U.S. DEPARTMENT OF ENERGY

America's Strategy to Secure the Supply Chain for a Robust Clean Energy Transition

U.S. Department of Energy Response to Executive Order 14017, "America's Supply Chains"

February 24, 2022

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ABOUT THE SUPPLY CHAIN REVIEW FOR THE ENERGY SECTOR INDUSTRIAL BASE

This document, "America's Strategy to Secure the Supply Chain for a Robust Clean Energy Transition," lays out the challenges and opportunities faced by the United States in the energy supply chain as well as the Federal Government plans to address these challenges and opportunities. It is accompanied by several issue-specific deep dive assessments produced in response to Executive Order 14017, "America's Supply Chains," which directs the Secretary of Energy to submit a report on supply chains for the Energy Sector Industrial Base. The Executive Order is spurring the Federal Government to build more secure and diverse U.S. supply chains, including energy supply chains.

To combat the climate crisis and avoid the most severe impacts of climate change, the United States is committed to achieving a 50- to 52-percent reduction from 2005 levels in economy-wide net greenhouse gas pollution by 2030, creating a carbon pollution-free power sector by 2035, and achieving net zero emissions economy-wide by no later than 2050. The U.S. Department of Energy (DOE) recognizes that a secure, resilient supply chain will be critical in harnessing emissions outcomes and capturing the economic opportunity inherent in the energy sector transition. Potential vulnerabilities and risks to the Energy Sector Industrial Base must be addressed throughout every stage of this transition.

This DOE energy supply chain strategy report summarizes the key elements of the energy supply chain as well as the strategies the U.S. Government is starting to employ to address them. Additionally, it describes recommendations for congressional action. DOE has identified technologies and crosscutting topics for analysis in the one-year time frame set by the Executive Order. Along with this policy strategy report, DOE is releasing 11 deep dive assessment documents, corresponding to this report, covering the following technology sectors:

- carbon capture materials,
- electric grid including transformers and high voltage direct current (HVDC),
- energy storage,
- fuel cells and electrolyzers,
- hydropower including pumped storage hydropower (PSH),
- neodymium magnets,
- nuclear energy,
- platinum group metals and other catalysts,
- semiconductors,
- solar photovoltaics (PV), and
- wind.

DOE is also releasing two deep dive assessments on the following crosscutting topics:

- commercialization and competitiveness, and
- cybersecurity and digital components.

More information can be found at energy.gov/policy/supplychains.

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Nomenclature or List of Acronyms

APP	Affirmative Procurement Programs
ATVM	Advanced Technology Vehicles Manufacturing
BIL	Bipartisan Infrastructure Law, otherwise known as Infrastructure Investment & Jobs Act
CCS	Carbon Capture and Storage
CISA	Cybersecurity and Infrastructure Security Agency
CO_2	Carbon Dioxide
DFC	U.S. International Development Finance Corporation
DHS	U.S. Department of Homeland Security
DOC	U.S. Department of Commerce
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DOL	U.S. Department of Labor
DOS	U.S. Department of State
DRC	Democratic Republic of the Congo
ED	U.S. Department of Education
EERE	DOE Office of Energy Efficiency and Renewable Energy
EIA	Energy Information Agency
EPA	U.S. Environmental Protection Agency
EOP	Executive Office of the President
ERGI	Energy Resource Governance Initiative
ESIB	Energy Sector Industrial Base
EXIM	Export-Import Bank of the United States
FAR	Federal Acquisition Regulation
FECM	DOE Office of Fossil Energy and Carbon Management

FERC	Federal Energy Regulatory Commission
GHG	Greenhouse Gases
GW	Gigawatt
GW_{dc}	Gigawatt Direct Current
HALEU	High-Assay Low-Enriched Uranium
HVDC	High Voltage Direct Current
ICT	Information and Communications Technologies
IEA	International Energy Agency
IIJA	Infrastructure Investment and Jobs Act
IT	Information Technology
ITC	Investment Tax Credit
LED	Light-Emitting Diode
LIB	Lithium-Ion Batteries
LPO	Loan Programs Office
NASA	National Aeronautics and Space Administration
NDAA	National Defense Authorization Act
NDS	National Defense Stockpile
NIST	National Institutes of Standards and Technology
NRC	Nuclear Regulatory Commission
NREL	National Renewable Energy Laboratory
NSF	National Science Foundation
NSTC	National Science and Technology Council
OMB	Office of Management and Budget
OT	Operational Technology
PPA	Power Purchase Agreements
PSH	Pumped Storage Hydropower
PTC	Production Tax Credit

PV	Photovoltaics
R&D	Research and Development
RD&D	Research, Development, and Demonstration
SBA	Small Business Administration
TPCC	Trade Promotion Coordinating Committee
TWh	Terrawatt Hour
USDA	U.S. Department of Agriculture
USTDA	U.S. Trade and Development Agency

Executive Summary

The opportunity for U.S. global leadership on clean energy is enormous. On February 24, 2021, President Biden issued Executive Order 14017, "America's Supply Chains," directing the Secretary of Energy to submit a supply chain strategy overview report for the Energy Sector Industrial Base (ESIB). This report lays out the myriad challenges and opportunities facing the energy supply chain along with key strategies to secure America's position as a clean energy superpower in the years and decades to come.

The challenges are immense for the United States related to: raw material availability; manufacturing capacity; dependence on foreign supplies; worker training; global trade practices; cybersecurity; and research and data analysis needed to create the clean energy economy we need. But the opportunities to address the energy supply chain are also immense for the American people: millions of family-sustaining clean energy jobs spread throughout the country; world-class training and research; access to clean and lower-cost energy for all Americans, including those who have been historically left behind; a more resilient American economy for the long term; and an energy system that protects our climate.

The climate crisis poses an existential crisis to American and global national security and economic interests. It also presents a tremendous opportunity for American innovation, allowing for a reinvestment in the American manufacturing base and for the widescale creation of high-quality jobs in the clean energy economy. The United States has committed to an ambitious and achievable goal to reduce net greenhouse gas (GHG) emissions 50 to 52 percent below 2005 levels by 2030, create a carbon pollution-free power sector by 2035, and achieve net zero emissions economy-wide by no later than 2050. The U.S. Department of Energy (DOE) recognizes that sustained investment to build a secure, resilient supply chain will be critical in achieving these goals and capturing the economic opportunity inherent in the energy sector transition.

