



FEBRUARY 2025 | U.S. FOREIGN POLICY FOR CLEAN ENERGY TASKFORCE

# How the U.S. Can Stop Losing the Race for Clean Energy

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**The following paper is in support of the Carnegie Endowment for International Peace's U.S. Foreign Policy for Clean Energy Taskforce, a nonpartisan working group seeking to bolster U.S. clean industrial goals with cooperative decarbonization abroad.**

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*Over the past year, the Carnegie Endowment for International Peace convened the U.S. Foreign Policy for Clean Energy Taskforce. This bipartisan group of twenty-three past and potentially future policymakers met monthly to explore how the United States could strengthen clean energy supply chains to enhance its security and prosperity. This paper summarizes for policymakers the key takeaways and recommendations from those taskforce meetings, as well as from the taskforce's underlying analysis of supply chain and international relations. This summary was written by the Carnegie team, and none of its statements or recommendations may be attributed to any taskforce member.*

*For more information on the project, please see the project hub, which includes the technical paper that provides analysis of clean energy supply chains; the foreign policy mapping paper that gives a detailed overview of U.S. diplomatic and financial engagement on clean energy; the assessment of opportunities for leapfrog technologies; and a paper providing detailed recommendations for American geopolitical strategy. The project hub also includes other publications by Carnegie scholars and taskforce members.*

## The Problem

The rise of clean energy creates enormous economic and diplomatic opportunities for the United States, but also presents significant strategic and geopolitical challenges. We highlight three aspects of the problem: clean energy technologies are essential to America's economic future, but competition is heating up, and the United States is losing the race to lead in new technologies. In this paper, we argue that a focused industrial strategy supported by international partnerships can help the United States compete for technological leadership in a new age.

## The Rise of Clean Energy Is Inevitable

Solar, wind, and batteries are proliferating rapidly because they are now cost competitive or even cheaper than other options. These technologies have critical long-term advantages. They are thermodynamically efficient, creating free streams of electrons without combustion, and they can source those electrons from the local environment rather than through a complex fuel supply chain. Solar and wind therefore create economic advantages and enable countries currently dependent on fuel imports to reduce vulnerability.

Even though global fossil fuel consumption is expected to continue, the area of highest growth is clean energy: annual global investment in clean energy is now nearly double fossil fuel investment.<sup>1</sup> Grid-scale battery storage is also now being deployed at faster rates. In 2023, global battery storage installations nearly tripled compared to the previous year.<sup>2</sup> In 2025, new batteries that can store days—not hours—of intermittent wind and solar energy are expected to be deployed.<sup>3</sup> Intermittent renewables are becoming firmer sources of power for electric grids around the world.

Additional clean energy advances are on the horizon. The cost of next generation geothermal power—which is clean and firm—is now falling as quickly as fracking and other renewables did.<sup>4</sup> Nuclear, too, is having a renaissance because of its proven ability to provide twenty-four seven power.<sup>5</sup> And an arsenal of new technologies are being deployed to efficiently electrify heat in the industrial sector.<sup>6</sup> Across the United States, first of a kind cement and steel factories—some of the most challenging industries to decarbonize—are coming online without the need for fossil fuels.<sup>7</sup>

Electric vehicles (EVs) may prove the most disruptive of these technologies. EVs are not only more energy efficient than internal combustion engines (ICE) but are also reportedly cheaper to maintain because they have fewer moving parts.<sup>8</sup> Global ICE sales are now down 23 percent from their peak in 2017, largely thanks to the unstoppable rise of EVs, especially in China and from Chinese firms.<sup>9</sup> Once a constraint, the number of global EV chargers quadrupled from 2020 to 2023, and new chargers are being deployed that can top-up a vehicle in twenty minutes.<sup>10</sup> By the end of the decade, EVs are projected to be cheaper than their ICE competitors without subsidies.<sup>11</sup> The ICE age is thawing.

Investment patterns reveal the depth of the shift to clean energy. Global annual investment in fossil fuels remains stagnant at around \$1 trillion, whereas energy transition investment is growing annually at about 25 percent, surpassing an astounding \$2 trillion in 2024.<sup>12</sup> At this rate, energy transition investment would be triple that of fossil fuels by 2026. Although initially concentrated in Western countries and China, this surge in clean energy investment is permeating across emerging and developing markets, with the majority of new power installations in these countries being clean.<sup>13</sup> The impact is already visible. Pakistan deployed 17 gigawatts of solar panels in just nine months in 2024—surpassing Germany’s annual installations, a leading global solar market.<sup>14</sup> In 2024, both Türkiye and India were on pace to double their solar deployments compared to the previous year.<sup>15</sup> Emerging markets, long thought to be a source of growth in hydrocarbon demand, are increasingly industrializing with clean energy.<sup>16</sup>

What does this mean for the United States, the world’s largest producer, refiner, and exporter of oil and gas? The Donald Trump administration has made clear that it will remove any potential restrictions on the supply of American hydrocarbons and withdraw regulations that may reduce domestic demand, such as fuel economy standards that disadvantage ICE vehicles vis-a-vis EVs.<sup>17</sup>

But global demand may be a problem for plans to bolster oil and gas. Nearly every energy forecaster agrees that by around 2030, crude oil demand will plateau, with long-term consequences for U.S. exports and business opportunities abroad.<sup>18</sup> One key driver is China’s transition to EVs. China’s gasoline consumption peaked in 2021 and is now down 6.4 percent, with EVs constituting over half of all light-duty sales and an increasing share of heavy-duty vehicles.<sup>19</sup> Both trends will continue to dampen oil demand in the world’s



largest market for crude oil.<sup>20</sup> These trends also risk impacting emerging and developing markets: from Brazil to Ethiopia, staggering amounts of Chinese EVs are being sold in these countries, which could further impact fuel demand.<sup>21</sup> China is also piloting programs for sustainable aviation fuel and marine fuels that would decrease oil demand from those sectors.<sup>22</sup>

There are also warning signs that the U.S. liquefied natural gas (LNG) boom could be short-lived. While the United States' export capacity for LNG is slated to double by the end of the decade, analysts have raised concerns that global LNG markets will be well supplied and demand is unlikely to match what the country hopes to unleash.<sup>23</sup> Countries may offer LNG deals to the United States as diplomatic negotiating tools, but this will not alter economic realities in power markets. Europe's transition from Russian pipeline gas to the global LNG market can only happen once. In addition, developing countries including Pakistan and Cameroon are importing record quantities of Chinese solar panels, which unlike gas-fired power plants, do not require the constant exchange of scarce foreign dollars for energy imports.<sup>24</sup>

Even if oil and gas demand persists above projections, the scale of clean technology growth and opportunity is too big to ignore. In the scenario where clean technologies are most aggressively deployed, annual global investment in low-carbon energy systems will exceed \$6 trillion by 2030, according to BloombergNEF.<sup>25</sup> This is a market opportunity the United States cannot afford to let slip away; it should take clean energy technology and supply chains seriously.

