | **313%** | **1006%** |
| Manganese | 12,800 | 16,866 | 322 | 3% | 8% |
| Molybdenum | 162 | 214 | 31 | 19% | 59% |
| Nickel | 1,408 | 1,855 | 1,070 | **76%** | **239%** |
| Selenium | 1.5 | 2 | 0.25 | 16% | 54% |
| Silver | 15 | 21 | 33 | **223%** | **557%** |
| Tellurium | 0.17 | 0.22 | 4 | **2419%** | **7816%** |
| Tin | 151 | 198 | 260 | **173%** | **547%** |
| Zinc | 5,340 | 7,036 | 1,458 | **27%** | **86%** |

Notes: Projected production in 2030 is based on high historical growth rates. Projected demand for democratic countries in 2030 is based on a 1.5-degrees-Celsius scenario. Democratic countries included are Argentina, Armenia, Australia, Austria, Belgium, Bhutan, Bolivia, Brazil, Bulgaria, Canada, Chile, Finland, France, Georgia, Germany, Ghana, Iceland, Indonesia, Japan, Mexico, Mongolia, Nigeria, Norway, Peru, Poland, Portugal, Senegal, Sierra Leone, South Africa, South Korea, Spain, Sri Lanka, Sweden, Ukraine, and the United States.

Source: Johns Hopkins University's Net Zero Industrial Policy Lab and the U.S. Geological Survey.

[35] Austrian Federal Ministry of Finance. 2022. World Mining Data. https://www.world-mining-data.info/?World_Mining_Data___Data_Section

To assess which metals are likely to be supply-constrained on an annual basis, we looked at two indicators. First, we analyzed annual demand in democratic countries with a percentage of 2021 production. This gives a sense of the scale of the production challenge. On this indicator, 25 percent or above is concerning. In the case of graphite, 2030 demand requires supply chains 2,500 percent of the current size. A massive build-out of graphite is required.

Second, we compared annual demand to the additional production created by scaling according to the rates of the last commodity supercycle. The assumption here is that existing production is needed elsewhere in the economy, so only new production is available. Here, any number over 100 percent represents a shortfall.

The findings are stark: even after a major mining expansion, there are significant shortfalls in cobalt, copper, graphite, lithium, nickel, silver, tellurium, and tin.

The liability of nickel emerges despite the fact that, as noted above, the model reduces nickel-rich batteries to 50 percent of the battery fleet, with the world relying on iron-phosphate batteries for the other 50 percent. Further action to reduce reliance on nickel, such as prioritizing hydrogen fuel cells for long distance trucking, may be required. This suggests that nickel projects in friendly countries and a processing project inside Indonesia, which imposes an export ban on raw nickel, should be urgent priorities for the U.S.-led global partnerships.[36]

The core finding of the production analysis is that scaling mineral production to meet 2030 needs is an immense challenge. Any democratic friendshoring group will struggle to meet internal demand. Thus, while all democratic countries could achieve critical mineral independence based on reserves, increasing production to achieve clean energy targets for 2030 would require unprecedented action.

If real supply chain diversification is to be achieved, a clear and coherent strategy for focusing and aligning joint industrial policies among the United States and its partners is needed.

## Conclusions

This study shows that the US and its key partners have the reserves to friendshore production in a meaningful way. However, the real challenge lies in scaling production. An unprecedented build-out of the mining industry would be needed to achieve real diversification. To achieve 2030 friendshoring goals, the United States and its partners have to build primary production capacity at a rate faster than that seen in the last commodity supercycle. However, a massive

[36] Tritto, Angela. 2023. How Indonesia Used Chinese Industrial Investments to Turn Nickel into the New Gold. https://carnegieendowment.org/2023/04/11/how-indonesia-used-chinese-industrial-investments-to-turn-nickel-into-new-gold-pub-89500

mining build-out is subject to social, environmental, and political constraints. Protests and legal challenges can slow mining development.[37]

Success will require nothing less than a highly coordinated joint industrial strategy that aligns and focuses global investment. However, existing legislation does not include funding for what was called the Build Back Better World agenda. Without this additional support, the US will need to rely on existing instruments for foreign industrial policy, such as the Export-Import Bank and Development Finance Corporation.

A targeted, strategic approach to global investment is necessary to rapidly diversify supply chains. This study can support efforts for global industrial policy by identifying priorities for the PGII and the Minerals Security Partnership. It lays out quantitative targets for development programs and identifies which metals that are likely to face shortfalls.

