Environmental Science & Technology

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Perspective

Closing the Infrastructure Gap for Decarbonization: The Case for an Integrated Mineral Supply Agreement

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Cite This: *Environ. Sci. Technol.* 2022, 56, 15280−15289

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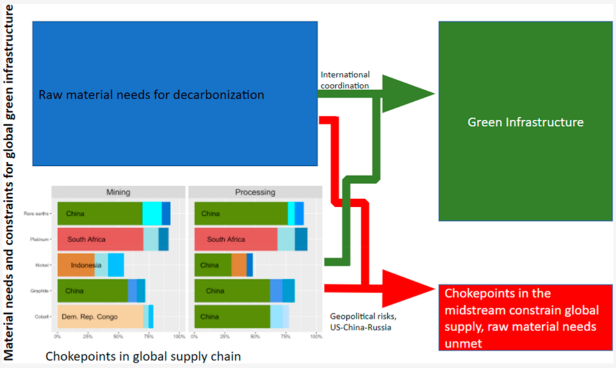
ABSTRACT: Significant amounts of feedstock metals will be required to build the infrastructure for the green energy transition. It is currently estimated, however, that the world may be facing an "infrastructure gap" that could prevent us from meeting United Nations Sustainable Development Goal targets. Prior investigations have focused on the extractive aspects of the mining industry to meet these targets and on looming bottlenecks and regional challenges in these upstream market segments. Scant attention has been paid to the downstream processing segments of the raw materials value chain, which also has a high degree of market concentration. Growing international tensions and geopolitical events have resulted in a shift toward "reshoring" and "near-shoring" of mining processing capabilities as regional powers attempt to make metal supply chains more secure. While increasing resilience, these shifts can also dilute the overall effectiveness of the global mining supply network and subsequently hamper the world's ability to close the green energy infrastructure gap. We argue that broadening the remit of the International Renewable Energy Agency (IRENA) to include coordinating these mission-critical metal processing functions can mitigate these issues. The G20 is one potential forum for enabling an integrated mineral processing agreement under the auspices of IRENA.



KEYWORDS: *critical materials, energy transition, climate change, decarbonization, infrastructure gap*

1. INTRODUCTION

The immediate threat of irreversible climate change underscores the importance of rapid investment in solar, wind, and energy storage infrastructure.[1] However, the global "infrastructure gap" may prevent the world from meeting the targets set forth by the United Nations Sustainable Development Goals by 2030.[2] An immediate challenge is how to acquire the unprecedented volumes of raw materials essential to close the infrastructure gap and decarbonize global energy systems in a sustainable manner. How we address this gap at local and national levels is the subject of considerable debate. The international dimension and complexity of globally connected and interdependent raw materials and advanced materials supply chains and ecosystems are often underestimated. While there has been a policy focus on recycling, efficiency, and reductions in material intensity—efforts that collectively contribute to the concept of the circular economy[3]—projected gains are not expected to meet most demand forecasts,[4] further exacerbating the problem.

At the same time, we are confronted with a protracted geopolitical conflict between China and the West (specifically, the U.S.). This destabilizes four decades of global economic integration around the global supply chains for raw materials, many of which depend on Chinese scientific and manufacturing expertise in the upstream and midstream parts of raw materials' value chains. States and private companies have developed technological components essential to closing the infrastructure gap and meeting decarbonization targets around this supply nexus. Yet, the Russia−Ukraine war and the COVID pandemic exposed the fragility of supply chains dominated by a strong actor. It vividly demonstrated the fragility of the European energy supply system and adversely impacted major industrial powers because of supply disruptions for a number of raw materials vital to the global green transition. Moreover, partial decoupling of U.S. and European economies from China may align with broader goals to reinvigorate the domestic manufacturing capacity or build

Published: October 26, 2022

https://doi.org/10.1021/acs.est.2c05413
Environ. Sci. Technol. 2022, 56, 15280−15289