## **The Global Competition for Developing and Deploying Clean Energy Tech Is Intensifying**

Since the passage of the U.S. Inflation Reduction Act (IRA), other countries have continued to invest in their bids for technology leadership. Japan, South Korea, the European Union, and, of course, China all have industrial policies for solar, wind, and batteries, among other clean technologies.<sup>26</sup> Indonesia, Mexico, Brazil, and India are working on new strategies designed to position their countries in clean energy supply chains.<sup>27</sup> India's Production Linked Incentive scheme, which began before the IRA, has funneled billions of dollars to domestic solar, battery, and hydrogen production in pursuit of developing an industrial base and positioning India as an alternative clean tech producer to China.<sup>28</sup> Emerging economies such as Morocco, Vietnam, and Serbia have received investment from both China and Europe in the hopes of emerging as new energy middle powers.<sup>29</sup>

One clear indication of the transition has been the response of the Gulf states. While petroleum powers such as Saudi Arabia and the United Arab Emirates (UAE) continue to invest in the oil and gas that have made them rich, they also have serious economic diversification strategies focused on clean energy.<sup>30</sup> Middle Eastern nations are making strategic investments in solar, financing projects in Indonesia and Egypt and building domestic manufacturing at home.<sup>31</sup> These investments are pushing the limits of what clean power can deliver, as seen with the UAE's recent gargantuan solar project that has enough

battery storage to provide round-the-clock power for local data centers.<sup>32</sup> Over the rest of the 2020s, Saudi Arabia will invest more in renewable energy and clean hydrogen than in upstream oil and gas.<sup>33</sup> Most interestingly, the Gulf states are investing in critical minerals extraction and processing projects. They understand that critical minerals will enable their capital to generate long-term wealth and hedge against the prospect of decreasing hydrocarbon rents.<sup>34</sup>

Fossil fuels have strengthened the United States throughout history and especially in recent decades, as the shale revolution has turned the nation into the world's largest oil and gas producer.<sup>35</sup> But if investment in fossil fuels today comes at the expense of the investments necessary to win the global battle for clean energy, it would be shortsighted and risks locking the United States out of essential geostrategic technologies and minerals of the twenty-first century. In the long term, it could risk rendering American energy assets outdated incumbents: stallions in the era of Ford's Model T.

Voices across the political aisle agree: the United States cannot cede leadership in the technologies of the future to China and other countries.<sup>36</sup> China's industrial strategy poses challenges not just to U.S. manufacturing but to long-term technological leadership and economic security. The United States must strategically and selectively compete through a comprehensive response that incorporates industrial policy, technology standards, and coordination with allies.

## The U.S. Is Losing the Race to Produce the Technologies of the Future

The bipartisan CHIPS and Science Act recognized a fundamental truth: America's prosperity and global position depend on technological leadership.<sup>37</sup> But simply onshoring the production of incumbent chips, batteries, and reactors misses the point. The United States needs an *innovation first* policy that can pragmatically target products and processes of the future. With the IRA and the Bipartisan Infrastructure Law, the United States has gained ground in the race for certain future technologies. However, it is still miles behind China and other countries in critical areas such as minerals and subcomponents.<sup>38</sup> China intends to be the clean tech hegemon of this century, and it is deploying the resources to get there.<sup>39</sup> Table 1 shows that China's global market share has grown in most supply chain segments since 2021.

**Table 1. Change in China's Share of Global Manufacturing Capacity Since 2021\***

Technology	Stage	Change in China's Share Since 2021	China's 2023 Share
Solar	Modules	Increase	81%
Wind	Nacelles	Increase	68%
Batteries	Cells	Increase	82%
Electrolyzers	Stack Assembly	Increase	68%
Heat pumps	Final Assembly	Decrease	39%
SAF	Production Capacity	Decrease	17%
CCUS	Total Installed Capacity	Consistent	10%
DAC	Total Installed Capacity	Consistent	0%
Low Emissions Steel	Production Capacity	Consistent	32%
Low Emissions Aluminum	Production Capacity	Consistent	62%
Alternative fuel ships	Ship Assembly	Increase	53%
Low Emissions Ammonia	Production Capacity	Increase	< 10 %
Geothermal	Annual Installations	Consistent	0%
Nuclear	Annual Installations	Increase	57%

Source: "Energy Technology Perspectives," International Energy Agency, November 2024, <https://iea.blob.core.windows.net/assets/93db951b-afae-48fd-a2f8-bce22f24c625/EnergyTechnologyPerspectives2024.pdf>; Carnegie analysis of IRENA, BNEF, World Nuclear Association, DNV, Global Energy Monitor, Mission Possible Partnership, and U.S. Department of Energy data.

Note: Geothermal and nuclear "Annual Installation" figures are based on a forward-looking five-year annual average of installations. Table 1 includes information on end-stage manufacturing capacities. For a full assessment of upstream components, please see the related publication, "Assessing Progress in Building Clean Energy Supply Chains: The Technical Paper of the U.S. Foreign Policy for Clean Energy Taskforce."

While the United States is still a world leader in primary innovation—generating new science and new technologies—it continues to lag in commercializing new technologies, getting things built, and maintaining a manufacturing and industrial base.<sup>40</sup> There is an enormous opportunity at stake. U.S. firms are currently innovating breakthrough energy technologies across sectors—from batteries to clean baseload power—that could put the country back in the race for these cutting-edge systems of the future. The United States' powerful venture capital ecosystem cannot bring new products to market while rebuilding the industrial base on its own.<sup>41</sup>

To push ahead in this race, the United States needs a bipartisan industrial policy that is consistent across presidencies and Congresses. This industrial policy should diversify supply chains to reduce overreliance on any foreign nation. It must focus on leapfrog opportunities where the United States can win in developing the next generation of technology, rather than trying to compete across the board. And it will require the United States to work with foreign partners who will make win-win deals that make America stronger.

# Why Building Overseas Clean Energy Supply Chains Matters

The United States must build clean energy supply chains abroad to achieve the following four goals.

