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KEYS TO THE US ENERGY TRANSITION: AN ENERGY PATHWAYS USA SERIES

Strengthening Supply Chains for US Decarbonization

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Series Overview

The United States is at an inflection point on its economy-wide decarbonization goals. The passage of the Inflation Reduction Act in 2022, along with rapid technological and operational shifts in the private sector, lends increased gravity to the decarbonization decisions taken in the coming years. Energy Pathways USA is producing a series of quarterly policy papers that explore the challenges and opportunities for meeting decarbonization goals in the current moment. This first paper focuses on strengthening US supply chains in essential sectors.

INTRODUCTION

Climate change requires rapid, economy-wide decarbonization strategies in the United States. The necessary shift from fossil fuels to renewable energy sources across power, industrial, and transportation sectors necessitates major new built infrastructure. This infrastructure, in turn, has massive material requirements. From the steel needed for wind turbines to the lithium needed for batteries to the cobalt, copper, nickel, and rare earth elements required across a range of decarbonization components, procuring materials efficiently and sustainably is a core challenge for reaching net-zero carbon emissions by midcentury.

Acquiring and processing these materials has historically leveraged sprawling global supply chains often employing low-cost just-in-time[1] operations. The COVID-19 pandemic brought the fragility and vulnerabilities of such supply chains into sharp relief. These vulnerabilities have since been reinforced by devolving US-China economic and trade relations, disruptions from the ongoing Russia-Ukraine conflict, and efforts by Group of Seven (G7) countries to collectively "derisk" their supply chains. Additionally, there are limited sources for many of the key materials needed for the clean energy transition, yielding supply chains further susceptible to bottlenecks, price volatility, and abrupt access interruptions. China, in particular, dominates sourcing and processing for multiple decarbonization-related materials, giving it an outsized influence over US access to the resources necessary to reach net-zero goals.

The United States is responding forcefully to these vulnerabilities. The 2022 Inflation Reduction Act (IRA) provides new sources of capital and incentives for accelerating net-zero efforts. The law concurrently seeks to shift supply chains vital for US decarbonization to domestic sources and, more selectively, to links with free-trade partners. The core goals are twofold: (1) to create more resilient and—over the long term—cost-effective supply chains and (2) drive the domestic economic growth, global industry leadership, new jobs, and social dividends that can attend such supply chain enhancements. Or, in the words of the Biden-Harris administration, to design programs that "boost domestic manufacturing, create good-paying jobs, and reduce the country's dependence on foreign nations for critical components of the clean energy supply chain" (The White House 2023a). These goals were fundamental to the passage of the IRA, which would have lacked requisite political support were it to pursue decarbonization without regard for wider-ranging domestic cobenefits.

However, US efforts to overhaul decarbonization supply chains create steep challenges. The investment and operational actions required of both public and private sector actors will take time and risk creating a temporal mismatch between the goals of rapid decarbonization and those of building robust domestic and "friendshored"[2] supply chains. The licensing and permitting processes for new mining, processing, manufacturing, and transportation infrastructure can slow project time horizons. Established supply chain flows within a complex global marketplace can prove resistant to change. Low-carbon infrastructure projects often include thousands of components and subcomponents that have supply chains of their own, creating complex justification requirements for what constitutes domestic production. Many variables, such as China's penetration of key materials sectors, involve wide-ranging forces beyond American control.

This policy paper responds by exploring challenges and opportunities inherent to rapidly creating just, low-carbon, and sustainable supply chains for key sectors of the US economy. First, it reviews the current state of US supply chains for key decarbonization materials. It then explores IRA provisions designed to drive onshoring and friendshoring, focusing on how they are affecting

[1] *Just-in-time* supply chains see the movement of materials right before they are utilized, reducing the role of stockpiles, lowering costs, and often increasing vulnerabilities to supply disruptions in the process.
[2] *Friendshoring*, used in this paper, refers to the supply chains based in allied countries. In the context of the IRA, there is a major preference and indeed many requirements for domestic content, with space for sourcing from countries with which the United States has free trade agreements.

sustainable supply chain calculations and development strategies. The primary contribution of the paper offers recommendations for accelerating domestic supply chain development while maintaining ambitious decarbonization efforts as these supply chains mature. These recommendations center upon the following key efforts:

- Expediting permitting for critical decarbonization materials
- Applying exceptions and special waivers on domestic content
- Incentivizing recycling and materials innovation
- Applying domestic content guidance progressively
- Developing human capital
- Developing decarbonization clusters
- Expanding domestic exploration incentives
- Prioritizing friendshoring, risk reduction, and low-carbon trade in foreign policy

US SUPPLY CHAINS ACROSS KEY DECARBONIZATION MATERIALS

Clean technologies and infrastructure have significant material needs. Wind turbines, solar photovoltaics (PVs), electrical networks, batteries, heat pumps, and electric vehicles (EVs) all require critical mineral inputs, the availability of which directly affects how quickly and widely they can be domestically deployed. These inputs are vital to the US energy transition and are sourced from a complex global network. Shifting these supply chains will take time and require policy support along multiple fronts.

Demand for cobalt, copper, lithium, nickel, and zinc has the potential to increase 400% to 600% in the coming decades (The White House 2022c), bringing alongside it associated technical, environmental, economic, and social challenges for ensuring reliable supplies (IEA 2021). Supply chains for lithium, cobalt, and rare earth elements are highly concentrated in top producing and processing countries, making markets vulnerable to natural and geopolitical disruptions and to reverberating impacts from local production changes and demand shifts (IEA 2021). Ore qualities are not static, and key materials such as copper are stretched to the point that continued production may cause higher extraction costs, material prices, and waste volumes (IEA 2021). Environmental concerns about greenhouse gas emissions, waste disposal, and water stress pervade for extraction practices across mineral types.