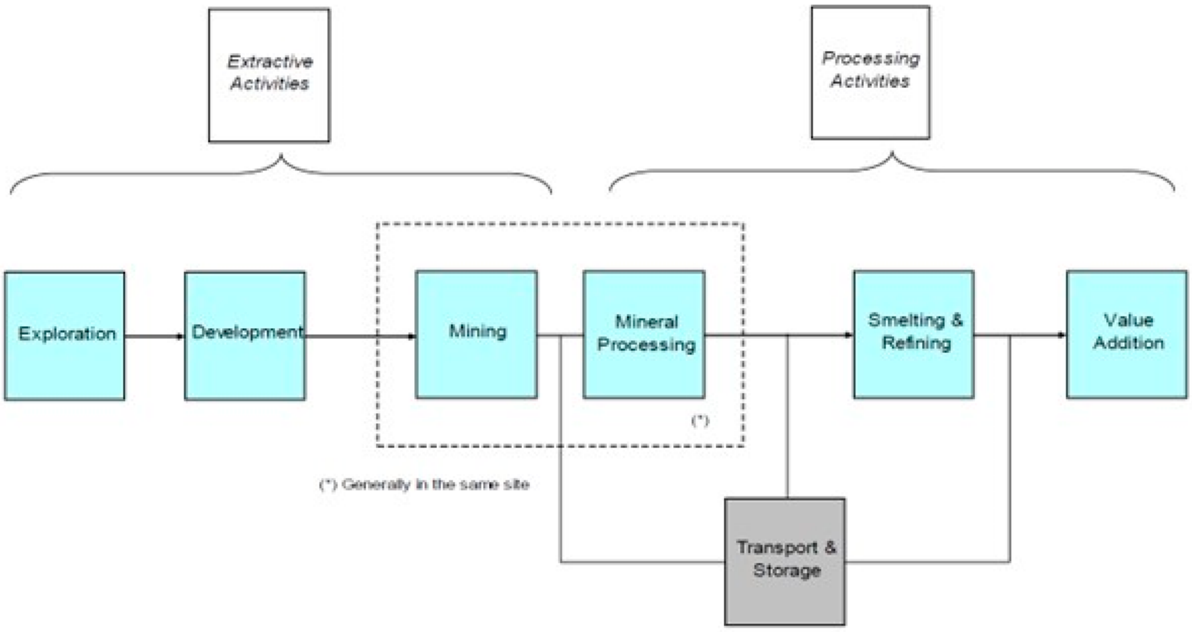


Figure 1. Mining industry structure.[10]

regional capabilities to help cut emissions from transoceanic trade. The material constraints linked to a lack of local mining, processing, and manufacturing capacities and logistics networks would need to be considered early in the political decision-making process, as they limit what is practically possible within the timeline needed for action on climate change.

Importantly, most countries have emission reduction targets outlined in their Nationally Determined Contributions (NDCs) under the Paris Climate Agreement. And there is a proliferation of new emission reduction and technology targets that seem disconnected from current and projected availability of raw materials. Achieving these targets will require major resource inputs and strategies, such as the energy transition policies described in China's 14th five-year plan, Japan's Green Growth Strategy, the American Green New Deal, and the European Green Deal.

Metals figure prominently in these resource strategies, but much of the research on critical metals has been at the level of the upstream mining and extractive stages of the resource supply chain. There has been a preoccupation with mining concerns for cobalt in the Democratic Republic of Congo (DRC)[5] or with source risk more broadly due to conflict[6] or concerns about biodiversity loss from mining exploration.[7] The weighting of risk from African sources led, for example, to the listing of aluminum (from Guinea), platinum (from South Africa), and cobalt from (DRC) as having particularly high supply fragility scores.[8] A growing genre of Geographic Information Systems (GIS)-informed literature that maps the biodiversity impacts of mining exploration[9] has consequently been added to the predominant literature on mining risks.

However, as shown in Figure 1, the sequence of activities that needs to occur in the mining supply chain to usefully deliver metals to the marketplace involves more than just these upstream mining extractive stages. Processing stages further downstream such as smelting and refining must also occur. The literature exploring the feedstock metal inputs that will be required for global decarbonization has shone a helpful amount of light on the upstream extractive parts of the industry's value chain but has paid far less attention to the downstream processing end.

This perspective piece will accordingly begin by explaining how much metal will be required to close the green energy infrastructure gap and then shed light on the high degree of market concentration in the processing parts of the mining industry. Next, we will show how growing international tensions and recent geopolitical events have resulted in a pronounced shift toward "reshoring" and "near-shoring" of mining processing capabilities as regional powers attempt to make metal supply chains more secure. We will then explain how these shifts will impair the overall effectiveness of the global mining supply network and, in so doing, impede the world's ability to close the green energy infrastructure gap. We will then conclude with a recommendation to broaden the remit of the International Renewable Energy Agency (IRENA) to include coordinating these mission-critical metal processing functions on a global level and offer specific policy suggestions to deliver this outcome.

2. PAST RESEARCH

2.1. Material Requirements for Green Infrastructure Targets. A number of policy resolutions have set targets for significantly reducing greenhouse gas emissions by 2030 and achieving carbon neutrality by 2050. To make its case for adopting what is colloquially known as the Green New Deal, the U.S. House of Representatives Resolution HR 109 of 2019 pointed to the findings of the 2018 UNFCC report according to which avoiding the worst impacts of climate change will require global reductions of anthropogenic greenhouse gas emissions by 40–60% of 2010 levels by 2030 and net zero global emissions by 2050.[11] Under the European Green Deal, the EU aims to reduce greenhouse gas emissions by 55% by 2030 compared to 1990 levels, and by 2050 the bloc's goal is to reach climate neutrality. The success of such green plans necessitates a rapid roll-out of renewable energy generation, transmission, and storage infrastructure—and the litera-

https://doi.org/10.1021/acs.est.2c05413
Environ. Sci. Technol. 2022, 56, 15280−15289