## Create Geopolitical Leverage

U.S. global leadership hinges on taking a forward-looking approach to international diplomacy. China has built up strong global relationships through its overseas investments and by delivering good products at a low price. By investing in clean energy supply chains, it both secured a strong position in critical supply chains and curried favor with numerous countries.<sup>42</sup> The United States and its allies must respond. To be effective, the response must mobilize large amounts of capital to deliver real economic and development value to developing and emerging economies. This means allowing countries to exercise their sovereignty and gain a genuine foothold in global value chains. The United States must be able to offer other countries what they demand, which in many places is not just oil and gas but also clean energy technologies, including nuclear, geothermal, and batteries.

## Bolster National Security with Dual Use Technologies

Many clean energy technologies have military applications.<sup>43</sup> Lithium-ion batteries, for example, are essential to a modern military force.<sup>44</sup> Drones provide a vivid example: the small, cheap, quiet, and agile fighting units are a critical capability enabled by electric technology like batteries and magnetic motors (also two primary components in EVs).<sup>45</sup> Advanced nuclear microreactors and geothermal systems could help ensure that U.S. military installations are resilient, prepared, and not subject to fuel cutoffs. The United States cannot allow the electrification of military force to be led and controlled by other states. It must lead in the frontier of such dual use technologies and sufficiently de-risk the supply chains for these elements.

## **Develop Knowledge that Supports Long-Term, Broad-Based Economic Growth**

Whether the language used to describe it is “energy dominance” or “energy abundance,” investment in clean energy technologies and their supply chains creates economic spillovers that benefit the whole economy.<sup>46</sup> America has prospered in the past by leading energy and technology revolutions, not by propping up old systems.<sup>47</sup> Investment in new technologies and their supply chains will create economic spillovers that benefit the whole economy. For example, an offshore wind industry creates demand for steel alloys, ships, and rare earth magnets, while a battery industry could unlock know-how in advanced material production. The countries that benefit from new technologies secure strong industrial positions. The United States can lead in next generation energy technologies with smart, strategic investment in leapfrog opportunities today.

## **Reduce Reliance on Foreign Powers and Secure Energy Autonomy in the Long Term**

Developing clean energy technologies provides an insurance policy in a world where future oil and gas demand is clouded by China’s rise as a clean tech empire. The United States already has significant clean power in place or under construction, and continued access to these resources and technologies will support U.S. energy generation in the long run, especially to ensure the scale of power needed for AI’s explosive load growth.<sup>48</sup> Supporting the supply chains for these technologies, at least up to a level appropriate to their potential significance to U.S. economic and security interests, is smart policy.<sup>49</sup>

In short, strategic work on overseas supply chains will generate geopolitical, national security, economic, and insurance benefits. The first Trump administration made progress on this issue: working with Congress on the International Development Finance Corporation (DFC), initiating tariffs to protect American manufacturing, and sounding the alarm on America’s critical mineral vulnerabilities.<sup>50</sup> The Joe Biden administration built on this legacy by accelerating domestic manufacturing and expanding bilateral and multilateral engagement on mineral security and technological cooperation. This legacy can be continued by reinvigorating U.S. strategy for overseas technology development.

## What Success Looks Like

To achieve these four, interlinked goals, the United States needs to combine domestic industrial policy and international collaboration to build supply chains and advance leapfrog technologies. Knowing when to onshore (bring production home), friendshore (bring production to trusted partner countries), or develop a new competitive technology pathway requires a strategic framework that identifies strengths and weaknesses.

### Onshoring and Friendshoring

The United States should onshore when it has existing economic strengths (most importantly, an industrial base, a trained labor force, and valuable intellectual property), high domestic potential to economically produce a technology, or critical national security interests in the technology. The United States should friendshore when it simply cannot produce the material (for example, many critical minerals) or when creating competitive economic advantages would be onerous (such as where the United States lacks the tacit knowledge or cost-effective industrial base to compete). For example, while the United States can and will mine more metal for energy technologies—the Trump administration aims to make the United States the “leading producer” of minerals<sup>51</sup>—it simply lacks the reserves and expertise to onshore all needed production.<sup>52</sup> It will need to friendshore nickel, copper, graphite, and other key metals but must do so in a focused, strategic manner.

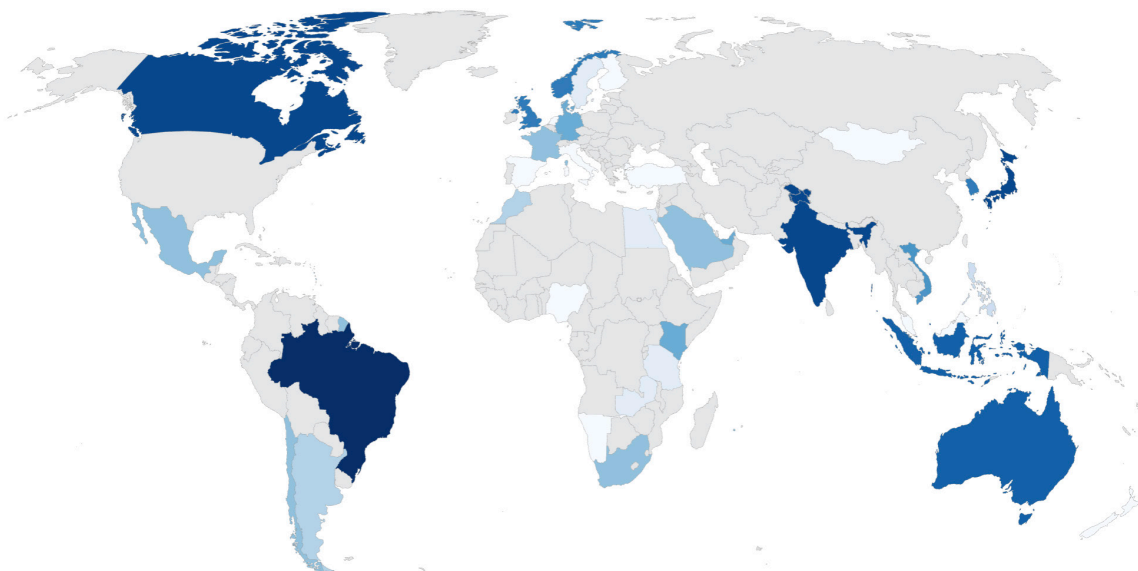
Onshoring is also limited by the fact that all modern technologies have global value chains because knowledge about how to produce and innovate is highly localized and therefore distributed across countries. While the United States seeks to manufacture solar panels and batteries, it cannot do this without learning from partners and potentially even adversaries. Many U.S. solar and battery projects, for example, are led by Korean, Japanese, and European firms.<sup>53</sup> If U.S. firms are to be internationally competitive, some will need to work with foreign companies to transfer the knowledge domestically. Figure 1 illustrates where the United States has, over the past two administrations, enacted bilateral diplomatic efforts for clean energy technologies and measures the number of sectors covered in each country.