Strategic Opportunities

- Increase domestic raw material availability
- Expand domestic manufacturing capabilities
- Invest and support the formation of diverse and reliable foreign supply chains to meet global climate ambitions
- Increase the adoption and deployment of clean energy
- Improve end-of-life waste management
- Attract and support a skilled U.S. workforce for the clean energy transition
- Augment supply chain knowledge and decision-making

DOE defines the ESIB as the energy sector and associated supply chains that include all industries, companies and stakeholders directly and indirectly involved in the energy sector.

The ESIB involves a complex network of industries and stakeholders that have a nexus to energy, including extractive industries, manufacturing industries, energy conversion and delivery industries, end of life and waste management industries, and service industries that include providers of digital goods and services. This report examines each of these arenas.

This supply chain review identified a range of risks and vulnerabilities that vary by technology and will require a sweeping set of diverse policy actions. In addition, DOE identified common threats, risks, and vulnerabilities across all selected technologies. These common risks and vulnerabilities are grouped into seven main

opportunities for action: 1) increase raw material availability, 2) expand domestic manufacturing capabilities, 3) support formation of and invest in diverse, secure, and socially responsible foreign supply chains, 4) increase the adoption and deployment of clean energy, 5) improve end-of-life energy-related waste management, 6) attract and support a skilled workforce for the clean energy transition, and 7) enhance supply chain knowledge and decision-making. Together, they create the "Strategy to Secure the Clean Energy Transition" that DOE will work with other Federal agencies to implement.

Finally, an analysis of the global energy marketplace shows that many governments and government coalitions have adopted coordinated, government-led strategies and industrial policies to advance and unlock significant investment in key supply chain segments. One example is China's investment in domestic cobalt production and processing paired with investment in international raw material inputs that enabled China to corner a significant market share in cobalt processing. Through this report, DOE maps out a strategy to rapidly secure the critical supply chains necessary to meet economic, national security, and climate goals. The policy strategies in this report are informed by 13 supporting deep dive supply chain assessment documents conducted by researchers from DOE and several of its national laboratories, in consultation with stakeholders across the public, private, and social sectors. In addition to targeted consultation, the policy strategies are informed by comments received on a formal request for information (RFI) issued by DOE.

The tables below highlight policies identified in this report that will enable the United States to build resilient supply chains to meet energy security, national security, economic, and climate objectives. **Table 1** identifies cross-cutting executive actions that address seven strategic opportunities applicable across all technologies, and **Table 2** includes technology-specific executive actions. **Table 3** identifies recommended congressional actions that address strategic supply chain objectives applicable across all technologies. And **Table 4** lays out technology-specific recommendations requiring congressional action. These policies will position the United States as a global leader in the energy economy while supporting good-paying jobs, strong domestic manufacturing, clean and sustainable energy production, and energy justice and equity across American communities. Through bold action, the United States is well-positioned to create a strong energy supply chain for the long term that supports the significant and necessary equitable clean energy transition.

Table 1. Summarized Cross-Cutting Policy Strategies: DOE and Interagency Actions

#	Strategy
	I. Increase Domestic Raw Materials Availability
1.	Review and update Federal mining laws and regulations to provide for more efficient permitting while strengthening Tribal consultation and community participation processes and improving environmental performance.
2.	Promote improvement and enforcement of global environmental, human rights, and labor standards for mineral extraction, mineral processing and product manufacturing and advance development and utilization of traceability solutions to enable greater supply chain visibility and standards enforcement.
3.	Coordinate and expand existing programs, market analysis, and technology commercialization activities for clean energy materials, including secondary/recycled and unconventional sources, that are vital for clean energy manufacturing, across multiple national labs, academia and in partnership with industry.
4.	Support innovation for environmentally sustainable and next generation critical mineral and material extraction, processing, and refining activities.

#	Strategy
5.	Consult with stakeholders to create a process under which DOE can specifically recommend or establish critical materials that are vital for DOE's mission areas.
6.	Explore establishing multilateral coordination mechanisms on voluntary energy transition-related critical material stockpiling, including through the International Energy Agency.
	II. Expand Domestic Manufacturing Capabilities
7.	Raise awareness, coordinate, and expand manufacturing programs needed to support the clean energy transition.
8.	Chart a path forward on how communities, industry, and government envision and should pursue next generation large industrial facilities (e.g., steel mills, processing, and fabrication sites, etc.) necessary for an expanded domestic manufacturing base.
9.	Leverage foreign direct investment in U.S.-based clean energy technology manufacturing by using targeted SelectUSA tools.
10.	Coordinate with manufacturers and state, local, and tribal governments to support the establishment of regional clean energy industrial clusters, including providing technical assistance.
11.	Enhance coordination of trade policy across the U.S. Government to support fair conditions for the U.S. clean energy industries and its workers.
	III. Invest and Support Formation of Diverse and Reliable Foreign Supply Chains to Meet Global Climate Ambitions
12.	Increase Federal government financial support to eligible U.S. companies investing in or exporting to foreign countries to secure supply chain inputs that fill challenging domestic gaps and support growth of other domestic segments of the supply chain.
13.	Establish and fund an initiative for expanding clean technology manufacturing capacity globally to achieve the dramatic scale-up in manufacturing of key climate and clean energy equipment associated with meeting net-zero commitments.
14.	Promote adoption and implementation of traceability standards to improve global supply chain mapping capabilities, instill integrity of product custody, promote social responsibility, and support carbon footprinting of energy supply chains.
	IV. Create Clear Market Signals to Increase the Adoption and Deployment of Clean Energy
15.	Leverage Federal purchasing power to provide a sustained demand signal for both domestic clean energy products and the capability to manufacture them domestically.
16.	Develop a preference list of materials that will be used for Federal procurement and as a basis to engage U.S. industry and foreign governments to secure capacity.
17.	Identify and advance activities to grow and sustain the demand signal for sustainable transportation fuels and associated supply chain industries.
18.	Ensure that implementation of the U.S. Government clean technology competitiveness export strategy harnesses the clean technology demand pull of international markets in a way that supports domestic manufacturing.