The US depends heavily on these at times overheated international supply chains for key decarbonization materials. Large volumes of critical minerals needed for decarbonization are mined and processed by relatively few countries. US import reliance varies widely for cobalt, copper, lithium, nickel, and zinc resulting from the unique markets, availability, and recyclability of each material. More than 75% of cobalt, rare earth elements, and lithium extraction is concentrated in the Democratic Republic of the Congo, Chile, and Australia, while mineral processing is heavily concentrated in China, which refines 35% of nickel, 40% of copper, and more than half of all lithium, cobalt, and rare earth minerals (IEA 2021). Canada and Mexico

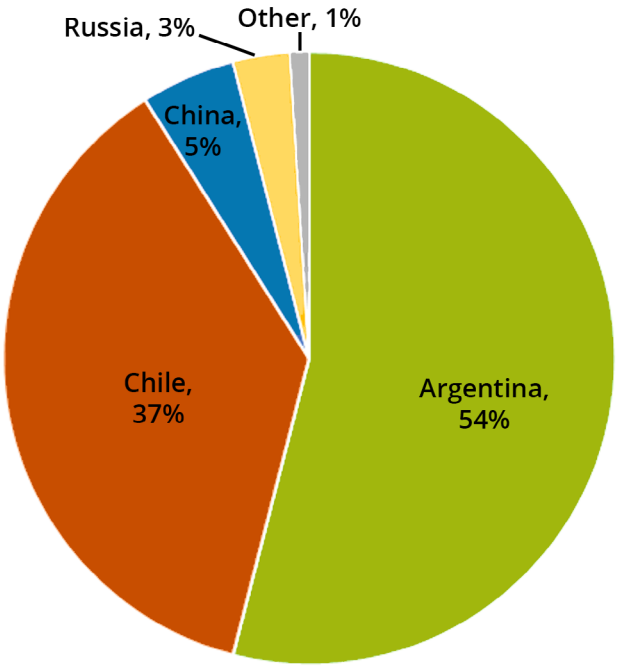
are the largest US import sources of nickel and zinc, Argentina and Chile provide 91% of total lithium imports, Finland 81% of total copper, and Norway 20% of cobalt (see Figures 1 and 2) (CRS 2022).

Net import reliance (Figure 3)—measured as imports minus exports plus adjustments for industry stock change—likewise varies by mineral. It is especially high for cobalt (76%) and relatively lower for copper (45%), nickel (48%), and zinc (less than 25%) because of higher domestic raw material potential. The net import reliance for lithium could potentially be less than 25% because of plentiful domestic reserves (CRS 2022a), but this would require major expansions of domestic mining and processing; subsequent sections demonstrate is an uncertain proposition.[3]

Deploying raw materials for clean energy generation, storage, and transmission will be crucial for transforming the power sector and, in turn, for economy-wide decarbonization prospects. Demand for copper and aluminum will surge by orders of magnitude for use in solar PV technology, wind turbines, energy storage, and fundamental electricity network infrastructure such as high-voltage transmission lines (IEA 2021). Solar panels themselves use arsenic, gallium, germanium, and indium, while concentrated solar power increases demand for chromium, copper, manganese, and nickel (USGS 2019). Key renewable energy generation components, such

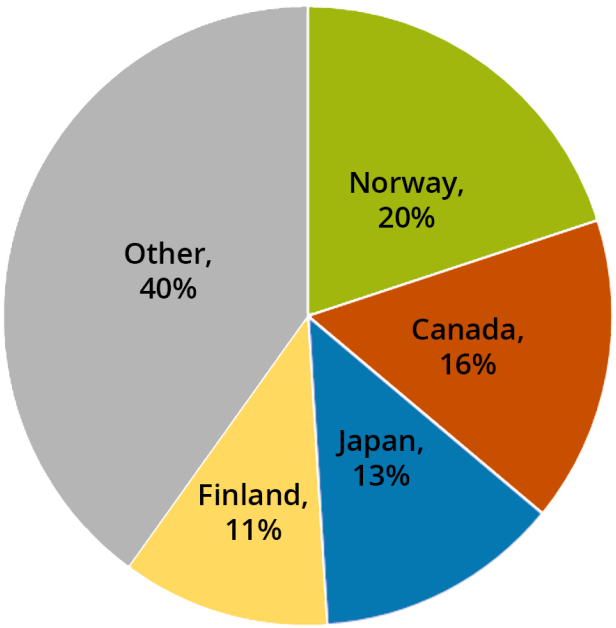
[3] While some domestic production of lithium currently occurs in Nevada, exact quantities are withheld to prevent disclosure of proprietary company data (CRS 2022a).

Figure 1. US lithium import sources, 2017–2020



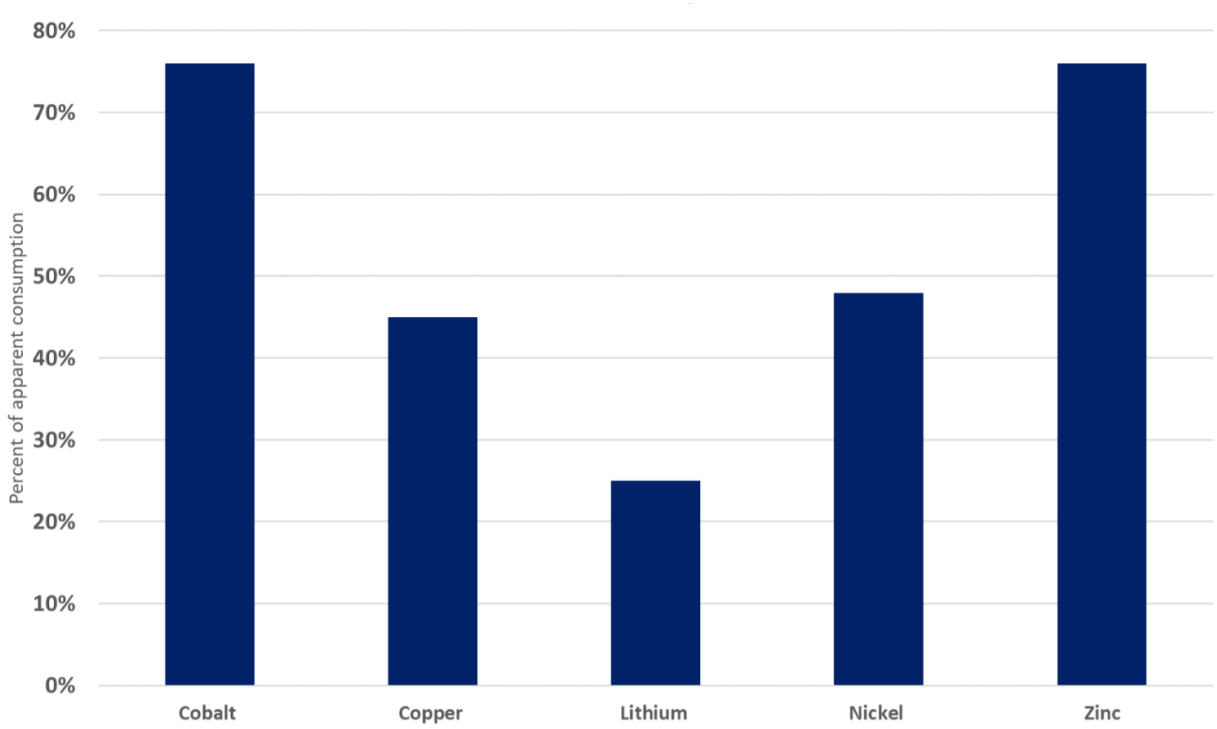
Source: Adapted from CRS 2022a.