This taskforce’s research on supply chain resilience also helps to calibrate the level of ambition that should be pursued in onshoring and friendshoring. The United States should go all-in for some technologies, and merely hedge for others. To compete, the United States must choose strategic priorities, rather than trying to compete across all segments.<sup>54</sup> This helps avoid spreading resources too thin while maximizing potential technologies with high levels of opportunity.

## Figure 1. Mapping U.S. Clean Energy Foreign Policy

Diplomatic Efforts Across 14 Clean Energy Supply Chains Span the World with Regional Anchors

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Source: Compiled documents from the White House Briefing Room, U.S. Department of Energy, U.S. Department of State, U.S. Department of the Treasury, Office of the United States Trade Representative, U.S. Trade and Development Agency, U.S. Agency for International Development.

Notes: Sample size includes forty of the world's largest economies relevant across clean energy supply chains. This map is illustrative; boundaries, names, and designations used do not represent or imply any opinion on the part of Carnegie or the authors. Dotted lines represent approximate disputed boundaries and contested territory..

In strategic areas, the United States should identify targets for onshoring and friendshoring that create sufficient resilience against geopolitical shocks (for example, onshore 50 percent of expected demand and friendshore 50 percent). In less strategic areas, targets could be lower (for example, 30 percent domestic plus 30 percent friendshoring). This will allow the United States to focus its energies where it has existing innovation advantages that could translate to manufacturing strengths and, eventually, durably competitive industries.

## Leapfrogging

A second critical strategy is to develop leapfrog plays. Rather than trying to catch up to China in current generation technologies (such as conventional solar panels and lithium-ion batteries), the United States should focus on developing and commercializing next generation technologies where supply chains and market dominance are not yet established. This would leverage the United States' innovation advantage while helping secure a leading edge in the industrial base for clean energy production. In some instances, leapfrogging could entail circumventing supply chain risks—like making solid-state batteries that do not need Chinese graphite—or unlocking new potential from a technology vertical, like geologic hydrogen or supercritical geothermal resources.<sup>55</sup>

This strategy entails bolstering investment in research and development (R&D) for emerging technologies such as solid-state batteries, next generation geothermal, and advanced nuclear reactors. Second, it requires developing sector-specific know-how, expertise, and regional ecosystems where new advancements can be tested in sandboxes. Third, innovative financing and derisking measures will be needed to address the “missing middle” of bringing first-of-a-kind pilots to demonstration scale.<sup>56</sup> Lastly, and most importantly, it will entail creating the demand-pull policies needed to accelerate commercialization of these new technologies both at home and abroad.

## Identifying the Optimal Strategy for Each Clean Energy Technology

Based on supply chain and economic analysis, table 2 demonstrates how different technology verticals score based on five key questions:

- **Domestic industrial potential:** Does the United States have (or is it developing) an industrial base to manufacture this technology?
- **Supply chain resilience:** What is the extent of supply chain risk at the present time?
- **Innovation opportunity:** Can domestic industries innovate new systems that are close to reaching the market and can they result in competitiveness?
- **National priority:** To what extent does this technology have national security and macroeconomic spillovers?
- **Global net-zero market:** What is the potential size of the global market opportunity for this technology in a net-zero scenario?



**Table 2. Identifying Strategies for U.S. Clean Energy Success: Maintain, Onshore, Friendshore, or Leapfrog?**

	Domestic Industrial Potential	Supply Chain Resilience	Innovation Opportunity	National Priority	Global Net-Zero Market	Strategy
Solar	Medium	Low	Medium	Low	Low	<b>Friendshore:</b> Develop a supply chain for silicon ingots and wafers that circumvents China in places such as Vietnam, India, and the Gulf states; expand commercial ties in the Quadrilateral Security Dialogue (Quad) plus South Korea for perovskite solar cells.
Wind	Medium	Medium	Medium	Low	Low	<b>Onshore:</b> Maintain domestic onshore production while expanding offshore to promote domestic supply of alloys, magnets, and ships.
Battery	High	Low	High	High	Medium	<b>Leapfrog and Friendshore Upstream:</b> Promote next generation tech, such as lithium metal and long duration storage at home and abroad to phase-out Chinese tech; expand Mineral Security Partnership (MSP) for chokepoints.
Magnet	Medium	Low	High	High	Low	<b>Onshore and Leapfrog:</b> Onshore processing and metallization through public procurement and domestic content and continue research and development (R&D) for non-rare earth element magnets.
Heat Pump	Medium	High	Low	Low	Low	<b>Maintain:</b> Design incentives for heat pump producers to procure metals from domestic and allied sources and advance domestic labor force for installations.
Electrolyzer	Low	Medium	Low	Low	High	<b>Friendshore:</b> Focus on proton exchange membrane (PEM) technology and foreign policy for iridium in South Africa and Canada and continue R&D for next generation clean hydrogen.
Nuclear	Low	Medium	Medium	High	Medium	<b>Onshore:</b> Innovate on domestic strength and leverage DFC/EXIM for exports of incumbent and next generation reactors. Friendshore uranium fuels via Sapporo 5.
Geothermal	High	High	High	Low	High	<b>Leapfrog:</b> Promote next-generation geothermal at home and in Europe, Southeast Asia, and Africa, while expanding and diversifying supply chains. Pursue R&D for supercritical resources at home and with key players like Iceland or Italy.