#	Strategy
19.	Examine and analyze costs and benefits of authorizing federal agencies to sign utility service contracts and power purchasing agreements that extend beyond the current 10 year maximum for power procurement from clean energy technologies.
	V. Improve End of Life Energy-related Waste Management
20.	Leverage U.S. Government's purchasing power and demand to support supply chains of recycled content products, market development, and sustainable sourcing practices.
	VI. Attract and Support a Skilled U.S. Workforce for Clean Energy
21.	Convene multiple agencies and workforce stakeholders to advance energy workforce development.
22.	Embed strong labor standards and support for organized labor in Federal funding for the Energy Sector Industrial Base.
	VII. Augment Supply Chain Knowledge and Decision Making
23.	Create and maintain a manufacturing and energy supply chain office as well as database and analytical modeling capabilities.
24.	Support studies that assess and quantify the economic, environmental, social, and human rights impacts of different aspects of the energy supply chain for all clean technologies.
25.	Support actionable, deep dive analyses that build on *The Long-Term Strategy of the United States* in a way that informs high-priority decarbonization and American economic leadership strategies.
26.	Engage government and private sector to develop a secure digital component supply chain strategy for the Energy Sector Industrial Base.
27.	Engage government and private sector to create national standards, guidelines, and requirements for the security of energy-related software, firmware, virtual platforms and services, and data.

Table 2. Summary of Technology-Specific Policy Strategies

#	Strategy	Technology
	Energy Infrastructure	
28.	Engage government and private sector to explore the idea of a hydrogen reserve.	Fuel cells and electrolyzers
29.	Develop an integrated waste disposal strategy, with an initial focus on consent-based siting process for the siting of Federal facilities for the temporary, consolidated storage of spent nuclear fuel.	Nuclear
30.	Engage government and private sector to deploy long duration (10-plus hours) energy storage projects that utilize a structured framework for meeting cost feasibility goals and supply chain sustainability metrics.	Energy storage
	Electricity Grid and Market	
31.	Provide technical assistance to design and support an "energy storage subscription" financing model, hosted by utilities or third parties to provide a financing option for storage.	Energy storage

#	Strategy	Technology
32.	Engage government and private sector to develop novel utility ownership structures and regulatory support, including a novel power purchase agreement structure for long−term contracts with electrolyzers and fuel cells.	Fuel cells and electrolyzers
33.	Conduct a study to evaluate the impact of second life grid applications for which parties own the batteries in a high EV-deployment scenario.	Energy storage
	Manufacturing and Innovation	
34.	Engage government and private sector to: • Expand RD&D on high voltage (up to 10 kilovolt) silicon carbide wide bandgap semiconductors for high-power and high-voltage electrification applications needed for decarbonization. • Invest in advanced packaging RD&D to expand U.S. capacity for the conventional semiconductor supply chain and promote competitive advantages for U.S. manufacturers.	Semiconductor
35.	Engage government and private sector to embed energy efficiency improvement efforts into research, development, demonstration, and commercial application investments to improve the energy efficiency of microelectronics over the next 20 years.	Semiconductor
36.	In coordination with Nuclear Regulatory Commission (NRC), support deployment of advanced nuclear reactors in a timely manner. Specific actions include: • Fully implement NEICA (Nuclear Energy Innovation Capabilities Act) to enable private sector partnerships with national labs to demonstrate novel reactor concepts and share technical expertise with NRC. • Fully implement NEIMA (Nuclear Energy Innovation and Modernization Act) to ensure successful and efficient licensing of the next generation of technology in the near term. • Implement DOE programs for advanced reactor demonstration projects and for HALEU availability to support timely deployment of these new technologies by private sector.	Nuclear
37.	Engage government and private sector to lead efforts to utilize the Defense Production Act to develop the domestic rare earth magnet market across multiple supply chain stages. Congressional appropriations would be required.	Magnets
38.	Engage government and private sector to expand RD&D to improve modularity, create flexible designs, improve efficiency, and lower manufacturing costs of Large Power Transformers (LPTs) and related materials.	Electric grid
39.	Engage government and private sector to expand RD&D to address logistical limitations for land-based wind, including modularization and onsite assembly and manufacturing of large components such as blades and towers.	Wind
	Aged/Outdated Infrastructure	
40.	• Increase the domestic content of hydropower components in the Buy American Act in accordance with trade agreements. • Consider how to maximize Buy American Act provisions to support rehabilitations and upgrades of federal hydropower plants.	Hydropower

The DOE one-year supply chain review reveals several supply chain opportunities that will require additional authority and funding in the next 10 years. **Table 3** and **Table 4** summarize sector-wide and technology-specific recommendations that will require congressional support to provide DOE and other Federal agencies additional authority needed to expand support for supply chains.

Table 3. Recommended Congressional Actions and Targeted Supply Chain Objectives

#	Congressional Action	Action Impacts			
		Increased Raw materials	Expanded Domestic Manufacturing	Increased Clean Energy Deployment	Improved End of life management
41.	As part of Executive Order 14017 100-day report-related implementation, expand the National Defense Stockpile inventory and/or strategic offtake agreements for priority critical minerals and materials, thus enabling the clean energy transition for civilian and industrial purposes and accounting for future demand needs.	✓	✓	✓	
42.	For certain critical supply chains, broaden the innovation requirement under Title XVII of the Energy Policy Act 2005 to include supply chain investments that support innovative clean technologies.	✓	✓	✓	✓
43.	Enact legislation to provide tax incentives to support domestic clean energy manufacturing and deployment, including incentives for building new facilities and for the ongoing operation of those facilities.	✓	✓	✓	
44.	Appropriate additional RD&D funding to DOE to further accelerate domestic manufacturing in a way that addresses supply chain vulnerabilities and promotes resilience for clean energy domestic manufacturing.	✓	✓	✓	✓
45.	Ensure national energy policy aligns with U.S. climate policy goals.	✓	✓	✓	✓
46.	Appropriate funding to DOE for use of Title III of the Defense Production Act to support domestic critical material supply.	✓	✓	✓	
47.	Amend Buy American Act to support clean energy technologies by extending the purchasing mandate to the equipment generating the electricity and storing the energy for new facilities.		✓		
48.	Enact a comprehensive set of policies to create the infrastructure for enabling reuse and recovery of key				✓

#	Congressional Action	Action Impacts			
		Increased Raw materials	Expanded Domestic Manufacturing	Increased Clean Energy Deployment	Improved End of life management
	components and materials through the circular clean energy economy.				
49.	Support disposition of hazardous materials critical for clean energy deployment.				✓
50.	Appropriate funds to establish regional and state-level sector partnerships and Registered Apprenticeships to recruit, train, and place workers into careers needed for domestic supply chains.	✓	✓	✓	✓
51.	Fund and expand supply chain analytical capabilities across DOE, the national labs, and in conjunction with partner agencies.	✓	✓	✓	✓