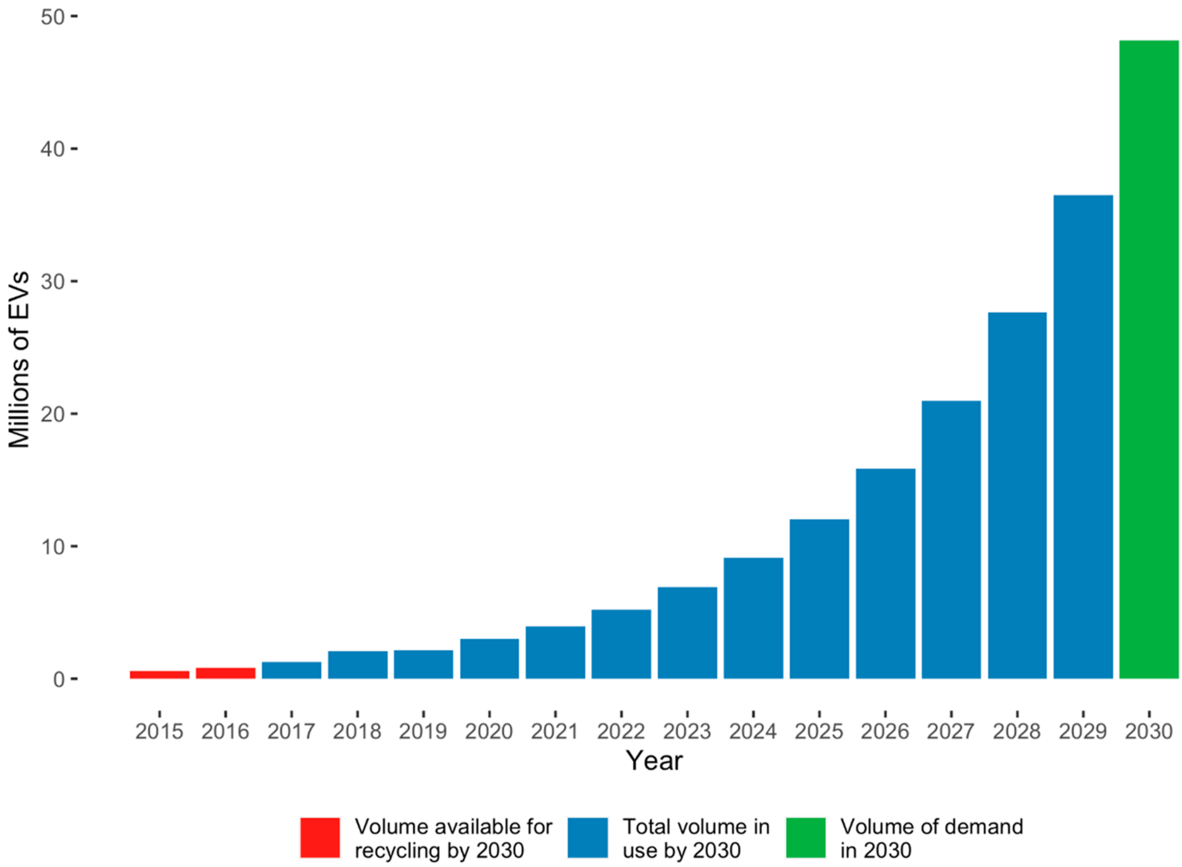


Figure 2. Recycling materials potential of EVs from 2015 to 2030. This assumes a lifetime of 14 years. Analysis by authors using historical data for the period 2015−2021. Figures for 2022−2030 are based on the same 32% compound annual growth rate applied in the International Energy Agency's "Sustainable Development Scenario."

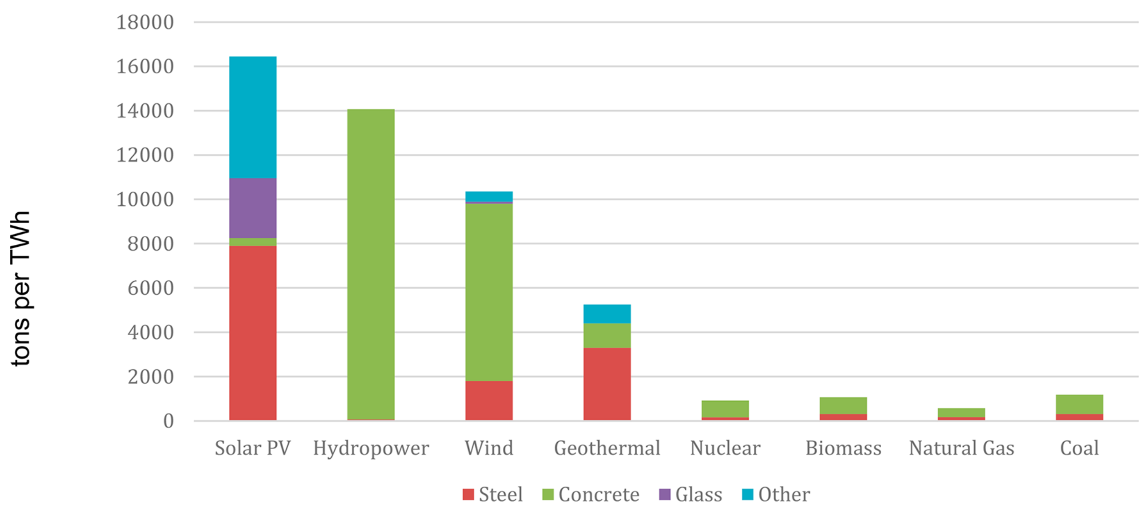


Figure 3. Materials needed for different forms of power generation. Figure based on data from U.S. Department of Energy Quadrennial Energy Review 2015.

ture[12,13] has quite thoroughly enumerated the significant amounts of feedstock metals that will be required to operationalize these plans.