Figure 2. US cobalt import sources, 2017–2020



Source: Adapted from CRS 2022a.
Note: Cobalt contained in metal, oxide, and salts.

Figure 3. US critical mineral net import reliance



Source: Adapted from CRS 2022a.
Note: Defined as imports – exports + adjustments for government and industry stock changes.

as offshore wind turbines, require rare earth elements for their lighter, more efficient, and more cost-effective material options (IEA 2021). Polysilicon sourcing, meanwhile, has shown its crucial position and contributed to solar PV supply chain bottlenecks even at times when these chains are otherwise oversupplied (IEA 2021).

China, meanwhile, is currently the dominant player across these decarbonization supply chains. It holds the majority of both extraction and processing markets for rare earth metals vital for clean power generation (IEA 2021). China likewise controls many sections of raw materials processing at the midstream of key supply chains, both for power and transportation (Castillo and Purdy 2022). Further downstream, China is responsible for nearly 97% of silicon wafer production (DOE 2022a), and 75% of all lithium-ion batteries are produced in China. China feeds this battery production with its own components, holding 70% of cathode production and 85% of anode production globally (IEA 2021).

These battery sector realities loom large over transportation sector decarbonization. The International Energy Agency projects that electric vehicles and battery storage will account for approximately half of clean energy's global mineral demand growth over the next two decades (IEA 2021). Supply chains for vehicle electrification and decentralized energy storage overlap significantly, as they require similar raw materials and circularly reinforce each others' need to expand storage and recycling. Through 2030, much of this supply chain is predicted to remain in China despite efforts in the United States and Europe to ramp up public-sector initiatives for

domestic production (IEA 2022a). Additionally, with limited domestic content partnerships, the United States will have to continue grappling with volatile and at times surging prices in raw materials, including nickel, cobalt, and lithium.

To realize its domestic sourcing goals, the United States will have to develop mining and processing for critical materials at unprecedented speed and volume. A battery plant takes an average of 24 months to build; the mining and refining operations needed to feed this plant take considerably longer to develop (Rohleder 2022). Mining projects alone take 16.5 years from discovery to first production, on global average (IEA 2021). The United States has very few operational critical mineral mines and quality depletion may interfere with production goals. For example, the United States has an estimated 1 million tons of cobalt, the majority of which is in Minnesota (USGS 2022e). However, the United States only has one cobalt mine (Idaho) and one nickel mine (Michigan), the latter of which is predicted to deplete by 2026. There are also very few lithium production centers in the United States, with operations based only in Nevada, where there is an estimated 3.6% of the global reserve (Kaplan 2022).[4]

As with mining, increasing critical mineral recycling is essential, and has major impacts on the domestic and global supply chains and markets for clean energy technologies. Nickel and zinc are already recycled at relatively high rates in the United States. In 2021, recycled nickel accounted for 52% of apparent domestic consumption, while 60% of zinc produced in the United States was recycled from secondary materials (USGS 2022l). Nearly one-third of copper production in the US was recovered from scrap, and approximately one-quarter of US cobalt supply was contained in purchase scrap (see Table 1 for US domestic material sources, including recycling) (USGS 2022a–l). Partnerships between automakers, technology companies, battery recyclers, and joint ventures have formed in recent years to diversify supplies of lithium for electric vehicles and batteries for energy storage. However, recycling will not eliminate the need for continued investment in the primary supply of minerals given inevitable demand growth.

Beyond recycling, materials innovation and circular system development is needed. Advancements in battery recycling and next-generation battery materials (e.g., more sodium and sulfur, less cobalt and graphite) would allow industry to avoid some international supply chain challenges and to produce cheaper materials. Widely used materials like aluminum, nickel, iron ore, and copper may see accessibility improve with grid technology modernization. Copper is often favored for wiring and transformers, but because it is more costly than the aluminum alternative, some cabling can be switched to aluminum to reduce raw materials costs (IEA 2021). Infrastructure and technology choices will likewise affect material input factors—for instance, through adopting high-voltage direct current transmission systems as a means to reduce copper and aluminum use (IEA 2021).

Building new domestic supply chains, amplifying recycling, and driving materials innovation and product substitution will all require policy support. While not the only relevant force, the IRA provides incentive structures and attending domestic content requirements that are disrupting the decarbonization supply chain status quo. These supply chain provisions require further analysis, and strategies for their implementation are paramount to the future of the US low-carbon transition.

[4] The largest current reserves are found in China, Australia, Chile, and Argentina.

Table 1. US domestic decarbonization material sources

Material	Uses	Domestic Recycling	Domestic Sources
Cobalt	Batteries	32% of copper supply	Alaska, California, Idaho, Michigan (Eagle Mine), Minnesota, Missouri, Montana, Oregon, Pennsylvania
Copper	Electricity networks, electric vehicles, geothermal, hydropower, nuclear, solar PV, wind turbines	24% of estimated consumption	Arizona (Safford Mine, Pinto Valley Mine, Gunnison Mine), Michigan, Missouri, Montana, Nevada (Pumpkin Hollow), New Mexico (Chino Mine), Utah
Lithium	Batteries	Not reported	Ohio (recycling facility)
Nickel	Batteries, electric vehicles, geothermal, hydrogen, nuclear, solar PV, wind turbines	52% of estimated consumption	Michigan, Missouri (recycling facility), Montana
Zinc	Bioenergy, hydropower, solar PV, wind	60% of refined zinc production	Arizona, New York, Tennessee

Source: Adapted from USGS 2022a–l.

THE IRA DOMESTIC CONTENT PUSH

The US federal government has nearly a century of experience promoting domestic content requirements for the material needs of the American economy. The Buy American Act (1933) instructed federal agencies and contractors to purchase domestically manufactured construction materials and end products—an effort still affecting federal procurement policies today (Castillo and Purdy 2022).[5] The IRA uses tax credits as tools toward the same objective, but now seeks to move private markets in decarbonization sectors toward domestic supplies and incentivizes domestic supply chain development in turn. Given massive aspirational expansions in low-carbon infrastructure, this approach seeks to address current dependencies on foreign supply chains before these dependencies become more entrenched.