Table 4. Summary of Recommended Technology-Specific Congressional Actions

#	Congressional Action	Technology	Actor(s)
	Energy Infrastructure		
52.	Prioritize financing of offshore wind ports and vessels utilizing existing DOT Maritime Administration (MARAD) programs and DOE LPO programs.	Wind	Congress, DOT, DOE
53.	Encourage intrastate and interstate transportation permit harmonization through research initiatives, competitive grant applications, and state programming of Federal aid funding, and explore multimodal infrastructure investment to alleviate bottlenecks.	Wind	Congress, DOT, DOE, state and local governments
54.	Examine and analyze possible tax incentives for fuel cells in emergency backup power and primary power applications, such as data centers, as well as incentives for hydrogen pipelines.	Fuel cells and electrolyzers	Congress
55.	Amend the Buy American Act requirement to include clean hydrogen and extend the purchasing mandate to hydrogen generation, delivery, storage, dispensing and end-use technologies, with a requirement of domestic content over 55 percent for all components, subsystems, and systems.	Fuel cells and electrolyzers	Congress, DOE
56.	• Further RD&D to address technical challenges and costs of carbon capture, storage, and transport.	Carbon capture storage and transport	Congress

#	Congressional Action	Technology	Actor(s)
	• Building on BIL, incentivize CO_2 infrastructure projects (pipelines and storage), including providing investment and permitting support.		
57.	Examine and analyze possible incentives to support modernization of the existing hydropower fleet, powering non-powered dams, and development of pumped storage hydropower.	Hydropower	Congress
58.	Continue funding critical gaps in R&D infrastructure, including a fast neutron irradiation reactor or Versatile Test Reactor	Nuclear	Congress
59.	Amend the Nuclear Waste Policy Act (NWPA) to enable DOE to implement an integrated waste disposal strategy (addressing Federal interim storage, permanent disposal, and related transportation).	Nuclear	Congress
	Electricity Grid and Market		
60.	Support RDD&D funding to agencies (DOD, NASA, and DOE) for the development and accelerated deployment of innovative nuclear energy systems.	Nuclear	Congress
	Aged/Outdated Infrastructure		
61.	Fund investment of upgrades and expansion of historical grid systems and undergrounding as appropriate.	Electric grid	Congress
	Manufacturing and Innovation		
62.	Fund semiconductor research, design, and manufacturing, which will be critical to accelerate the domestic semiconductor industry and assert global leadership.	Semiconductor	Congress, DOE, DOC, DOD

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1 Introduction

In order to achieve a thriving clean energy economy, there are major challenges and opportunities for the United States to confront up and down the energy supply chain. The analysis and strategy presented in this U.S. Department of Energy (DOE) report are wide-reaching. Success will mean that the U.S. Government and American businesses have seized the market opportunity for our country, created good jobs, secured more equitable outcomes for our people, and tackled the climate crisis. In this report, DOE groups common risks and vulnerabilities into main opportunities for action: 1) increase raw material availability; 2) expand domestic manufacturing capabilities; 3) support formation of and invest in diverse, secure, and socially responsible foreign supply chains; 4) increase the adoption and deployment of clean energy; 5) improve end-of-life energy-related waste management; 6) attract and support a skilled workforce for the clean energy transition; and 7) enhance supply chain knowledge and decision-making. Together, they create the "Strategy to Secure the Clean Energy Transition" that DOE is already working with other Federal agencies to implement.

The strategy presented in this report presents the DOE response to Executive Order 14017, "America's Supply Chains," 86 FR 11849 (February 24, 2021) which directs the Secretary of Energy to submit a report on supply chains for the eEnergy Sector Industrial Base (as determined by the Secretary of Energy) within one year of the date of the order. While the Department of Homeland Security's Cybersecurity and Infrastructure Security Agency (CISA) has published a description of the "energy sector" in its taxonomy of critical infrastructure sectors, the "Energy Sector Industrial Base" has not been formally defined (CISA, n.d.). For the purpose of the review and strategy laid out in this report, DOE defines the Energy Sector Industrial Base (ESIB) holistically to represent the energy sector and associated supply chains that include all industries, companies and stakeholders directly and indirectly involved in the energy sector. This complex network of industries and stakeholders spans from extractive industries, manufacturing industries, energy conversion and delivery industries, end of life and waste management industries, to service industries which include providers of digital goods and services—see **Figure 1**. These industries and associated stakeholders may be located within the U.S. states and territories, in foreign countries, or both.

The energy sector has undergone significant changes in the past two decades, and it will continue to evolve at an accelerated pace in the next 30 years due to rapid innovation, investment trends in private capital markets, and the urgent need to combat global climate change. Several key changes in the past two decades include the rapid cost reduction and deployment of solar and wind energy; wide-spread uptake of efficient light-emitting diode (LED) lighting; notable increases in nuclear reactor lifetimes and capacity factors; significant digitization of grid components and operation; and changing energy market economics that have led to natural gas and renewable energy displacing coal as lower cost electricity generation. These changes have fueled growth and investment in new industries, creating millions of good-paying jobs for U.S. workers. The U.S. energy economy currently employs about 7.5 million people, including more than 2 million in energy efficiency.[1] Stakeholders within and outside the energy sector have embraced a rapid transition to clean energy to address climate change. Stakeholders include the scientific community; corporate shareholders; local communities; state, national, tribal, and local governments; international organizations; consumers; and more.

[1] https://www.energy.gov/sites/default/files/2021-07/USEER%202021%20Main%20Body.pdf

Global energy end-use continues to be highly dependent on fossil fuels. In the United States, as of 2020, about 79 percent of primary energy end-use and 60 percent of electricity generation came from fossil fuels, including petroleum, natural gas, and coal (EIA, 2021). Multiple countries, including the United States, have pledged to achieve net zero greenhouse gas emissions by 2050 to keep the global temperature change below 1.5 degrees Celsius and avoid catastrophic global climate change. Achieving this goal will require massive deployment of clean energy technologies and an accompanying scale-up in their supply chains, both domestically and globally (IEA, 2021).