The list of metals necessary for the green transition includes the rare earth varieties but goes much further. Platinum group metals are also worthy of significant attention on account of the fact that they are vital for the hydrogen economy, particularly fuel cells.[14] Like rare earth metals, their primary extraction and processing are highly concentrated in a relatively small number of locations like South Africa and Russia, thereby resulting in a high supply risk.[15] The major difference to rare earths is their high intrinsic market value, which has led to the emergence of a robust recycling market for these metals capable of supplying considerable quantities of platinum from secondary sources such as recycled auto catalysts.[16]

Other key materials enabling the green transition are those found in batteries, e.g., battery-grade lithium, cobalt, nickel,

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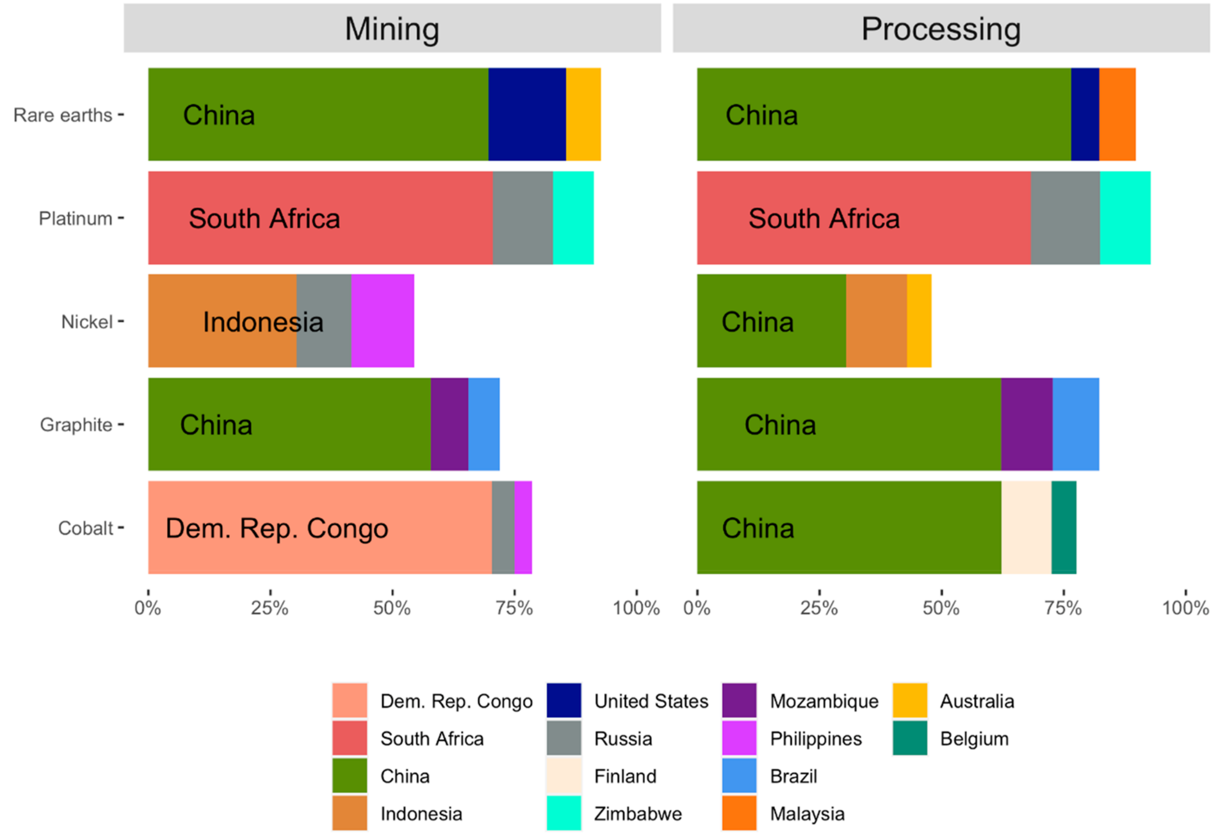

Figure 4. National shares of mining and processing—top three producers. Data sources: USGS Mineral Commodity Summaries 2021; British Geological Survey World Mineral Production 2021; Rare earth processing data shows total rare earth processing capacity from Adamas, 2016, Roskill 2018, IVL Swedish Environmental Research Institute, 2016; Graphite data include natural mined and synthetic graphite; synthetic graphite data reflect export data from World Integrated Trade Solution; platinum data from JM PGM Market report 2021.

manganese, and graphite (natural and synthetic).[17] All of these materials are currently extracted in various places around the world, but the processing of these materials into battery electrode materials is highly dominated by Chinese organizations, followed by South Korea and Japan. However, due to a proactive industrial policy, the outlook for European production facilities in this sector is promising. And while the focus of much of the discussion in this area has been on batteries for electric cars, it is also important to recognize that the supply chains of decarbonization technologies for shipping and air travel will require fluid fuels like hydrogen that carry with them metal requirements of their own. For example, platinum is frequently used as a catalyst for producing gaseous hydrogen, and rare earth metals are a promising option for hydrogen storage materials.