	Domestic Industrial Potential	Supply Chain Resilience	Innovation Opportunity	National Priority	Global Net-Zero Market	Strategy
Clean Steel	Medium	High	Medium	High	Medium	<b>Onshore:</b> Promote electric arc furnace (EAF), hydrogen in direct reduced iron (H2-DRI) production, and novel low-carbon processes with the aim to export into the European Union's and United Kingdom's carbon border adjustment mechanism (CBAM).
Aluminum	Low	Medium	Low	High	Medium	<b>Onshore and Friendshore Upstream:</b> Continue onshoring aluminum smelters while deploying public finance to scale bauxite extraction in Australia, Canada, and Brazil.
Clean Ammonia	High	High	High	Medium	High	<b>Onshore:</b> Indigenize clean ammonia production and promote exports for fertilizer and as fuel via USTDA and ITA, with a focus on Japan, South Korea, and the EU.
Carbon Capture, Utilization, and Storage (CCUS)	Medium	High	Low	Low	High	<b>Maintain:</b> Leverage U.S. industry expertise and export to key markets in Europe, Australia, Japan, South Korea, and the Gulf states—some emerging and developing markets like Indonesia and Chile.
Direct Air Capture (DAC)	High	High	Low	Low	High	<b>Maintain:</b> Finalize long-term demonstrations, ensure viability of domestic pipeline, and consider long-term export markets (such as Kenya, Canada, and the Gulf states).
Sustainable Aviation Fuels	High	High	Medium	Low	Medium	<b>Leapfrog:</b> Focus domestic production to third generation fuels and pair foreign development to co-locate with CCUS and DAC hubs abroad.
Ships	Low	Medium	Low	High	Medium	<b>Onshore:</b> Work with Japanese and South Korean conglomerates to re-industrialize the U.S. maritime manufacturing base and ensure that U.S. ships are ammonia and methanol ready.

Note: For analysis on specific minerals, please see the taskforce's "Assessing Progress in Building Clean Energy Supply Chains: The Technical Paper of the U.S. Foreign Policy for Clean Energy Taskforce."

**Domestic industrial base** is quantified by U.S. current and pipeline production capacity divided by expected U.S. demand in 2035. For geothermal and nuclear, present capacity was measured as a five-year average of production based on annual capacity additions. (Please see the Annex for exact metrics.) **Supply chain resilience** is based on internal analysis of Chinese and Russian shares of manufacturing capacities of these technology verticals and critical upstream inputs. (Please see the Annex for exact numbers on supply chain vulnerabilities). **Innovation potential** is based on Milo McBride's working paper "Catching Up or Leaping Ahead? How Energy Innovation Can Secure U.S. Industrial Stature in a Net-Zero World" from the Carnegie Endowment for International Peace, September 19, 2024. "Low" means that there are no observed next-generation technologies in that vertical, "medium" means that there are next-generation systems with varying likelihood to supplant the incumbent (rated both "low" and "medium" in the Catalytic Impact on Resilience metric), and "high" means that the next-generation technology could fully supplant the incumbent and its supply chains. **Global gap to net-zero** is the sector's production gap to net-zero manufacturing capacity benchmarks based on the global production gap divided by the global current capacity. (Please see the Annex for exact metrics and the associated technical paper Allan et al. for further analysis.)

These parameters help identify optimal, sector-specific industrial and foreign policy strategies. Although solar photovoltaic (PV) is the fastest growing energy source globally and unilaterally dominated by China, it is not in the interest of the United States to onshore an entire supply chain that has little chance of competing with Chinese incumbents and no national security importance.<sup>57</sup> Instead, the United States should focus on diversifying the global solar supply chain—specifically financing upstream components like polysilicon, ingots, and wafers—in third party countries such as India, South Korea, Vietnam, and the Gulf states. Simultaneously, the United States should focus on commercializing next generation, perovskite solar cells with partners in the Quadrilateral Security Dialogue (Quad) and South Korea.

Batteries and magnetic motors are key to national and economic security given their importance to defense, automobile, and consumer electronic sectors. While both are developing a domestic industrial base, they come with severe supply chain risks because of Chinese graphite and rare earths.<sup>58</sup> The United States should focus its battery strategy on the next generation of chemistries: silicon anode (which can be made without graphite), lithium metal (which does not require graphite), and lithium sulfur (which solely requires lithium).<sup>59</sup> As U.S. lithium metal and sulfur firms come to market, the country should promote its companies that can utilize existing lithium-ion factories, especially in Europe, to phase out the importance of Chinese dominated minerals and battery manufacturing. While the United States is developing magnet technologies that do not need rare earths, they are less advanced than next-generation batteries, implying that the United States should work with close security allies (such as the Five Eyes) to onshore a non-Chinese rare magnet supply chain while continuing to experiment with alternatives.<sup>60</sup>

Other technologies such as wind, heat pumps, and electrolyzers require less aggressive approaches that largely maintain course. The United States has a decent domestic industrial base and resilient supply chains for wind and heat pumps, but there is little present opportunity to innovate these systems and produce export markets.<sup>61</sup> Instead, the United States should maintain these industrial bases but design new incentives for them to act as demand drivers for domestic or allied-produced minerals, high-grade alloys, magnets, and ship building (in the case of offshore wind). For clean hydrogen production, the United States should consider friendshoring electrolyzer technology and its mineral supply chains while considering theoretical costs and technology limitations in pursuit of unlocking alternative hydrogen processes.

Clean firm power generation like nuclear and geothermal represent important new opportunities. The United States should continue to revitalize its domestic nuclear industrial base by producing incumbent and next generation reactors, while coordinating with allies in the Sapporo 5 pact to diversify away from Chinese and Russian uranium supply lines. Although recent industrial policy has unleashed enormous opportunities for nuclear energy, our analysis indicates that geothermal energy—which has a massively expanded resource potential thanks to the fracking revolution—represents a unique area of industrial strength, supply resilience, and market opportunity.<sup>62</sup> Future policy should act accordingly

and focus all efforts on bringing next generation geothermal to market at home and in high-opportunity countries through de-risking measures for drilling and funding for demonstration. Although outside the scope of this analysis, advanced grid technologies including long-duration storage pose a similar and perhaps undervalued opportunity for export.

Industrial products like clean ammonia, steel, and aluminum should be onshored given their macroeconomic importance, present industrial base, and defense demand. Western production will struggle to compete with Chinese overcapacity without explicit efforts to create a non-Chinese market and build new technology pathways to disrupt traditional production methods. The United States should continue to bolster its low-carbon advantage in industrial products through federal government procurement, specifically emboldening new processes to make clean metals.<sup>63</sup> Similarly, the United States should maintain its edge in carbon capture and direct air capture technologies, ensuring that projects being developed at home are world-leading while, in the long term, promoting U.S. tech in key markets, particularly in Gulf countries. Sustainable aviation fuels could also represent an opportunity given U.S. expertise in refining and the scale of net-zero opportunity, but cost premiums are presently prohibitive, implying further R&D is necessary.<sup>64</sup>

Ships are a unique challenge. The United States has lost its ability to manufacture civilian and military ships as China has increased control of the global shipbuilding market and various countries have worked to develop alternative, low-carbon fuels.<sup>65</sup> The United States should seize this moment by collaborating with Japanese and South Korean conglomerates to onshore a shipbuilding industrial base to manufacture ships capable of running on low-carbon fuels. In doing so, it should simultaneously develop ammonia- and methanol-ready refueling bunkers in line with clean shipping corridors to Asia and Europe. Both of these fuels present high opportunities for the United States given its dominance in energy production and refinement, existing bunkering infrastructure along the Gulf and Pacific coasts, and early prestige in startups developing alternative engines.<sup>66</sup>