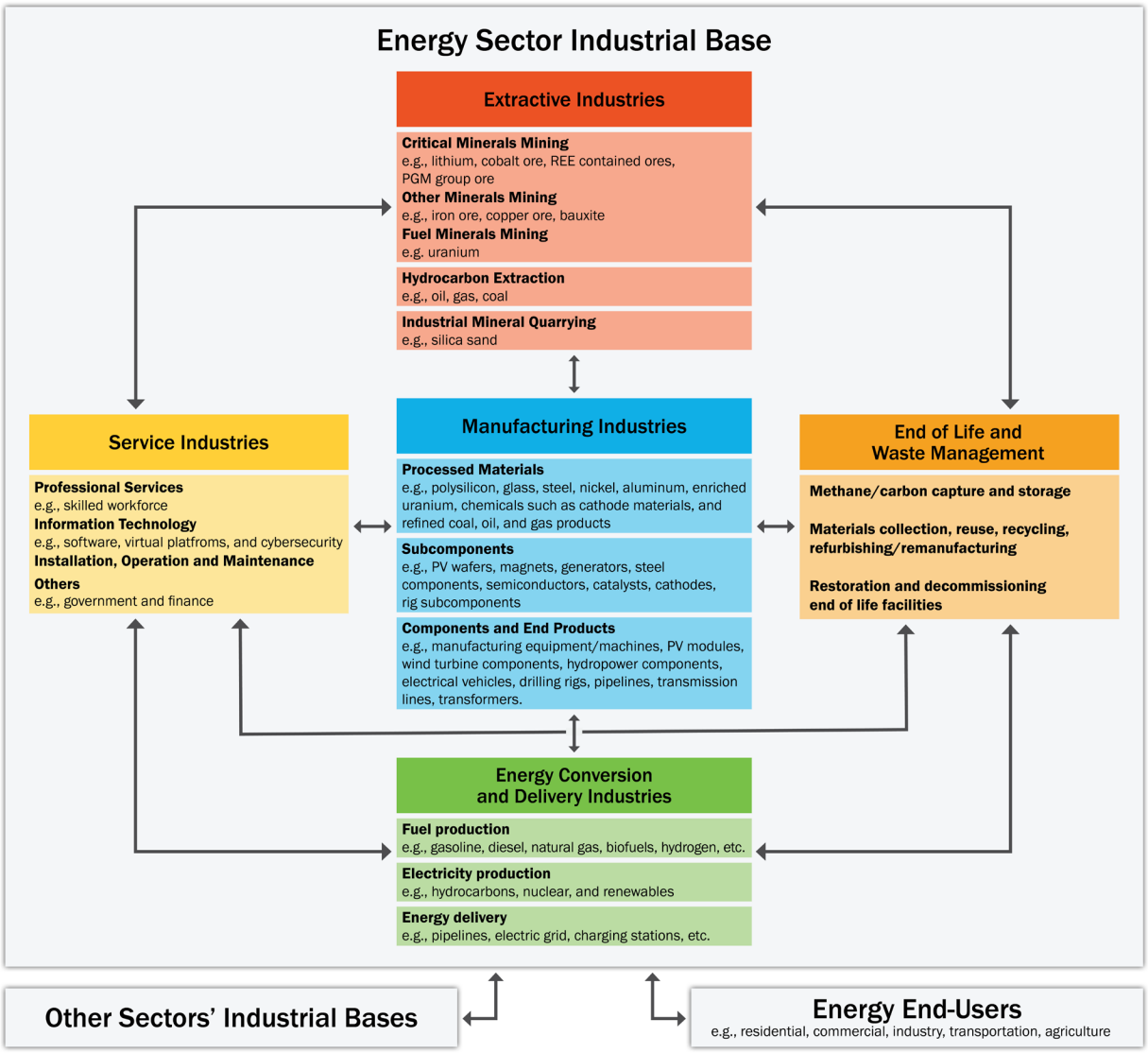

Figure 1. Energy Sector Industrial Base

All energy sources depend on supply chains, although each has different threats, risks, vulnerabilities, and opportunities. The fossil fuel-based energy sector supply chain risks and vulnerabilities have frequently had a ripple effect across the global economy (see example in Sharfedin et al., 2021). One of the major vulnerabilities includes few countries controlling a significant share of resources and using their market power to influence global prices (Reed, 2021). While some of the risks and vulnerabilities associated with fossil fuels may decline

as the global economy transitions to clean energy, the global shift to clean energy is introducing new sets of supply chain risks, vulnerabilities, and opportunities across the Energy Sector Industrial Base. In the fossil fuel-based economy, the major supply chain issue is centered around access to fuels; in the clean energy economy, the major supply chain issue is centered around access to materials and components needed to manufacture clean energy technologies and increasingly digitized components.

As part of global efforts to address climate change impacts, the U.S. Government is committed to reducing 50 to 52 percent of U.S. emissions by 2030, creating a carbon pollution-free power sector by 2035, and achieving net zero emissions economy-wide by no later than 2050 (The White House, 2021a). The U.S. Energy Sector Industrial Base in **Figure 1** must evolve to meet these commitments and increase its global presence. For example, clean energy deployment and associated raw material production and manufacturing will have to scale up significantly. The transition to a low carbon energy future provides opportunities to produce energy in all forms more sustainably and to capture methane and CO_2—opportunities that some fossil fuel companies have started to embrace. DOE recognizes the need to ensure this transition takes advantage of economic opportunities and supports national economic and security goals including social equity, quality job opportunities, defense capabilities, and cybersecurity, among others.

Based on several criteria listed in Appendix I, DOE identified for this energy supply chain policy strategy report 11 technologies and two crosscutting topics for priority deep dive assessments that are part of this one-year review set by Executive Order 14017. Technologies evaluated include: carbon capture materials; electric grid including transformers and high voltage direct current (HVDC); energy storage; fuel cells and electrolyzers; hydropower including pumped storage hydropower (PSH); neodymium magnets; nuclear energy; platinum group metals and other catalysts; semiconductors; solar photovoltaics (PV); and wind. Crosscutting topics are cybersecurity and digital components and commercialization and competitiveness. The analysis builds on the DOE 100-day report on high-capacity batteries and reviews the supply chain of the selected technologies from raw materials, processed materials, subcomponents, final products, to end of life management including material recovery and recycling (The White House, 2021b). DOE engaged energy sector stakeholders and subject matter experts throughout the process, including deep engagement with other Federal agencies. Addressing the energy supply chain requires a truly all of government approach. Each technology assessment includes the following elements:

- Mapping the supply chains.
- Identifying existing and future threats, risks, and vulnerabilities.
- Identifying opportunities and major barriers; including financial and commercial, scientific, technical, regulatory and market barriers.
- Identifying areas where government and private sector can collaborate to expand the energy industrial base as global demand of energy evolves.
- Identifying specific actions needed to incentivize companies in the energy sector to both transfer energy manufacturing back to and scale up supply chains in the United States.
- Identifying specific actions to address threats, risks, and vulnerabilities and help build resilient supply chains.