Improving recycling systems for these metals is an obvious strategy for increasing their availability, but, for the next few decades, this approach can supply only minor amounts of raw materials compared to the large amounts needed for any significantly growing industrial sector. Once significant numbers of electric vehicles and wind turbines reach the end of their lives and renewable energy moves into a saturated market, recycling can make a larger contribution to meeting the material demand for new equipment. Estimating recycling stocks of modular and reliable sources of metals such as electric vehicle (EV) batteries can provide us with a planning horizon to consider, as shown in Figure 2. With an expected life of 14 years, there will be a significant gap between the volume of available recycled battery material and the requisite demand for the metals by 2030. At least another two decades would be needed before the recycled stock could compete effectively with mined metals to meet this demand.[18]

While the proliferation of green tech alternatives like EVs explains much of the increases in the quantity of metals being demanded by the market, the pronounced rise in material intensity is also very important. Solar photovoltaic cells require the largest quantity of material per unit energy delivery, followed by hydropower and wind. Figure 3 shows the material intensity versus energy delivery for various energy sources. Renewable energy sources have underappreciated considerations that are often missed in overall cost projections and pollution control benefits.

Given the overall material intensity of the green energy transition, the World Bank's Climate Smart Mining program undertook a series of assessments of critical minerals sourcing. This further highlighted the scale of the challenge. Based on their analysis, the demand for the following three materials will grow by more than 450% by 2050 in comparison with 2018 production levels: (a) graphite, (b) lithium, and (c) cobalt. For indium and vanadium, the rise would be over 200% and for nickel around 100%.[19]

2.2. Diversification Along the Supply Chain. The supply chains of many of the minerals critical for green energy infrastructure are geographically concentrated. What is less understood among policymakers, however, is that this concentration occurs in the midstream and downstream parts of the critical minerals supply chain as well as the extractive activities in the upstream. Figure 4 shows where the majority of

https://doi.org/10.1021/acs.est.2c05413
Environ. Sci. Technol. 2022, 56, 15280−15289

these activities occur for several key types of metals: rare earths essential in magnets for electric motors; cobalt, graphite, and nickel for batteries and energy storage; and platinum, which is used in hydrogen fuel cells. With the exception of nickel, both the mining and processing stages of production are highly concentrated for these materials. The top producing nation for each material accounts for 60% or more of world output, while the top three countries account for more than three-quarters of production. This is true both in the mining and midstream processing stages, indicating that a disruption in that country could have major destabilizing global effects. For example, a disruption to platinum mining in South Africa could affect over 70% of the global supply in mined platinum, and almost 70% of processed platinum, slowing or stopping the potential for hydrogen fuel cells. Similarly, around 70% of global cobalt supply is mined in the DRC, and 62% is processed in a single country: China.

To establish supply chain resiliency to meet policy targets for solar, wind, and electric vehicles, it is necessary to diversify the supply chain, in mining as well as midstream processing and to include recycling. Available deposits are more geographically dispersed than current mining sites. Cobalt, for instance, can be found in a number of countries, but the DRC remains the dominant producer.[20] Diversifying mining should be followed by diversifying midstream processing to avoid bottlenecks.

3. CHANGING GEOPOLITICAL ENVIRONMENT

3.1. Challenge of Chinese Decoupling on Mineral Supply Chains. Over the past decade, advanced industrial nations' discomfort with dependence on China for critical materials has grown. China's dominant position across the supply chain[21] and more recent geopolitical tensions have shaken the broad economic and technological ties between the West and China,[22] which have in turn brought into question the case for managing these problems on a global level.[23] Economic statecraft has become an exceedingly powerful weapon. Decoupling from China scenarios have both intensified and proliferated in the past 18 months. For instance, disruptions caused by the worldwide COVID-19 pandemic[24] and fraught geopolitics have heightened the U.S. and EU's collective resolve to reduce their reliance on China's critical mineral value chains. However, unlike the former Soviet Union, China has maintained broad economic ties with the U.S. and many other Western countries,[25] making a total decoupling far too costly.[26] In fact, the oft-derided "cheap Chinese imports" played a key role in insulating consumers in these countries from the effects of long-term inflation combined with a decline in real wages and enabled Western industries and societies to benefit from a seemingly ever growing and unlimited commodities market. While high quality raw materials and advanced materials continue to be imported, problems related to the social license to operate—like, for example, the local acceptance of mining operations—and environmental concerns continue being exported.[27]

Indeed, global economic integration has deepened considerably since the Cold War era. China is no longer a simple assembly site for high-tech goods, and it has become a preeminent manufacturer of sophisticated critical components, making its value to importers very hard to replicate and relocate.[28] International companies in China usually maintain strong relationships with highly integrated dealers and suppliers built over decades. In such a context, a total decoupling would compel American and European industries and companies to leave and lose the Chinese market. Prices for consumer goods would likely rise, further enhancing the current inflation crisis. It took 40 years to build economic interdependence between the U.S., the EU, and China; it would take several years to move industrial and manufacturing capacity elsewhere. Such a timeline is not compatible with urgent decarbonization and emission reduction targets, especially as many have placed critical milestones at the end of this decade. The solution can only be to continue to collaborate globally to cope with a truly global challenge that is climate change. At the same time, diversification of raw materials and circular raw materials value chains will help deepen decarbonization efforts and accelerate the green transition.