Core decarbonization sectors, such as wind and solar, have driven major cost declines in part through leveraging global supply chains. Like semiconductors and electronic products before them, the United States has provided leading research and development input into these sectors, with mining, processing, and production largely outsourced. Also, like semiconductors, there is growing logic and political support for onshoring larger segments of these and other core decarbonization supply chains in the name of resource security and strategic value. A resilient supply of renewable energy only exists where the products and components used to generate solar, wind, and other forms of clean energy are reliably and consistently accessible to utility operators and, by extension, energy consumers (Williams and Sutton 2021). While front-end cost savings

[5] The Buy American Act's requirements can be waived at the discretion of the president to comply with international treaty obligations.

from global supply chains will continue to play a role, supplementing and/or combining these supply chains with domestic sourcing can lead to both strategic and economic dividends in the longer term.

Where successful, onshoring supply chains for low-carbon systems and infrastructure can enhance environmental and social justice, drive domestic economic growth and human capital development, and improve energy and economic security. Environmental and social justice is negatively affected by both extractive (Joshi and Loewenstein 2020) and labor (Saraiva and Victor 2022) practices in core parts of the low-carbon material supply chains upon which the United States depends. Extracting, processing, and producing these products domestically would give the United States a greater ability to drive more responsible environmental and social footprints throughout the decarbonization supply chain.[6]

Creating new domestic commerce, from mining to processing to production, creates multiplier effects in which a raft of industries capture value from a single product or installation. There is evidence that, when accounting for such upstream material inputs, manufactured products already account for far higher percentages of US gross domestic product than is conventionally recognized (Manufacturers Alliance 2016). Potential economic benefits abound, from domestically mining ore to processing metals that are then used in batteries, photovoltaics, and turbines—these are in turn manufactured and assembled into finished products. Coupled with the relatively high compensation rates in these industries,[7] benefits would extend to labor markets as well (Mishel 2018).

To these ends, the IRA extends existing tax credits for renewable energy and clean technology and adds new tax credits and incentives to stimulate domestic production, encourage "green" economic growth, and support environmental justice initiatives (see Table 2 for a summary of key IRA supply chain provisions). More specifically, the IRA provides increased rates for production tax credits and investment tax credits (PTCs and ITCs) to activities that satisfy domestic content requirements, including the requirement that any steel, iron, or manufactured product in applicable projects must be produced in the United States. These qualify as having been produced in the United States if at least 40% (or 20% for offshore wind facilities) of the total manufactured product costs are attributable to components that are mined, produced, or manufactured in the United States (Schurle et al. 2022). The US Department of the Treasury can offer exceptions to these requirements in select circumstances, such as if the domestic content requirements would result in cost increases of more than 25% or if comparable products are not readily available domestically. In both PTC and ITC cases, the credit is adjusted upward 10% when domestic content requirements are met.[8]

[6] This issue can extend to greenhouse gas emissions as well, where the embedded emissions of some imported products such as steel are higher in the United States than emissions levels when these products are produced domestically.

[7] Manufacturing workers, in particular, earn more than 13% more in hourly compensation than comparable workers in other industries.

[8] These increases represent an inflation-adjusted credit amount and are combined in the IRA with parallel prevailing wage and apprenticeship requirements seeking stronger labor and human capital outcomes. Where prevailing wage and apprenticeship requirements are not met, the domestic content enhancement is still available, albeit on a smaller scale (a 2% increase in the ITC rate and 10% increase in the base PTC rate). Projects not subject to the prevailing wage and apprenticeship requirements for purposes of the PTC bonus rate or ITC bonus rate are not subject to the requirements for the full domestic content enhancement.

Table 2. Key IRA supply chain provisions

Provision	Key Elements	Time Horizon
New Advanced Manufacturing PTC (45X)	Tax credit for clean energy components produced in the US. Eligible parts include (nonexhaustive): solar components (PV wafer, polysilicon, solar module, fasteners, and more), wind turbine and offshore wind components (platform, blade, tower, nacelles, and more), inverters, battery components (battery cell, modules and more), and applicable critical minerals.	Phase-out begins in 2029, ends in 2032
Extension of Renewable Electricity PTC	Extends renewable PTC for applicable renewable sources with 1.3 cent/kWh (including open-loop biomass, landfill gas, and municipal solid waste) and 2.5 cent/kWh (for wind, geothermal, and closed-loop biomass). Provides bonuses (10% each) for projects that locate in "energy communities" or meet domestic manufacturing requirements for steel, iron, or manufactured products.	PTC ends in 2024, replaced by the new tech-neutral Clean Electricity PTC (45Y)
New Clean Electricity PTC (45Y)	Provides bonuses (10% each) for projects that locate in "energy communities" or meet domestic manufacturing requirements for steel, iron, or manufactured products. Launches in 2025, replacing the Extension of Renewable Electricity PTC when it expires.	Credits set to phase out in 2032 or when emission targets are achieved
Extension of Energy ITC	Maintains 30% credit for the following property types: solar, geothermal, fiber-optic solar, fuel cell, microturbine, small or offshore wind, combined heat and power, and waste energy recovery property constructed in 2024. Provides bonuses (10% each) for projects that locate in "energy communities" or meet domestic manufacturing requirements for steel, iron, or manufactured products.	Replaced by Clean Electricity ITC (48E) beginning in 2025
New Clean Electricity ITC (48E)	Tech-neutral replacement for the Energy ITC. Provides bonuses (10% each) for projects that meet domestic manufacturing requirements for steel, iron, or manufactured products or locate in "energy communities," low-income communities, or on tribal land.	—
Advanced Energy Project Credit 48C	Extends the 30% investment tax credit for qualified advanced energy projects, including those that expand or establish manufacturing facility capacity for using renewables or reducing greenhouse gases.	—
Domestic Manufacturing Conversion Grants	Funds totaling $2 billion to retrofit existing domestic auto manufacturing facilities for increased capacity for production of electric, hybrid, and hydrogen fuel cell vehicles.	Expires 2031

Table 2. Key IRA Supply Chain Provisions *(continued)*

Provision	Key Elements	Time Horizon
Enhanced Use of Defense Production Act	Appropriates $500 million from Defense Production Act of 1950 for critical mineral production.	Available until September 2024
Clean Vehicle Credit (30D)	Consumer credit for purchasing qualified new clean vehicle (including electric, plug-in hybrid, and hydrogen fuel cell vehicles). To qualify for this credit, a certain percentage of materials must be sourced domestically or from countries with whom the United States has free trade agreements.	Expires 2032

Source: Inflation Reduction Act of 2022, H.R.5376, 117th Congress (2021–2022); see also BPC (2022) and Bond (2022).