These deep dive assessments that provide further detail for the 13 issue areas identified can be found at energy.gov/policy/supplychains. Drawing from those assessments, this policy strategy report summarizes DOE key energy supply chain findings and policy strategies needed for executive action as well as recommendations for congressional action.

2 Key Findings

The Department of Energy's strategy to secure the energy supply chain is aligned with U.S. Government climate, national security, and economic goals. The clean energy transition presents opportunities to build supply chains differently and better, support American innovation, spur economic growth, reinvest in the domestic manufacturing base, enhance U.S. competitiveness, generate high quality jobs, and advance equity and justice.

2.1 Key Opportunities

Approaching the energy supply chains with renewed vigor provides the U.S. Government with essential opportunities to advance American interests in jobs, manufacturing, climate protection, and community engagement. The Bipartisan Infrastructure Law (BIL) signed into law in 2021 allows the United States to invigorate domestic supply chains of clean energy and create quality jobs, strengthen domestic manufacturing across the energy supply chains, and boost U.S. competitiveness and global leadership in clean energy markets. The DOE one-year supply chain review identified a suite of opportunities. Some of which are summarized below.

> "By the end of this decade, the global market for clean energy and carbon reduction technologies is going to reach $23 trillion—at a minimum—and so we want to corner that market by building clean energy supply chains and solutions here, sourced in America with American labor."
> *Secretary Granholm, 2021*

2.1.1 Expand global presence of U.S. technologies and help meet global climate goals

Transitioning to clean energy is a priority for many countries around the world, and innovative technology solutions are central to these efforts. The global clean energy markets are expected to reach $23 trillion by the end of the decade.[2] These markets present many opportunities, such as emerging technologies to support deep decarbonization, energy storage, semiconductors, and nuclear energy. The United States can expand global exports of these technologies. For example, with government support, the United States pioneered commercial solar PV, thus accelerating innovation for solar technology. Through the 1990s, the United States was a global leader in solar PV applications, but due to lack of strong, systematic, and consistent industrial policy to support the solar industry, other countries—most recently China—subsequently took over global leadership in solar PV manufacturing. With strategic government investment and policy support paired with strong industry and community partnerships, the United States can expand global market share in a wide array of growing clean energy markets, including those listed below.

Emerging technologies

Below are several examples of emerging technologies that, with targeted policy support and focused investment, the United States can expand global market share.

Carbon capture and storage

Carbon capture and storage (CCS) is an emerging market with strong potential for growth. CCS can be used to capture emissions from industrial processes such as steelmaking, cement production, and chemical production. Fossil power generation with CCS can provide a firm electricity resource that can balance increased variable generation. CCS represents an important opportunity for the United States to advance a clean energy technology that does not rely heavily on the building out of supply chains for rare critical minerals and materials. Since this technology is still an emerging technology, it needs government investment and policy support to demonstrate its economic and technical viability and scalability, and to grow its market in the United States and abroad. With the BIL, the U.S. Government has provided resources to grow this technology by investing more than $10 billion for carbon capture, direct air capture, and industrial emission reduction.[2] With CCS technology, the United States will not only have an opportunity to expand its global share of clean technologies, but the success of this technology provides potential to spill over to U.S. heavy industries. This will create further opportunities to improve the domestic manufacturing base and U.S. global market share for steel, cement, and chemical solvents as well as other engineered equipment.

Fuel cells and electrolyzers

Fuel cell and electrolyzer technologies are another set of emerging technologies with the potential to transform global energy use in the industrial, transportation, and power sectors.[3] Some countries recognize the need for clean hydrogen to decarbonize, but they lack the electricity generation resources to address the need. The United States is resource-rich and may be able to export low-carbon, electrolytic hydrogen, related chemicals, electrolyzers, fuel cells, and related equipment. Electrolytic hydrogen is currently more expensive than steam methane-reforming (SMR)-produced hydrogen, which is currently widely used. Over the past decade, DOE has been working in partnership with national labs and industry to overcome challenges to commercialize and scale hydrogen through R&D such as through the H2@Scale program.[4] With BIL, the U.S. Government has provided DOE an additional $1.5 billion for clean hydrogen manufacturing and recycling and electrolysis RD&D and $8 billion for clean hydrogen hubs to support the production, processing, delivery, storage, and end-use of clean hydrogen.

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[2] https://www.energy.gov/articles/doe-fact-sheet-bipartisan-infrastructure-deal-will-deliver-american-workers-families-and-0

[3] https://ourworldindata.org/emissions-by-sector

[4] https://www.energy.gov/eere/fuelcells/h2scale

Selected Bipartisan Infrastructure Law Clean Energy Supply Chain Highlights

Batteries: More than $7 billion to support supply chain and manufacturing.

Carbon Capture: More than $10 billion for demonstrations to advance carbon capture, direct air capture, and industrial emission reduction.

Critical Materials: $1.1 billion for critical mineral RD&D, recycling, processing, and critical material innovation, efficiency, and alternatives to strengthen clean energy technology supply chains.

Clean Hydrogen: $1.5 billion for clean hydrogen manufacturing and advancing recycling RD&D and $8 for clean hydrogen hubs – to support clean hydrogen demonstrations from production, processing, delivery, storage, and end-use of clean hydrogen.

Nuclear Energy: $2.5 billion for advanced nuclear demonstrations.

Grid-scale energy storage

While lithium-ion batteries (LIB) and pumped storage hydropower (PSH) make up the majority of existing and planned energy storage deployments, new next-generation technologies provide an opportunity for U.S. investment. Technologies such as flow batteries and thermal storage represent promising emerging technologies that may provide near- or medium-term opportunities for grid storage. There are also a large number of high-impact long-duration energy storage technologies that have not reached commercialization yet and may be potentially disruptive but require additional R&D for commercial viability. These include sodium-ion batteries, metal-air batteries, and other long-duration technologies like hydrogen and innovative approaches to mature technologies such as PSH and compressed-air energy storage. The potential for emerging grid energy storage technologies is high and a large range of currently immature technologies may be critical in meeting future deployment targets. Through the BIL, the U.S. Government has designated more than $7 billion to support supply chain and manufacturing of batteries and additional funds towards storage deployments and grid infrastructure upgrades, which may include storage.