Despite the growing concern in the West about China's dominant role in these parts of critical mineral value chains, however, actual instances of China blocking exports of critical materials (following the short-lived rare earths crisis of 2010)[29] have not materialized so far.[30] In fact, even during the COVID pandemic, China's mineral production showed remarkable resilience.[31] Moreover, at the intergovernmental level, standards development to enhance transparency and sustainability of the raw materials supply chains is taking place through the Geneva-based International Standards Organization. There, China, the U.S., Japan, and many other countries that may be locked in geopolitical disputes in other domains have delegates engaged in this long-term collaborative process. Among industry partners, the Brussels-based Rare Earth Industry Association is developing peer-to-peer supply chain transparency with industry partners across the globe, including in China. These intergovernmental and industry efforts are establishing ground rules and best practices as a baseline for reliable and diversified global supply chains because a sustainable green infrastructure supply chain must include China.

The interests of advanced manufacturing countries, including the U.S., EU, China, Japan, Australia, Canada, and South Korea, may therefore be best served by opting for a sustainable framework of competitive coexistence, which after all is the essence of a global free market economy.[32] While most of these countries are already taking steps to manage vulnerabilities and increase resilience by diversifying supply chains, they continue to preserve most normal exchanges of goods, ideas, information, and people-to-people ties. The U.S. and the EU, for instance, have vocalized their grievances regarding intellectual property theft and protectionism of Chinese industries. For its part, in response to trade restrictions and limited technological decoupling, the Chinese government is also now openly espousing a dual economic circulation strategy to build resilience,[33] even while it continues to champion deepening globalization and free trade. Japan has a new focus on supply chain resilience in sectors deemed critical since 2020, offering subsidies for companies to either reshore or diversify to multiple countries and passed a comprehensive Economic Security Law in 2022 codifying the approach,[34] and South Korea is following in Japan's footsteps.[35] Competitive coexistence and diversification, as opposed to total decoupling or "thwarting", may prove a more suitable global strategy given the most recent disruptions resulting from Russia's 2022 invasion of Ukraine.[36] Such an approach allows space for the economic development priorities and renewable energy agendas of other nations by encouraging the re-region-

https://doi.org/10.1021/acs.est.2c05413
Environ. Sci. Technol. 2022, 56, 15280−15289

alization—also known as reshoring and near-shoring—of supply chains to reduce global carbon emissions. We recognize, however, that prerequisites for competitive coexistence include a level playing field in terms of environmental, social, and governance standards and transparency across value chains.

3.2. Reshoring or Near-Shoring in the Minerals Sector. The concept of "reshoring" is often presented as a means of bringing back more vertical integration and industrial employment to countries that had, under late 20th century development doctrines, shifted to a service-oriented, high-consumption society. It prioritizes "repatriating" heavy industry and is usually motivated by political or security concerns. Such agendas have proven elusive in the U.S. and European countries over the past decade, largely because comparative advantage and international trade remain the highly efficient means to secure affordable supply chains, although East Asian countries such as Japan and South Korea with more recent histories of coordinated industrial policy have returned to more direct intervention. However, a hybrid form of industrial relocation across several countries in Europe, the Americas, or the Indo-Pacific, known as "near-shoring" would be capable of delivering a significant percentage share of raw materials and intermediates to the local industrial ecosystems and could form the basis of a competitive coexistence with China. Australia, for example, as a key supplier in many critical material supply chains, is actively participating in new international negotiations and business relationships as part of a multination drive toward resilience.[37]

Thus, there could be new refining capacity set up in the West but in a way which considers overall systems impacts of the transition. In the case of rare earths, the midstream and downstream face fundamental unit economics challenges when located in European or North American jurisdictions. The largest cost factor is raw materials, which is charged with a 13% VAT when imported from China for separation and magnet-making in Western jurisdictions. In addition, energy and labor cost factors are almost half in China of what they are in Western jurisdictions. This leads Western midstream and downstream facilities in the permanent magnet value chain to have a cost of production which is at least 40% higher than the cost of imported magnets from China.[38] For base metals, there are only two smelters which can handle nickel extraction—one in Greece and one in Finland—and both are stretched to capacity with financial challenges.

The processing industry is indispensable to develop a circular economy, which is particularly important considering the high materials' intensity of clean energy technologies mentioned above. In this context, the promotion of innovation and accelerated industrial deployment of new technologies are vital. However, there remains a core opposition to siting of mineral extraction and processing facilities, particularly in the West, as exemplified by numerous cessations to recent projects and ongoing activism.[39]

As an example of building resilience and diversification through near-shoring efforts, the European Commission has mandated the European Institute of Innovation and Technology (EIT) to cofinance the Knowledge and Innovation Community (KIC) on raw materials called "EIT RawMaterials".