Friendshoring critical minerals production (including for copper, nickel, lithium, graphite, and rare earths) will require an all-hands-on-deck approach, with the United States and its allies working together. This should include the continuation of onshoring efforts through faster access to financing and permitting, while pursuing multilateral and bilateral mineral partnerships with explicit financial backing via U.S. agencies. The United States should continue efforts to maintain high labor and environmental standards in foreign mining projects that include transparency and strong governance in its dealmaking. For more niche, illiquid, yet strategically relevant metals (such as rare earths), the federal government could continue to investigate opportunities in price insurance, like contracts for difference, to hedge against volatile fluctuations as well as civilian-use stockpiling to stimulate demand drivers akin to the Strategic Petroleum Reserve. All the while, the United States and its partners must accelerate R&D in mineral processing and advanced material production to build the whole supply chain from mines to critical components.

Finally, the United States should continue to collaborate with its allies in mutually unlocking high reward technologies that can trigger step changes in energy and climate power dynamics. Supercritical geothermal, nuclear fusion, and geologic hydrogen all offer potential opportunities for clean energy abundance and play to America's strengths of subsurface expertise and advanced fusion science.<sup>67</sup> While the United States has a strong early position, these supply chains, like others, will likely be global. The United States can and should work to lead sector specific coalitions for frontier technology alongside countries looking to de-risk from, and compete with, China.

## How to Achieve Success

The United States needs a focused, pragmatic, and coordinated foreign policy for clean energy supply chains. Under the past two administrations, the country began to enact foreign policy that advances its interests in energy technology and related minerals—but with shortcomings. Reflecting on these years, some political and financial capital was invested in low-return areas that were not crucial to developing U.S. energy technology, security, or dominance—let alone to reducing emissions. Going forward, U.S. policymakers, diplomats, and trade delegates can leverage their stature and tools to advance high-opportunity sectors by addressing supply chain vulnerabilities and identifying American technologies with export potential.<sup>68</sup>

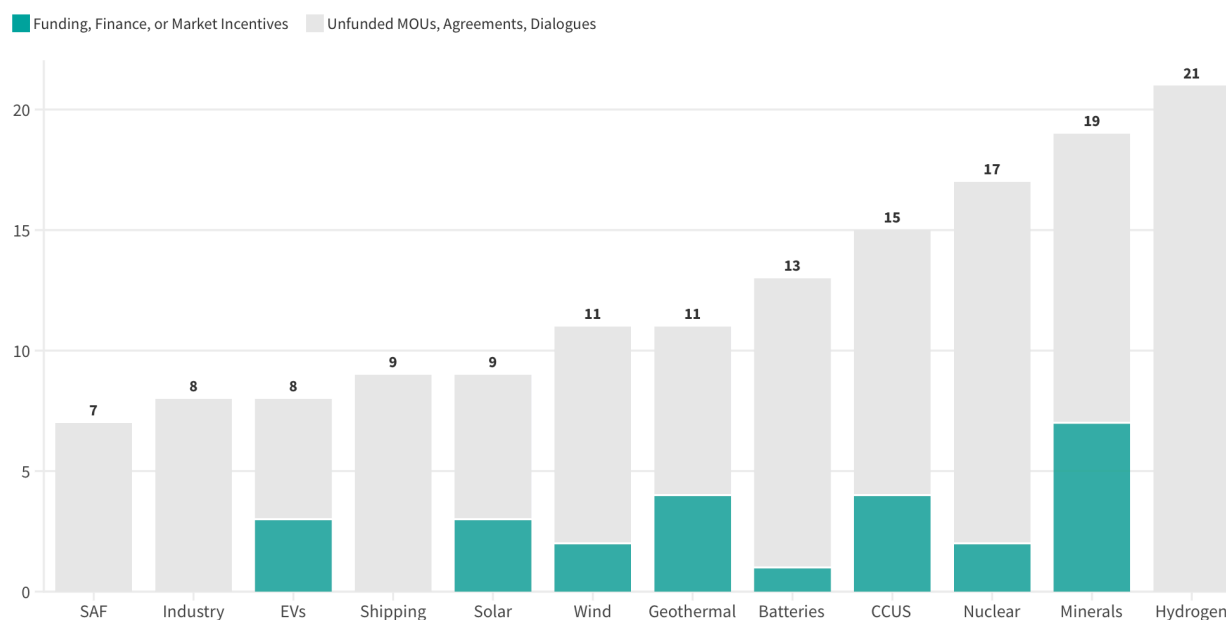
Thus far, the United States has focused its diplomatic muscle primarily on several key clean technology verticals—minerals, hydrogen, and nuclear—across a diversity of aligned and non-aligned actors in the BRICS+ and the Organisation for Economic Co-operation and Development (OECD). Alongside this fragmented bilateral strategy, some key minilateral efforts emerged, such as the Mineral Security Partnership (MSP) and coordination with members of the Sapporo 5 agreement on advanced nuclear reactors. Such partnerships are essential to building durable, multi-stakeholder buy-in and non-Chinese pipelines for technological build-out. But they represent piecemeal efforts sometimes informed by low-hanging political fruit and routinely without the financial capital required. They have not yet resulted in a cohesive foreign industrial strategy.<sup>69</sup>

The United States needs a robust international industrial policy for clean energy supply chains. This can be achieved by transforming the Partnership for Global Infrastructure and Investment (PGI) into a more focused and strategic effort. To deliver on its promise, the PGI needs a clear policy framework to enable the integration of a wide range of existing initiatives into more targeted domestic and international processes.

The goal must be to use the PGI to bring together U.S. foreign tools, bilateral diplomatic initiatives, multilateral partnerships, and international financial institutions into a comprehensive global collaboration. Increased coordination both within the U.S. government and with its external partners is necessary to achieve the level of strategic action and investment scale to compete with China.