The IRA also feeds into other policy measures seeking to boost domestic mining and supply chain segments further downstream. The continuing use of the outmoded Mining Law of 1872 and lack of single federal agency oversight of domestic mining led the Biden-Harris administration to create an Interagency Working Group (IWG) to steer mining reform. Part of the IWG's 2022 response to this mandate has been wide-ranging consultations with policymakers, mining industry practitioners, scientific and policy experts, and local communities and tribal nations with the goal of establishing strong environmental and engagement mining standards (The White House 2022d). The Biden-Harris administration also invoked the Defense Production Act (DPA), which gives presidential authority to use incentives to boost mineral supplies and to provide federal resources for new and existing mines, and called on the Department of Defense to consider a basket of core decarbonization metals as essential to national security. The IRA has appropriated up to $500 million for the "enhanced use" of the DPA to assist with strengthening the US supply chain for critical minerals.

For the transportation sector, the IRA's Clean Vehicle Credit (CVC) seeks to drive domestic supply chain development through requiring domestic content levels for battery component sourcing (extraction or processing) and vehicle assembly. The critical minerals and metals targeted in the IRA's specifications on EVs and batteries include aluminum, copper, cobalt, graphite, lithium, manganese, nickel, and rare earth elements (IEA 2021, USGS 2019). A certain percentage of materials must be sourced domestically or from countries with which US has free trade agreements: the required percentage of onshored or friendshored battery components increases from 40% in 2024 to 80% in 2026 and the required percentage for assembly increases from 50% in 2024 to 100% in 2026 (BPC 2022). Perhaps more pressingly, no EVs can contain constituent parts from "entities of concern"—which includes China—and enjoy the CVC. In the near term, many US vehicles available on the market may not qualify for the Clean Vehicle Credit (30D)[9] because of the convergence of these stipulations and low US battery production capacity.

[9] Numbers in parentheses refer to sections in the IRA the provisions are found.

The IRA's building provisions address both retrofitting and new building construction. IRA tax credits could incentivize the construction of 650,000 new energy-efficient homes (45L), retrofit 115 million ft^2 of commercial building space (179D), and spur the installation of 7.2 million residential heat pumps (25C) (Smedick et al. 2022). There are fewer critical mineral supply chains involved in IRA building provisions and more of a focus on domestic base metals (e.g., iron, steel) and low-carbon building materials, as well as strategic cost-saving home upgrades including insulation, windows, updated electric wiring, efficient heat pumps/furnaces, induction stovetops, and upgraded appliances. However, all of these IRA provisions—and building electrification as a whole—hinges on the power sector's supply chain and successful grid infrastructure buildout with materials such as lithium and aluminum.

Questions on the application of IRA domestic content provisions abound. While implementation policies will evolve, core IRA language suggests that domestic content requirements are applied on project-wide levels for ITCs and on a facility-by-facility level for PTCs. Additional implementation guidance is needed as to whether and how service and other nonphysical asset costs, in addition to the hard costs of property, plant, and equipment, are included in the domestic content calculation. Processes for accounting for the domestic content of components and subcomponents—or lack thereof—within manufactured products are complex and vital for implementing the IRA effectively, particularly for final products that combine domestic and foreign-sourced parts.

Signs of the direction of such accounting requirements surfaced with the May 12, 2023, issuance of Notice 2023-38 on IRA domestic content provisions by the US Treasury Department and Internal Revenue Service (IRS) (IRS 2023). The notice seeks to clarify how projects can qualify for multiple energy tax credits, including ITCs under IRA Sections 48 and 48E and PTCs under Sections 45 and 45Y, by meeting domestic content requirements. Two key points emerged:

First, the notice further defines the characteristics of "applicable projects" that qualify for the relevant tax credits by function of having domestically produced "applicable project components"—iron, steel, and "manufactured products"—which are the targets of domestic content requirements. While adding details on the IRA implementation, these definitions leave questions. All manufacturing processes relating to steel and iron must take place in the United States for a project to qualify, except for metallurgical processes to refine steel additives. A grey area persists as to whether raw iron ore and scrap steel need to be domestic or not. The notice defines the characteristics of manufacturing processes covered by IRA provisions and distinguishes these from "assembly" processes. These lines could become blurred, however, leaving question of interpretation where, for example, manufactured products are modified or altered during assembly processes (Loomis et. al. 2023). The notice also defines "manufactured product components" broadly and without substantively defining subcomponents or clearly delineating between a component and a subcomponent. Components are subject to domestic manufacturing requirements, whereas subcomponents are not. This ambiguity is especially germane to many clean energy technologies and projects with hundreds or thousands of components and subcomponents.

Second, the Adjusted Percentage Rule—which is key to determining if a project qualifies for relevant ITCs and/or PTCs—creates potential implementation challenges. The rule creates a framework for calculations that determine and then divide the domestic manufactured products and components cost by the total manufactured products cost to arrive at a percentage that will either qualify or disqualify a project from the tax credits. Complexities abound in determining these costs, increasing the administrative burden of meeting IRA requirements. The stipulations also risk implementation hurdles by requiring developers to acquire and report potentially sensitive cost information from both domestic and international manufacturers (Loomis et al. 2023).

It is clear that compliance with domestic content requirements will require coordination with suppliers throughout multiple streams of the supply chain. Similarly, the IRA will require substantial cross-agency coordination. The Treasury Department (and the IRS in particular), Department of Energy, Department of the Interior, and Environmental Protection Agency, among others, are responsible for steering personnel and policies toward the interpretation of the IRA, distributing funding, and liaising with the public (including private sector actors). It is at the intersection of these policy implementers, private-sector drivers of low-carbon commerce, and the affected public that key supply chain challenges must be addressed.

PATHWAYS FORWARD

Expedite Permitting for Critical Decarbonization Materials

Accelerating permitting processes for infrastructure and operations from mining to product assembly, and doing so in environmentally and socially just ways, is both difficult and essential. More substantial analysis is needed on the pathways and processes that constitute effective, expedited permitting,10 which includes a range of actions specific to critical decarbonization sectors and much of which will require congressional action. Measures include the following:

- Codifying time limits for all environmental impact statements
- Mandating streamlined cooperation between lead and coordinating agencies
- Increasing lead agency oversight power and accountability
- Requiring lead agencies to develop single-permit plans and timetables for multiple review and approval processes
- Prioritizing infrastructure with clear decarbonization value in review and permitting queues
- Fostering best practices in land use for integrated supply chains for specific federal and state lands
- Setting permitting targets for lead agencies
- Clarifying, digitizing, and streamlining permit application processes
- Clarifying and expediting judicial review processes
- Expanding staffing and resources for permitting agencies.