Second, the study identifies which countries are likely to be the linchpins of the transition metals market. Indonesia (which has large reserves of nickel and tin), Peru (silver), Brazil (graphite), and Türkiye (graphite and chromium) are all likely to play a significant role. Given that they already partner with the United States and other democracies in the security and economic domain, these countries should be a priority for engagement efforts by the U.S. and its allies. The key will be ensuring that these countries have the policy space to articulate and pursue their own goals. They have to see value of being part of global supply chain partnerships, and that value is likely to be cashed out in development and autonomy.

Third, the study has implications for how countries can pursue and coordinate industrial strategies. As suggested above, the demand for nickel can be reduced by incentivizing hydrogen use in some road applications. Graphite can potentially be substituted with silicon and other anode materials. Finally, more ambitious policy proposals, such as significantly reducing car usage and sales, will lower demand for battery metals and potentially decrease electricity demand, reducing the need for solar panels and turbines.[38]

*Bentley Allan is the director of the Net Zero Industrial Policy Lab and an associate professor of political science at Johns Hopkins University.*

*Hannah Jeong is a research associate in the Net Zero Industrial Policy Lab and a recent graduate of Johns Hopkins University.*

*Cathy Wang is a research associate in the Net Zero Industrial Policy Lab and is pursuing an undergraduate degree in international studies and applied math at Johns Hopkins University.*

---

[37] Reuters. 2022. Green Activists Stage Tent Protest. https://www.reuters.com/business/environment/green-activists-stage-tent-protest-halt-lithium-exploration-serbia-2022-02-11/; Reuters. 2022. U.S. judge orders waste rock study for Thacker Pass lithium project. https://www.reuters.com/legal/us-judge-orders-fresh-review-part-lithium-americas-nevada-permit-2023-02-07/

[38] Riofrancos, Thea, Alissa Kendall, Kristi K. Dayemo, Matthew Haugen, Kira McDonald, Batul Hassan, and Margaret Slattery. 2023. Achieving Zero Emissions with More Mobility Less Mining. https://www.climateandcommunity.org/more-mobility-less-mining

## Appendix A: Democratic Countries

| Liberal Democracies | |
|---|---|
| Australia | LD |
| Barbados | LD- |
| Belgium | LD |
| Bhutan | LD- |
| Botswana | LD- |
| Canada | LD |
| Chile | LD- |
| Costa Rica | LD |
| Cyprus | LD- |
| Denmark | LD- |
| Estonia | LD |
| Finland | LD |
| France | LD- |
| Germany | LD |
| Greece | LD- |
| Iceland | LD |
| Ireland | LD |
| Israel | LD |
| Italy | LD- |
| Japan | LD |
| Latvia | LD |
| Luxembourg | LD |
| Netherlands | LD |
| New Zealand | LD- |
| Norway | LD- |
| Seychelles | LD |
| South Korea | LD |
| Spain | LD |
| Sweden | LD |
| Switzerland | LD |
| Taiwan | LD |
| United Kingdom | LD |
| USA | LD |
| Uruguay | LD- |

| Electoral Democracies | | | |
|---|---|---|---|
| Argentina | ED | Niger | ED- |
| Armenia | ED | North Macedonia | ED |
| Austria | ED | Panama | ED |
| BiH | ED- | Paraguay | ED- |
| Bolivia | ED- | Peru | ED |
| Brazil | ED | Poland | ED |
| Bulgaria | ED | Portugal | ED+ |
| Burkina Faso | ED | Romania | ED |
| Cape Verde | ED | S.Tomé & P. | ED+ |
| Colombia | ED | Senegal | ED+ |
| Croatia | ED+ | Sierra Leone | ED- |
| Czech Republic | ED | Slovakia | ED+ |
| Dominican Republic | ED | Slovenia | ED |
| Ecuador | ED | Solomon Islands | ED |
| Georgia | ED | South Africa | ED |
| Ghana | ED+ | Sri Lanka | ED |
| Guatemala | ED- | Suriname | ED |
| Guinea-Bissau | ED- | Timor-Leste | ED |
| Guyana | ED- | Trinidad and Tobago | ED+ |
| Indonesia | ED | Ukraine | ED- |
| Jamaica | ED | Vanuatu | ED+ |
| Kosovo | ED | | |
| Lesotho | ED | | |
| Liberia | ED | | |
| Lithuania | ED+ | | |
| Malawi | ED+ | | |
| Maldives | ED | | |
| Malta | ED+ | | |
| Mauritius | ED- | | |
| Mexico | ED | | |
| Moldova | ED+ | | |
| Mongolia | ED | | |
| Namibia | ED+ | | |
| Nepal | ED | | |

Source: V-Dem Institute. 2022. Democracy Report 2022. https://v-dem.net/media/publications/dr_2022.pdf.