## Figure 2. U.S. Clean Energy Outreach

Bilateral Clean Energy Engagement in Select Countries since 2016



Source: Compiled documents from the White House Briefing Room, U.S. Department of Energy, U.S. Department of State, U.S. Department of the Treasury, Office of the United States Trade Representative, U.S. Trade and Development Agency, U.S. Agency for International Development

Note: Sample includes 40 of the world's largest economies and relevant players in clean energy supply chains

We propose an overarching framework to focus the work of the PGI with five key elements:

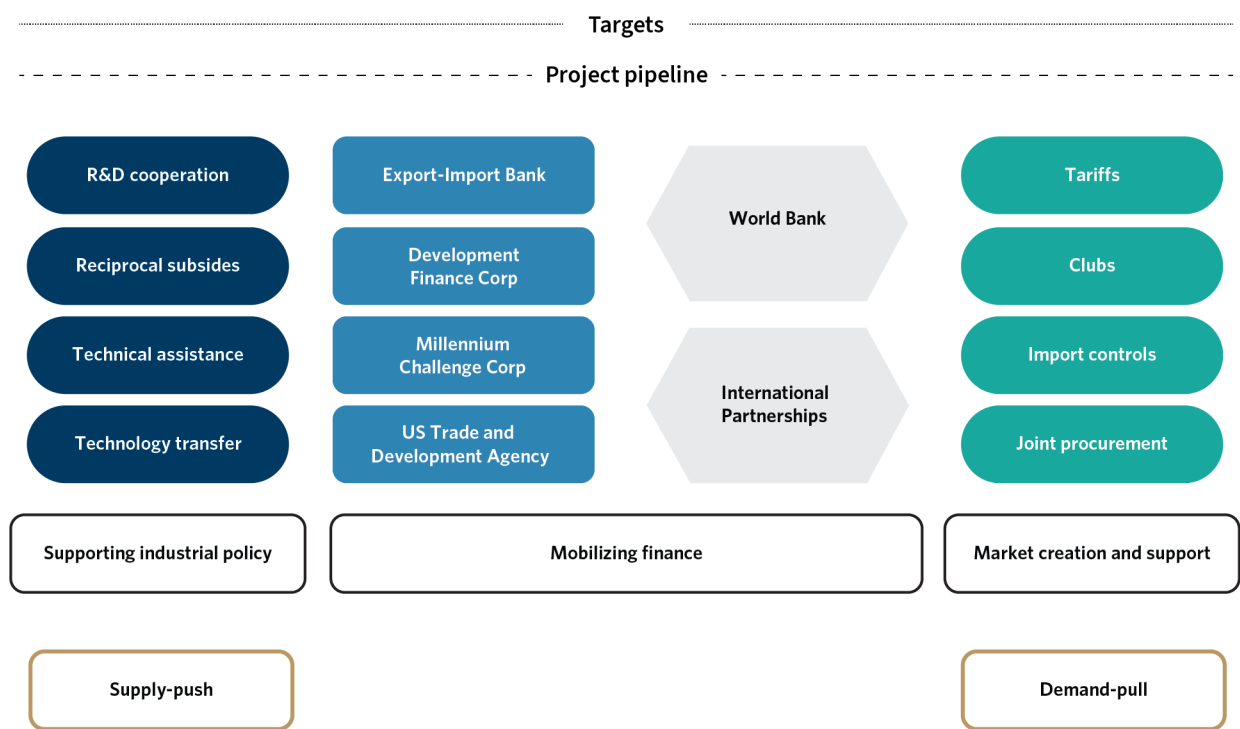
1. **Targets:** Quantitative goals indexed to bottlenecks and geopolitically significant nodes to focus the work of the United States and its partners<sup>70</sup>
2. **Priority project pipeline:** An organized interagency process for advancing priority projects
3. **Support for industrial policy:** Technical assistance and bilateral support for countries developing their own strategic approaches to building energy security
4. **Finance:** Mobilizing money from domestic sources—such as the DFC, the Export-Import Bank (EXIM), U.S. Trade and Development Agency (USTDA), and the Defense Production Act—and international sources (the World Bank, regional development banks, and partner sovereign wealth funds, among others)
5. **Market creation and market shaping:** Create demand-pull for de-risked supply of key technologies and materials by creating domestic and global markets

Counterintuitively, the PGI needs to be simultaneously broadened *and* focused. It must be broadened by serving as an umbrella to bring together the foreign policy tools created during the first Trump administration and the Biden administration. It would serve as a coordinating body for the wide variety of foreign policy experiments initiated over the past eight years. It must be focused by being disciplined to meet supply chain targets.

This new PGI needs a project pipeline that flows directly from the targets. It should assign each priority project to a country that will lead on project development and financing. For projects the United States leads, it should organize its foreign policy tools through Katie Auth’s proposal for Energy Security Compacts (ESCs).<sup>71</sup> As Auth argues, the United States needs a mechanism to provide holistic support for energy project development abroad. ESCs would take the form of bilateral compacts between the United States and priority countries to create a pipeline of bankable projects. It would create a structured interagency process to assess priorities, developing coordinated investment plans across ten U.S. agencies, and deliver targeted support ranging from early-stage feasibility studies to large-scale project financing.

The compacts would also provide a platform for technical assistance on industrial policy, which was pioneered by the Clean Energy Supply Chain Collaborative in the Biden White House.<sup>72</sup> Further, they would increase the impact of the DFC, EXIM, and other agencies while strengthening U.S. influence through more effective investment.

Figure 3. A Framework for Targeted Foreign Industrial Policy



Source: Author's illustration

On the supply side, joint industrial policy means coordinating R&D and technical assistance. The United States and its partners do a lot of this right now, but in an opportunistic rather than systematic and targeted fashion. They currently do not do enough to create reciprocal or aligned subsidies. Reciprocal subsidies within clubs allow allies to compete with one another through markets while protecting their industries from Chinese non-market competition.

To fund priority projects coming through the pipeline, the United States and its partners will need to mobilize finance through domestic and international sources. This means strategically aligning the World Bank with clean energy priorities, but also organizing sovereign wealth funds and pension funds. Specific technology partnerships, such as the Sapporo 5 nuclear cooperation group or the Global Partnership for Climate Smart Infrastructure, would also be organized under the broadened PGI umbrella.

Finally, creating secure demand is essential to protect markets outside of China from intense non-market competition. China can, for example, depress the prices of critical minerals or solar modules unless the United States and partners create secure markets. Tariffs are a piece of this, but, on their own, they will not create competitive industries. They risk raising costs and prompting drags on productivity. Joint procurement can also be used to bolster nascent industries and create the critical mass needed to secure ex-China supply.