In the U.S., a smaller analog to EIT RawMaterials is the Critical Materials Institute (CMI),[40] with funding of some US$ 240 million over 10 years from the Department of Energy. CMI is a collaboration of national laboratories, universities, and companies aimed at accelerating innovation that will foster resilient and sustainable supply chains for raw materials essential for clean energy technologies. CMI focuses on early stage, applied research to enhance and diversify primary production, to increase material reuse and recycling and to develop substitute materials for those with the riskiest supply chains. CMI also undertakes activities to improve education and workforce development and more broadly aims to enhance the overall innovation environment around critical materials in the United States.

Achieving a balanced mix of public and private sources in capital formation for critical raw material supply chains that are necessary for the production of low carbon technologies, is financially vital but politically difficult. Policymakers globally can draw insights from the successful case study of the European Battery Alliance. This EU initiative of €2.9 billion in public funding made it both attractive and possible to unlock an additional €9 billion of private capital investment. As a result, most major global and domestic battery producers are building battery facilities in EU member states—including CATL from China. An example from North America is Ontario's $500 million contribution to Ford Motors to entice the company to manufacture EV trucks there.

These examples demonstrate that there is room for policy innovation and leadership in developing the tools to ensure a balanced public−private investment in the critical raw materials sector and particularly in the frequently overlooked midstream and downstream parts of the value chain. In the midstream and downstream operations within the rare earth industry, the bipartisan U.S. legislative proposal of the Rare Earth Magnet Manufacturing Production Tax Credit Act, for example, paves the way for bolder thinking.

More of this novel approach will be required as rare earths are not only indispensable to many technologies of the green transition, but both the U.S. and the EU are import-dependent along the entire value chain of rare earth magnet materials. Given this vulnerability, it may prove helpful to conceptualize uninterrupted supply chains as an infrastructure issue and therefore under the lens of a Public-Private Partnership (P3) funding/procurement framework. For example, public funding could contribute to making the economics of critical infrastructure materialize, allowing for a minimum rate of return on private capital and placing engineering, procurement, construction (EPC)/operations and maintenance (O&M) responsibility to plant operators. Under an infrastructure lens, the much-needed operating expense support by governments does not have to be perceived as a "trade distorting subsidy," but instead it can be viewed as an "infrastructure availability payment."

4. POLICY RECOMMENDATIONS

4.1. The Case for a Multilateral Response. Instead of a negative spiral of resource nationalism that could in turn lead to ecologically and economically inefficient outcomes and exacerbate hypercompetition in a fraught geopolitical landscape, we urge a coordinated multilateral response that complements and builds upon existing initiatives. One possibility would be through empowering the International Renewable Energy Agency (IRENA) to work on a protocol on material supply security for green technology, perhaps drawing on the example and work done by the European Raw Materials Alliance. IRENA has already launched an inclusive partnership that welcomes all stakeholders, from governments and

https://doi.org/10.1021/acs.est.2c05413
Environ. Sci. Technol. 2022, 56, 15280−15289

international organizations to the private sector, to accelerate decarbonization, scale up climate action, and translate ambitious national climate targets into concrete investments. IRENA has produced high-level reporting on technology choices, investment needs, policy frameworks, and the socioeconomic impacts of achieving a sustainable, resilient, and inclusive energy future. However, it has been limited by its mandate and will require greater authority to interface with robust trade mechanisms within the World Trade Organization as well, which has a record of resolving disputes on metal supply between China, Europe, Japan, and the United States within the past decade.

With a greater level of "hard power" and interface with the WTO, IRENA may be ideally situated to take the lead in drafting a pact by which the rapid infrastructure uptake needed is sourced efficiently, equitably, and sustainably and is consequently less likely to be bogged down by international rivalries. The U.S., EU, and China are all members of IRENA, as are most UN member states. Countries which sign on to a protocol under the auspices of IRENA would not be ceding rights to royalties or individual benefits from their mineral extraction. Instead, they would be making a commitment to not withhold supply, thereby ensuring both reliable income for themselves and a more predictable decarbonization trajectory for the planet. In many ways, this is already enshrined in the WTO rules but not linked to global environmental policy. Existing multilateral safeguards on social performance such as ILO Convention 169 (on the rights of indigenous and tribal peoples) as well as the major environmental treaties should be more robustly linked to the green infrastructure gap. This can be achieved through an intertreaty protocol to track system-wide costs and benefits of specific sourcing paths.

However, while IRENA would be a useful organizational structure for managing the mid- and downstream processing aspects of the mining industry with a global perspective, the organization has historically had minimal direct participation in those particular aspects of the renewable energy sector. It therefore follows that a few policy mechanisms, management frameworks, and tools would probably need to be introduced in order to extend IRENA's organizational capabilities to meet those needs—like, specifically, a specific protocol for environmental standards and the application of blockchain technologies to improve the transparency of the critical metals value chain. Each of these will be explored in turn.