[10] Energy Pathways USA will publish a future policy paper dedicated to this issue.

Expediting permitting for critical decarbonization sectors must not come at the expense of consultations with affected communities. Rather, it is vital that such discussions are pursued early on and with thorough, good-faith engagement by both regulators and private-sector project implementers across supply chain infrastructure development processes. This entails good-faith engagement with local communities and civil society groups that responds to concerns and clearly delineates local value propositions for decarbonization supply chain projects.

Apply Exceptions and Special Waivers on Domestic Content

Given time horizons necessary for developing domestic extraction and processing capabilities for critical materials—even under expedited conditions—the effectiveness of exceptions and special waivers for attaining tax credits under the IRA is vital. These tools will provide an important bridge to allow time for the United States to progressively decrease its reliance on net imports for core decarbonization goals and provide investing confidence for transitioning industries during the multiyear process of mine and facility development (Rohleder 2022). The IRA includes waivers for cases in which domestic products are not available or when these products would increase facility cost by more than 25% (CRS 2022b). Accessing these waivers will require delineating and calculating complex domestic content requirements across products and facilities with wide-ranging components, which could significantly increase transactional costs for policy implementers and companies alike. These processes need to be streamlined and resourced financially and through human capital development within the US government's IRA implementation apparatuses, particularly in the Treasury Department.

Incentivize Recycling and Materials Innovation

Recycling energy components, particularly battery materials, reduces the need for and production impacts of harvesting new materials (DOE 2022b). Recycled materials qualify under IRA tax credits (e.g., 45C, 48X, 13401) for tax incentives, which will over time provide companies with greater impetus to acquire and use recycled inputs. But incentivizing downstream company behavior is insufficient on its own, especially in the near term, and further coordinated recycling policies for strategically valuable decarbonization materials are needed at national and subnational levels. Greater funding for recycling, circular economy innovation, and material substitution is likewise needed, starting with US national labs and the National Science Foundation. Such investments will take time to bear fruit, but still constitute essential near-term actions for creating a more robust and sustainable material base for the energy transition.

Apply Domestic Content Guidance Progressively

Given the current state of US and global supply chains, and the complexity of some key decarbonization manufactured products, the requirement that all manufactured product components be of US origin will often be difficult to meet. The head of a turbine has tens of thousands of distinct pieces, for example, and assessing the overall domestic content for wide-ranging subcomponents will require large transactional costs, and greater information sharing on cost and production in upstream supply chains—foreign and domestic—than may be pragmatic for a rapid energy transition. Specifically, the Adjusted Percentage Rule of Notice 2023-38 (IRS 2023), which puts burdens on developers to report the manufacturing costs of their

suppliers, may prove too onerous to be practical. This could in turn increase developers' real and perceived risk calculations, decelerating energy transition investment and project actuation. Future guidance needs to respond to these developer-oriented challenges by reducing the level of upstream cost information required and lowering transaction costs and risk assessments as a result. More broadly, domestic content provisions need to be implemented progressively as US decarbonization supply chains mature, rewarding good-faith efforts to find domestic suppliers where possible. These measures will be more effective with more modest early applications followed by steeper domestic content requirements in the future.

Develop Human Capital

The expansion of domestic decarbonization supply chains demands a corresponding expansion of skilled workforces. The extraction, transportation, processing, construction, and management involved in decarbonization supply chains requires a litany of engineers, planners, manufacturing workers, installers, assessors, and more. The Department of Energy's Clean Energy Corps and Building Technologies Office funding program are two examples of government-supported workforce creation. More is needed, including providing public support for promising industry startups to grow as a resource for education, training, and job placement (Zimmerman 2022). Both state and federal governments can likewise prioritize skills and subject matter expertise needed to build decarbonization supply chains in their investments in public education.

The private sector both feels the crunch from labor and skill shortages and has a role to play in addressing them. This entails evaluating the existing skills in communities where projects are sited, along with what skills are needed, what certificates are necessary, what schools in the area are positioned to provide training, and what are the barriers for members of the community that must be addressed (down to strategic transportation options for accessing training and times of day when trainings are held). Such efforts to build a future workforce are ripe for public-private partnerships. One example is the US Department of Education Careers Z Challenge, which sees industry partners work with state agencies and local high schools to create career and technical education programs that match local and regional needs. Such efforts should be further prioritized and funded at private and public levels.

Human capital expansions are likewise essential for the public sector. Permitting and IRA implementation processes require skilled personnel, and human capital deficits in these arenas create bottlenecks to building decarbonization supply chains. Tracy Stone-Manning, Director of the Bureau of Land Management (BLM), argues that an institutional loss of expertise is more to blame for slowing down the BLM's clean energy permitting than the processes themselves; the BLM has requested funding to hire 500 more employees—including more who focus entirely on renewable energy (The Economist 2023). The BLM is not alone, and a centralized strategic review is needed on the human capital required across agencies to build domestic decarbonization supply chains in line with UN net-zero goals.

Develop Decarbonization Clusters

One key opportunity in addressing supply chain challenges is to develop subnational energy decarbonization clusters. Both state and federal government actions can incentivize the

colocation of complementary activities across segments of the decarbonization supply chain. Such industry clusters can extend to innovation, which can make more efficient use of the inputs for key wind, solar, and battery technology. Place-based economic development is likely to take hold through private sector responses to public investments and effective regulations. Where effective, this combination can yield high-quality jobs, redress environmental and social injustices, drive transitions in energy communities, and produce essential decarbonization systems. Such virtuous outcomes require improving coordination among private industry actors and a range of government agencies (DOE 2022b). Currently, it is often difficult for companies to find solutions to their challenges that cross agency mandates, which are often fundamental to the needs of creating decarbonization clusters. While the IRA's diverse and stackable incentives provide an essential foundation for clusters, creating them at scale will require improving interagency and national-to-subnational coordination across the range of relevant government bodies, interfacing with private sector project implementers throughout.

Expand Domestic Exploration Incentives

Invocations of the Defense Production Act, the National Defense Authorization Act, and funding committed through the IRA and Infrastructure Investments and Jobs Act for the exploration and extraction of critical minerals in the US signal widespread support across government for growing the upstream decarbonization supply chain. However, the economics of mining for critical minerals in the US remain daunting. Accelerated and well-resourced surveying of public land mineral endowments for strategically vital decarbonization materials is needed. More effective domestic loan programs and congressionally earmarked grants and loans are essential for defraying upfront costs and lowering risk assessments for building and expanding mining and processing operations. While the IRA has made great strides in altering demand-side calculations for domestic minerals, much more investment is needed to ensure that supplies increase commensurately.