Wide bandgap semiconductors

The United States led the world in semiconductor technology development and thus has always been a leader in semiconductor development. However as identified by the 100-day supply chain report, this global leadership is at risk due to years of underinvestment.[5] Building on the 100-day supply chain report, this report takes an energy-focused deep dive assessment on conventional and wide bandgap semiconductors. Conventional semiconductors, also known as microelectronics, are used primarily in data applications. Wide bandgap semiconductors—used primarily in power electronics—comprise less than 0.1 percent of the global market today, but their impact and market size are growing rapidly. This class of semiconductors includes silicon carbide

[5] https://www.whitehouse.gov/briefing-room/statements-releases/2021/02/24/fact-sheet-securing-americas-critical-supply-chains/#:~:text=The%20100-day%20review%20will%20identify%20near%20term%20steps,of%20a%20broader%20set%20of%20U.S.%20supply%20chains.

and gallium nitride semiconductors that are essential for controlling power flow in applications for clean energy generation, electric vehicles, and industrial technologies. The United States has an opportunity to preserve leadership in wide bandgap semiconductors as this market grows, securing the jobs and economic opportunity associated with it. Secure domestic production of wide bandgap semiconductors will also improve supply chain resilience for U.S. manufacturers that rely on semiconductors as inputs, particularly for clean energy generation and electric vehicles. Implementation of policy recommendations in the 100-day review and some of the proposed legislation, such as the CHIPS Act, which would allocate around $52 billion to support domestic semiconductor production, could help preserve U.S. leadership in semiconductors including wide bandgap.[6]

Nuclear energy technology leadership

The United States has the largest commercial nuclear power fleet in the world, which generates the largest source of carbon-free electricity in the country and supports approximately half a million jobs. Driven by innovation and public-private partnerships, the U.S. nuclear industry is poised to diversify further in coming years as advanced nuclear plants with different coolants, fuels, sizes, and delivery methods are developed, demonstrated, and deployed to provide low-carbon energy for broader applications. Bolstered by a domestic nuclear industry boasting the highest efficiency and safety standards in the world, accelerated deployment of these innovative clean technologies provides the United States the opportunity to re-establish international leadership in this critical sector. Such international deployments and the U.S. leadership in their supply chain will decarbonize regions where other clean energy technologies are infeasible and ensure that nuclear energy is deployed with the highest safety, quality, and non-proliferation standards in the world. As an initial step, the BIL is leading to the investment of about $2.5 billion for advanced nuclear, but more will be needed, as discussed in the policy suggestions in section 3 of this report, for nuclear energy to reach its full potential in meeting U.S. climate goals.

2.1.2 Leading in social equity, energy, and environmental justice

The global transition to a clean energy economy must aim for increased equity and environmental justice across all aspects of the global supply chain. This includes the provision of safe, affordable, reliable, and sustainable energy for all stakeholders, while paying explicit attention to the equitable distribution of costs and benefits of energy systems. It is also important for decision-making and policymaking about energy extraction, production, transportation, jobs, and energy access to meaningfully involve communities, particularly those communities most impacted.

The United States has the opportunity to lead by example in the global energy transition. Domestically, we should strengthen policies that ensure meaningful consultation and treatment of communities when it comes to extraction and processing of materials and sighting of heavy manufacturing. Federal implementation plans under Executive Order 14001 will promote environmentally sustainable manufacturing practices to limit environmental impacts to the planet and to communities located near manufacturing facilities. Through trade,

[6] https://www.semiconductors.org/chips/

international diplomacy, and business policies, the United States can and should be a force for good to influence foreign actions. For example, in December 2021, the U.S. Department of Labor awarded a $3 million grant to support progress on labor standards in the Democratic Republic of Congo.[7]

2.1.3 Delivering the clean energy transition to meet U.S. climate goals

The United States cannot meet its climate goals without ramping up manufacturing of clean energy technologies. There are many clean energy technologies with a proven track record of commercialization, scalability, and significant domestic market share – these include electrical vehicles, energy efficiency technologies, and a range of clean electricity technologies, including geothermal, hydropower, nuclear, solar, and wind. For example, solar is a fast growing and affordable technology with applicability for grid-scale, commercial and residential use—over 85 GW installed capacity.[8] Land-based wind has achieved nearly 122 GW cumulative installation as of 2020, providing more than 10 percent of electricity in 16 states and over 30 percent in Iowa, Kansas, Oklahoma, South Dakota, and North Dakota.[9] While significant strides have been made in these clean technologies, the United States has an opportunity to secure their supply chains to meet U.S. climate goals by building domestic manufacturing while creating quality jobs for American families. Examples of opportunities are highlighted below.

Building a solar supply chain not dependent on China

The global demand for solar PV is anticipated to explode in the coming years as countries race to meet their climate goals. With the right combination of targeted policies and incentives, the solar PV industry could respond rapidly at home and across the globe to diversify the global solar supply chain and reduce reliance on China. Significant financial support and incentives from the U.S. Government could lead to the reestablishment of a strong domestic solar manufacturing sector. In developing a strategy for diversifying global solar PV supply chains and increasing global production, the U.S. Government has an opportunity to prioritize full utilization of existing U.S. capacity, reshore domestic production, and expand opportunities abroad with allies and partner countries. About $8 billion of investment in domestic supply chain facilities is needed to meet an anticipated domestic demand of 40 GW_{dc} per year by 2030.[10] DOE estimates indicate with manufacturing incentives domestic solar production capacity could reach 10 GW_{dc} in two years, 15 GW_{dc} within three years, and meet the current domestic demand of 25 GW_{dc} in five years.

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[7] https://www.dol.gov/newsroom/releases/ilab/ilab20211214

[8] https://www.seia.org/solar-industry-research-data

[9] https://www.energy.gov/eere/wind/articles/land-based-wind-market-report-2021-edition-released

[10] Feldman, David, Vignesh Ramasamy, Ran Fu, Ashwin Ramdas, Jal Desai, and Robert Margolis. 2021. "U.S. Solar Photovoltaic System and Energy Cost Benchmark: Q1 2020." NREL/TP-6A20-77324. January 2021.