4.2. Need for Specific Mechanisms Addressing Environmental Standards. The economics community has long understood that global trade agreements facilitating the movement of capital, goods, and labor between nations also frequently need to specifically address the environment.[41] When world trading rules permit countries to protect their own environments but not to protect their domestic industries from foreign competitors who do not do so, then only richer nations will tend to enforce environmental protection within their own borders. The upstream parts of the mining sector create nontrivial amounts of CO_2 and other greenhouse gases, but downstream processes like smelting often generate even more[42] and are consequently more deserving of careful scrutiny on this front.

The good news, however, is that many recent trade agreements—like, for example, the United States–Mexico–Canada agreement (USMCA) that replaced the North American Free Trade Agreement in 2020—involve the coming together of trading partners facing large disparities in their relative levels of wealth. The USMCA includes specific guidance on a broad range of environment-related topics, from how to do environmental impact assessments (Article 24.7) to how to sustainably manage forests (Article 24.23).[43] To successfully cover the processing-related parts of the mining value chain, IRENA would need to be expanded to cover these kinds of topics—but these extensions could significantly build upon battle-hardened precedents like USMCA.

4.3. Application of Blockchain for Monitoring and Management. A natural consequence of facilitating the processing of critical minerals in a more global way through an international organization like IRENA is that it complicates the task of monitoring and measuring the flow of the metals as they are being processed. These complications can arise when collaborating countries at different points in the value chain have different levels of digital capabilities and infrastructure, or when incompatibilities emerge in their legal frameworks for managing and sharing data across international borders.[44]

Blockchain technologies are well positioned to make the data arising from these processes—including environmental data such as greenhouse gas emissions—more transparent to participants all the way through the value chain, as well as to any external stakeholders or regulators that might want to know about them. Blockchain is essentially a mathematical structure for storing data in a way that is nearly impossible to fake. Bitcoin and digital currencies are the most famous and conspicuous examples of this innovation, but, beyond digital money, the technology has also been applied within supply networks to transparently share data that can be trusted even if the participating organizations do not entirely trust another.[45] IRENA is already using blockchain as a foundation technology for "smart contracts" through which power delivery systems can become more flexible and economical and for improving how EVs connect to the electrical grid.[46] No forays have been made by IRENA to date into the mineral processing domain, however. But here, too, it will be possible to benefit significantly from prior work in this area. Several companies have already experimented with blockchain in a range of applications in the mining industry,[47] and IRENA will accordingly be able to leverage the learnings from these earlier attempts.

The Russian invasion of Ukraine also has the potential for serious impact on mineral supply. The price of nickel and other technology metals rose dramatically following the announcement of sanctions by the West. The European Union has thus far not listed explicitly rare earth metal exporters on their sanctions list (as of October 2022). In other cases, where sanctions targeted high-profile oligarchs, such as Roman Abramovich's Evraz which produces vanadium, there were restrictions placed on the capital markets dimension—e.g., London Stock Exchange suspension on trading of Evraz and prevention of scheduled dividend issuance on March 10, 2022. However, there appear to be no explicit sanctions on Evraz's operations of vanadium, which is the largest global supplier of this electronic metal outside of China. This careful calibration of how sanctions are applied reflects limitations of finding alternative technology metal supply streams.

Geological constraints coupled with infrastructure and energy supply challenges for mineral processing suggest the need for an integrated mineral supply agreement which can be a buffer in times of conflict. Such an agreement which is linked to IRENA's mandate in our aforementioned policy recom-

https://doi.org/10.1021/acs.est.2c05413
Environ. Sci. Technol. 2022, 56, 15280–15289

mendation could also be empowered through the G20 (all of whom are members of IRENA). Representing more than 80% of the global economy and still inclusive of Russia and China, this grouping has the potential to deliver such an agreement with efficient alacrity. Such an approach would not preclude contingency planning by the G7 for supply shocks but would mitigate a proxy war through mineral supply.

5. CONCLUSIONS

In an ideal world, targets for mineral sourcing should be based on ecology, geology, and physical chemistry limits of metal performance in terms of batteries or PV or wind turbine magnets as well as economics, rather than determined by geopolitics or narrowly defined interests. Our core messages therefore are (i) we need global agreement across raw materials value chains to rapidly and robustly implement measures against climate change; (ii) EU and U.S. should not completely decouple from global raw and advanced materials supply chains; however, they should strategically invest to partially re- and near-shore industries in these value chains in order to (a) promote diversification, thus competition, and innovation along the entire value chain and to derisk them; (b) influence standards, specifications, and material designs directly; (c) invest in infrastructure desperately needed for the circular economy. The good news is that robust mechanisms for collaboration currently exist and can be strengthened to meet the defining challenges of our time: acquiring the unprecedented volumes of raw materials required to close the infrastructure gap, decarbonize global energy systems, and digitalize the global economy.

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Notes

The authors declare no competing financial interest.

Biography

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ACKNOWLEDGMENTS

We would like to thank the Research Institute for the History of Science and Technology at Caltech and the Huntington (RIHST@CH) that brought our cohort together and underwrote the conference "Rich Rocks, the Climate Crisis and the Tech-Imperium," that took place in July 2021. Special thanks to Jed Buchwald, Chris Berry, Arjun Bhalla, Vasileios Tsianos, and Dan Lewis for their support.

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