Prioritize Friendshoring, Risk Reduction, and Low-Carbon Trade in Foreign Policy

Domestic content requirements necessitate new priorities in US foreign policy. Requirements that constituent parts for EVs not come from China and other "entities of concern" risks undermining IRA incentives if new supply chain links are not established quickly. This requires new investments and capacity building in key destination countries.[11] Further coordination between domestic IRA implementers and the executors of foreign policy at the State Department, the Treasury Department's Development Finance Corporation, the Department of Energy's

[11] Efforts are underway on this front. In March 2023, the Office of the United States Trade Representative reached a deal with the Government of Japan to "seek to cooperate bilaterally and in plurilateral fora, as appropriate, regarding efforts to ensure secure, sustainable, and equitable critical minerals supply chains," among other cooperative measures. Similarly, the May 2023 G7 Leaders' Statement centers around cooperating to foster "resilient and sustainable value chains," emphasizes derisking supply chains to become less dependent on China, and calls on G7 members to "enhance resilient supply chains through partnerships around the world, especially for critical goods such as critical minerals, semiconductors and batteries" (The White House 2023b). This Energy Pathways USA recommendation calls for such efforts to be redoubled and systematically pursued across a comprehensive range of government actors. (See USTR 2023; The White House 2023c.)

international operations, and through the US-led G7 Partnership on Global Infrastructure and Investment is necessary, with accountability driven from the US Executive Branch. Such coordination should proceed with the recognition that shifting supply chains away from an emphasis on lowest cost to one prioritizing robust, diversified, and allied sources may incur short-term cost increases but could ultimately create downward price pressure through lower risk calculations and fewer disruptions. The US can further strengthen these supply chains by investing in the expensive midstream systems and infrastructure for strategic materials in developing countries that crave these capabilities—such as nickel in Indonesia or copper in Peru. The US can also help drive trade arrangements, or *carbon clubs*, that reward the exchange of low-carbon products. While it is unlikely that the United States will pursue a carbon-pricing oriented border adjustment system similar to that in the European Union, border adjustment proposals based on embedded carbon are emerging from across the political spectrum, including the FAIR Transition and Competition Act from the left and soon-to-be proposed Foreign Pollution Fee legislation from the right. An effective carbon club would see a growing band of countries sharing data on carbon content as a function of their commercial exchanges. The size of the US market would create a demand pull within this club, amplifying the forces for friendshoring supply chains as a result.

CONCLUSION

The ultimate supply chain challenge for US decarbonization is timing. The IRA and other incentives and pools of capital are currently driving demand for new supply chains and domestic production more rapidly than material supplies are available. The IRA contains both supply and demand levers, and these must be married in ways that align with US decarbonization commitments and with the current state of supply chains and manufacturing capabilities for key energy transition sectors. This is a difficult task, but is one without viable alternative.

Reaching net zero will ultimately require rapidly building and enhancing equitable and sustainable supply chains. While the IRA provides credits and incentives for the clean energy transition, there is a current temporal mismatch between domestic content provisions and decarbonization supply chains. There are opportunities for accelerating the onshoring and friendshoring of decarbonization supply chains, and maintaining the international connections needed to drive decarbonization as these domestic efforts mature. This will require concentrated and coordinated policies and strategies from across public and private sectors, particularly during the early years of IRA implementation.

REFERENCES

Bond, D. E. 2022. "New US Climate Bill Seeks to Bolster Domestic Critical Minerals Supply Chain." *White & Case*. Washington, DC: White & Case LLC. https://www.whitecase.com/insight-alert/new-us-climate-bill-seeks-bolster-domestic-critical-minerals-supply-chain.

BPC. 2022. *Inflation Reduction Act Summary: Energy and Climate Provision.* Washington, DC: Bipartisan Policy Center. https://bipartisanpolicy.org/blog/inflation-reduction-act-summary-energy-climate-provisions/.

Castillo, R., and C. Purdy. 2022. *China's Role in Supplying Critical Minerals for the Global Energy Transition What Could the Future Hold?* Washington, DC: The Brookings Institution. https://www.brookings.edu/wp-content/uploads/2022/08/LTRC_ChinaSupplyChain.pdf.

CRS. 2022a. "Critical Minerals in Electric Vehicle Batteries." *Congressional Research Service*, August 29, 2022. https://crsreports.congress.gov/product/pdf/R/R47227.

CRS. 2022b. "Proposed Tax Preference for Domestic Content in Energy Infrastructure." *Congressional Research Service,* August 5, 2022. https://crsreports.congress.gov/product/pdf/IN/IN11983.

DOE. 2022a. "Achieving American Leadership in the Solar Photovoltaics Supply Chain." *US Department of Energy*, February 24, 2022. https://www.energy.gov/sites/default/files/2022-02/Solar%20Energy%20Supply%20Chain%20Fact%20Sheet.pdf.

DOE. 2022b. "America's Strategy to Secure the Supply Chain for a Robust Clean Energy Transition." *US Department of Energy*, February 24, 2022. https://www.energy.gov/policy/articles/americas-strategy-secure-supply-chain-robust-clean-energy-transition.

The Economist. 2023. "Congress Should Fund the BLM (No, Not That One)." *The Economist*, March 18, 2023. https://www.economist.com/united-states/2023/05/18/congress-should-fund-the-blm-no-not-that-one.

IEA. 2021. "Mineral Requirements for Clean Energy Transitions." *The Role of Critical Minerals in Clean Energy Transitions*. Paris: International Energy Agency. https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions.

IEA. 2022a. Global Supply Chains of EV Batteries. Paris: International Energy Agency. https://iea.blob.core.windows.net/assets/4eb8c252-76b1-4710-8f5e-867e751c8dda/GlobalSupplyChainsofEVBatteries.pdf.

IRS. 2023. Notice 38-2023: Domestic Content Bonus Credit Guidance under Sections 45, 45Y, 48, and 48E. Washington, DC: Internal Revenue Service. https://www.irs.gov/pub/irs-drop/n-23-38.pdf.

Joshi, K., and A. Loewenstein. 2020. "Clean Energy Can't Have Dirty Roots." Foreign Policy, October 15, 2020. https://foreignpolicy.com/2020/10/15/clean-energy-dirty-roots-electric-vehicles-climate-change-mineral-supply-chain/.

Kaplan, D. A. 2022. "How the US Plans to Transform its Lithium Supply Chain." Utility Drive, November 1, 2022. https://www.utilitydive.com/news/us-strengthening-lithium-supply-processing-ev-batteries/635338/.