To operationalize this plan, the PGI needs to be upgraded from an initiative housed within the State Department to a directorate of the national security advisor or an independent coordinating office within the White House. A critical problem, however, is that the National Security Council team or another coordinating office does not have direct access to the complex supply chain analysis and project evaluation teams that would be needed to make the PGI more strategic. Such teams are currently dispersed across the Department of Energy, the Department of State, the Department of Commerce, the DFC, and so on. Instead, a consolidated international industrial policy secretariat must be created within the National Security Council or an independent Energy Security Compacts Coordinators Office (as proposed by Auth and Moss).<sup>73</sup> Dedicated expert capacities bringing together technological, financial, and supply chain knowledge must be built to inform and coordinate all the aspects of this framework.

In the absence of a strong, independent office, the PGI will continue to be driven by the schedules of the principals instead of the national interests of the United States. If the country is to regain geopolitical advantage, strategic investments need to be coordinated and executed in a more focused way and backed with larger and more flexible financial tools.



# Conclusion

Four main recommendations flow from this analysis.

**1. Focus domestic industrial policy on leapfrog opportunities and use foreign policy to stimulate export markets and advance joint R&D.<sup>74</sup>**

- Congress should demand a report on the state of U.S. industrial policy and competitiveness and use it to create bipartisan consensus around long-term technological and material priorities.
- The report's findings should inform key policies to accelerate early stage R&D through related tax policy and government funding, prepare the domestic labor force, incubate regional innovation hubs, and propose long-term demand-pull incentives to drive clean energy systems to market.
- Foreign policy should be leveraged specifically for science diplomacy that targets coordinated R&D as well as trade and diplomatic efforts to stimulate early stage exports of novel U.S. technologies.

**2. Broaden and focus the Partnership for Global Infrastructure and Investment with clear supply chain targets, an improved domestic policy process, and an integrated set of foreign policy tools.**

- The United States and partners need to create a working list of targets to focus the work of the PGI. The targets should be sector specific and benchmarked to expected ex-China demand.
- The executive branch through the National Security Council could work with the State Department to bring together existing programs and technical assistance efforts to advance clean energy supply chains under the PGI. The PGI should focus, as the Clean Energy Supply Chain Collaborative projects did, on building value-added processing and manufacturing overseas.
- The United States should use the PGI to create clubs for critical minerals, nuclear power, and steel and aluminum. These clubs should bring together supply-side coordination with market creation activities, such as harmonized tariffs. Such activities can be coordinated through the NSC-led interagency process, but new capacities will have to be built in the State Department to support project development and implementation.

**3. Create a domestic interagency process, such as the one proposed for Energy Security Compacts, to generate a project pipeline for building out overseas supply chains.<sup>75</sup>**

- The NSC and State Department must work together to integrate project pipelines into target-setting processes under the PGI to ensure that resources are focused on high priority technologies and minerals in key countries.
- The ESC process enables the United States to correctly match tools to problems in the project pipeline, so that DFC, EXIM, and other international dollars are used for the right projects based on their commercialization level or scale.
- This could be done within the NSC or by creating an independent coordinating office.

**4. Bolster the International Development Finance Corporation, the Export-Import Bank, and other agencies to make them proper tools of strategic industrial policy overseas.<sup>76</sup>**

- The DFC and EXIM will both be up for reauthorization by Congress in the next two years, presenting opportunities to expand the scale of funding. These should coincide with a bolstered USTDA to expand the potential for early stage projects.
- DFC will be reauthorized in 2025. It could be altered to increase how much it can spend in sum and on a project basis, as well as making it applicable to higher income countries. Additional financial alterations could include scoring projects as equity investments for greater flexibility and providing political risk insurance.
- EXIM's reauthorization in 2026 could include raising the default rate cap, creating a technology neutral definition of renewable energy (including manufacturing and mineral processing), and developing a new National Interest Account to crowd-in capital with other development financial institutions or sovereign wealth funds.

The U.S. Foreign Policy for Clean Energy Taskforce has made more detailed recommendations on leapfrog technologies; how a broadened and focused PGI could help rebuild geopolitical advantage; how to improve the DFC and EXIM, which can be found in our U.S. foreign policy mapping paper; and how ESCs can improve grants and aid.

**Annex 1: For Table One Identifying Strategies for U.S. Clean Energy Success: Maintain, Onshore, Friendshore, or Leapfrog?**

<b>Technology</b>	<b>Domestic Industrial Potential</b>	<b>Supply Chain Resilience</b>	<b>Global Net-Zero Market</b>
Solar modules	29.58%	81%	9%
Solar cells	23.19%	89%	12%
Solar wafers		94%	
Onshore wind nacelles	13.23%	60%	177%
Onshore wind blades		55%	
Onshore wind towers		43%	
Offshore wind nacelles	0%	76%	32%
Offshore wind blades		78%	
Offshore wind towers		60%	
Battery cells	52.18%	82%	373%
Battery cathode		73%	
Battery anode		96%	
Battery Electrolyte		86%	
Sintered permanent magnet	31.82%	92%	215%
Rare earth oxides		70%	
Rare earth mining		68%	
Electrolyzers	7.93%	68%	1,696%
PGM		41%	
Heat pumps	33.41%	39%	238%
SAF	67.24%	17%	3,500%
CCUS	43.58%	10%	6,632%
DAC	106.75%	0%	3,383,233%
Steel	15.47%	32%	422%
Iron ore		15%	
Aluminum	4.8%	62%	315%
Alumina		61%	
Bauxite		22%	
Alternative fuel ships	0%	52%	1,054%
Low Emissions Ammonia	105.89%	0%	10,133%

Technology	Domestic Industrial Potential	Supply Chain Resilience	Global Net-Zero Market
Geothermal	98.15%	0%	784%
Organic rankine cycle		0%	
Nuclear reactors	0.84%	58%	343%
Nuclear fuels (UO2)		23%	
Nuclear enrichment (SWU)		59%	
Nuclear processing (UF6)		44%	
Uranium mining (U3O8)		9%	

Domestic industrial base: Low = 0-10%, Medium = 10-50%, High = 50%+  
Supply Chain Resilience: Low = 90%+, Medium = 50-90%, High = 0-50%  
Global Net-Zero Market: Low = 0-250%, Medium = 250-750%, High = 750%+

Note: Magnet figures are based on 2023 production, rather than total manufacturing capacities. Information about SAF, CCUS, and DAC supply chains is scarce due to industrial nascency. Therefore, Domestic Industrial Potential, Supply Chain Resilience, and Global Net-Zero Market figures are benchmarked to total installed production/capture capacity. Domestic Industrial Potential and Global Net-Zero Market measures are included for end-stage products or processes. For information on available upstream component data, please see the associated technical publication “Assessing Progress in Building Clean Energy Supply Chains: The Technical Paper of the U.S. Foreign Policy for Clean Energy Taskforce.”

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