Loomis, A. C., A. C. Kobos, R. S. Reigner, Jr., and M. T. Emmert. 2023. "Treasury and IRS Issue Domestic Content Guidance Under IRA." *Troutman Pepper*, May 15, 2023. https://www.troutman.com/insights/treasury-and-irs-issue-domestic-content-guidance-under-ira.html.

Manufacturers Alliance, "Infographic: A New Model for Manufacturing's Multiplier Effect," April 27, 2016. https://www.manufacturersalliance.org/sites/default/files/2021-06/Importance%20of%20US%20Manufacturing%20Today%20Report.pdf.
Mishel, L. 2018. *Yes, Manufacturing Still Provides a Pay Advantage, but Staffing Firm Outsourcing is Eroding It*. Washington, DC: Economic Policy Institute. https://www.epi.org/publication/manufacturing-still-provides-a-pay-advantage-but-outsourcing-is-eroding-it/.
Rohleder, N. 2022. "Opportunities and Challenges in the Inflation Reduction Act." *NASDAQ*, September 16, 2022. https://www.nasdaq.com/articles/opportunities-and-challenges-in-the-inflation-reduction-act.
Saraiva, J., and D. Victor. 2022. "Rethinking Global Supply Chains for the Energy Transition." *The Davos Agenda, World Economic Forum*, January 31, 2022. https://www.weforum.org/agenda/2022/01/rethinking-supply-chains-for-the-energy-transition/.
Schurle, A., T. Roessler, and D. B. Weisblat. 2022. "The Inflation Reduction Act: Key Provisions Regarding the ITC and PTC." *National Law Review*, August 12, 2022. https://www.natlawreview.com/article/inflation-reduction-act-key-provisions-regarding-itc-and-ptc.
Smedick, D., R. Golden, and A. Petersen. "The Inflation Reduction Act Could Transform the US Buildings Sector." *RMI*, August 31, 2022. https://rmi.org/the-inflation-reduction-act-could-transform-the-us-buildings-sector/.
The White House. 2023a. *Building A Clean Energy Economy: A Guidebook to the Inflation Reduction Act's Investments in Clean Energy and Climate Action*, Version 2. Washington, DC: The White House. https://www.whitehouse.gov/wp-content/uploads/2022/12/Inflation-Reduction-Act-Guidebook.pdf.
The White House. 2023b. *G7 Hiroshima Leaders' Communiqué*. Washington, DC: The White House. https://www.whitehouse.gov/briefing-room/statements-releases/2023/05/20/g7-hiroshima-leaders-communique.
The White House. 2023b. *G7 Leaders Statement on Economic Resilience and Economic Security*. Washington, DC: The White House. https://www.whitehouse.gov/briefing-room/statements-releases/2023/05/20/g7-leaders-statement-on-economic-resilience-and-economic-security/.
USGS. 2019. *Critical Mineral Commodities in Renewable Energy*. Washington, DC: US Geological Survey, US Department of the Interior. https://www.usgs.gov/media/images/critical-mineral-commodities-renewable-energy.
USGS. 2022a. "Aluminum." *Mineral Commodity Summaries*. Washington, DC: US Geological Survey. https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-aluminum.pdf.
USGS. 2022b. "Arsenic." *Mineral Commodity Summaries*. Washington, DC: US Geological Survey. https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-arsenic.pdf.
USGS. 2022d. "Chromium." *Mineral Commodity Summaries*. Washington, DC: US Geological Survey. https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-chromium.pdf.
USGS. 2022e. "Cobalt." *Mineral Commodity Summaries*. Washington, DC: US Geological Survey. https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-cobalt.pdf.
USGS. 2022f. "Copper." *Mineral Commodity Summaries*. Washington, DC: US Geological Survey. https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-copper.pdf.
USGS. 2022g. "Gallium." *Mineral Commodity Summaries*. Washington, DC: US Geological Survey. https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-gallium.pdf.

USGS. 2022h. “Germanium.” *Mineral Commodity Summaries*. Washington, DC: US Geological Survey. https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-germanium.pdf.
USGS. 2022i. “Lithium.” *Mineral Commodity Summaries*. Washington, DC: US Geological Survey. https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-lithium.pdf.
USGS. 2022j. “Nickel.” *Mineral Commodity Summaries*s. Washington, DC: US Geological Survey. https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-nickel.pdf.
USGS. 2022k. “Rare Earths.” *Mineral Commodity Summaries*. Washington, DC: US Geological Survey. https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-rare-earths.pdf.
USGS. 2022l. “Zinc.” *Mineral Commodity Summaries*. Washington, DC: US Geological Survey. https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-rare-earths.pdf.
USTR. 2023. *Agreement Between the Government of the United States of America and the Government of Japan on Strengthening Critical Minerals Supply Chains*. Washington, DC: Office of the United States Trade Representative. https://ustr.gov/sites/default/files/2023-03/US%20Japan%20Critical%20Minerals%20Agreement%20Text%20March%202023.pdf.
Williams, M., and T. Sutton. 2021. “Creating a Domestic U.S. Supply Chain for Clean Energy Technology.” *American Progress*, October 4, 2021. https://www.americanprogress.org/article/creating-domestic-u-s-supply-chain-clean-energy-technology/.
Zimmerman, L. 2022. “Advancing the Energy Transition Amidst Global Crises.” *MIT Energy Initiative*, October 21, 2022. https://energy.mit.edu/news/advancing-the-energy-transition-amidst-global-crises/.

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The Nicholas Institute for Energy, Environment & Sustainability at Duke University accelerates solutions to critical energy and environmental challenges, advancing a more just, resilient and sustainable world. The Nicholas Institute conducts and supports actionable research and undertakes sustained engagement with policymakers, businesses, and communities—in addition to delivering transformative educational experiences to empower future leaders. The Nicholas Institute's work is aligned with the Duke Climate Commitment, which unites the university's education, research, operations, and external engagement missions to address the climate crisis.

Energy Pathways USA

Energy Pathways USA, an autonomous regional initiative of the global Energy Transitions Commission, works with leading private sector companies, public bodies, nongovernmental organizations, and thought leaders to advance the US net-zero agenda. Convened by the Nicholas Institute for Energy, Environment & Sustainability at Duke University, Energy Pathways USA brings together experts from diverse sectors and organizations to explore and analyze current and proposed federal, state, and regional policy incentives and the broad range of their potential impacts, including on emissions, costs, technology, and consumer behavior. By advancing cross-sectoral dialogue based on robust policy, technology, and modeling analyses, this partnership aims to develop actionable pathways to accelerate an equitable energy transition.

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