Preserving and expanding the domestic wind supply chain

Rapid supply chain expansion for land-based and offshore wind will be required to meet the expected demand growth with wind turbines manufactured in the United States. Current domestic supply chain capacity for land-based wind ranges from 10 to 15 GW/year for major components; this must grow to 30 GW per year by the end of this decade to meet the demand required under aggressive decarbonization.[11] For offshore wind, the U.S. supply chain is in its infancy and needs to reach 5 GW/year in capacity over the next five years to meet the Administration's 30 GW by 2030 target.[11] Achieving this expansion represents a massive opportunity that requires a stronger, more stable demand signal for wind energy technologies, incentives, and innovation. This demand signal will help address declining U.S. competitiveness in labor-intensive wind components, especially blades, and investment to address logistical and infrastructure needs, particularly the lack of specialized ports and vessels for offshore wind installation.

2.1.4 Growing job opportunities

The transition to a clean energy economy offers the potential to create millions of new good-paying jobs across a range of sectors and throughout the American economy. Collectively, the energy supply chain deep dive assessments have identified the need to recruit and train significant numbers of workers for jobs at all levels and across multiple areas of the energy sector. Potential new jobs in the clean energy transition exist throughout the supply chain segments from raw materials production to end of life and recycling. These include but are not limited to manufacturing plant workers, construction workers, researchers, engineers, technicians, administrative workers, station operators, supply chain analysts, and transportation workers. Through BIL, and policies such as the proposed Build Back Better Act, industry and other stakeholders will create millions of quality domestic jobs—adding an average of 1.5 million jobs yearly. These are a down payment on the many more jobs that can be created through pursuing the executive and congressional actions described in section 3 of this report. For example, a trade association estimates if 226 GW of energy storage is deployed by 2030, it has the potential to create about 461,000 jobs by 2030 from project development and operations, manufacturing, construction, whole trade, and other categories.[12] DOE/NREL internal analysis suggests if 545 GW of wind—both land-based and offshore—is deployed by 2035, the United States has the potential to create 436,000 jobs by 2035 from professional services, manufacturing supply chains, and construction, and operations and maintenance. Emerging technologies like fuel cell and electrolyzers have potential to add 700,000 jobs by 2030, including managers, engineers, technicians, manufacturing plant workers, station operators, and fuel transporters.

[11] https://www.energy.gov/sites/default/files/2021-08/Land-Based%20Wind%20Market%20Report%202021%20Edition_Full%20Report_FINAL.pdf.

[12] https://cleanpower.org/wp-content/uploads/2021/06/ACP-Labor-Supply-Report.pdf

2.2 Supply Chain Risks and Vulnerabilities and the Strategy to Secure the Clean Energy Future

To realize the opportunities summarized in section 2.1 we will have to manage supply chain risks and vulnerabilities. Some of the risks and vulnerabilities are technology-specific and will require policies tailored to address them. However, there are common risks and vulnerabilities across all the selected technologies, and these can be grouped into seven main categories.

2.2.1 Common risks and vulnerabilities

The list of common risk and vulnerabilities identified through the DOE one-year supply chain review is not new; many of these issues are well-known. DOE has been working with national labs, industries, communities, state and local governments, and other Federal agencies including engaging U.S. allies to address them over the years and has made significant strides. For example, DOE established the Critical Material Institute in 2013—an energy innovation hub led by Ames Lab to address material availability through innovation and technology advancement needed to develop resilient and secure supply chains for rare-earth metals and other critical materials key to the clean energy technologies.

DOE has other initiatives underway that serve to mitigate some of these identified risks and vulnerabilities. For example, about $7 billion has been appropriated through BIL, to address battery supply chain, including cobalt and lithium. Also, the DOE Loan Programs Office's (LPO) Title XVII Innovative Loan Guarantee Program currently supports a number of crosscutting efforts to finance innovative domestic clean energy supply chain scale-up and that may help enhance domestic manufacturing capabilities and improve end-of-life management. For example, based on amendments of the Energy Act of 2020 by the BIL, LPO can support nuclear energy supply chain critical minerals processing, and manufacturing to support increased domestic availability of materials as well as recycling to support reuse and end-of-life management for several clean technologies, though utilizing these authorities will require new appropriations. In addition, LPO's Title XVII and Advanced Technology Vehicles Manufacturing (ATVM) programs support various clean energy industry products and components in renewable energy sectors, including clean hydrogen and storage, and in advanced technology vehicle supply chains, including batteries, electric motors, and their respective components.

The common risks and vulnerabilities that inform the comprehensive DOE strategy to secure supply chains for the energy transition are summarized below.

Increasing raw material availability

The anticipated increase in demand of clean energy technologies such as wind turbines, solar PV, nuclear reactors, energy storage, and fuel cells and electrolyzers needed to support U.S. climate and competitiveness goals—at a time when other countries are similarly expanding their own clean energy sectors to meet national climate targets—has raised concerns about future availability of raw materials. Many of these clean technologies use rare earth elements, minor metals, and precious metals as key constituents. These materials are either produced as by-products of other materials or are highly concentrated in a few countries, or both. The United States lacks significant current domestic production of many of these important materials, and in a number of

cases, the United States lacks the foundational and/or economically viable resources to satisfy demand. For some materials, such as lithium and some rare earth elements, the U.S. has untapped potential to support greater domestic production. A significant portion of U.S. territory is still unexplored, presenting further opportunities to increase its domestic production of critical materials. Global and domestic exploration and production of raw materials will have to scale up with deployment of clean energy technologies in a way that is responsible and sustainable and maintains strong environmental, labor, and justice standards. In many cases, the use of these materials is not limited to clean energy technologies—other industries use them as well, which further exacerbates the risk.

Similar to the 100-day supply chain reports, the DOE one-year supply energy chain review report finds lack of domestic production is driven by a number of factors, including: lack of economically recoverable geological endowment of some resources in the United States; lack of knowledge regarding the extent of mineral resources in some areas of the country; lack of infrastructure and access in some locations; less-stringent environmental and worker protections and less oversight in many other nations; an outdated U.S. legal and regulatory structure for mining; and a growing mismatch between demand and supply of the trained workforce needed to support domestic production levels. Further, there are important environmental justice concerns related to mineral extraction, which disproportionately impacts underserved and overburdened communities. Mineral extraction also draws focus to environmental, wildlife, and other competing concerns and constraints, regardless of where the extraction occurs (globally or domestically). These competing concerns serve as an overarching vulnerability to raw material availability.

- *Examples of materials of concern include cobalt for batteries, rare earth elements like neodymium for offshore wind and electric vehicle motors, platinum group metals for catalysts, tellurium for solar PV, and uranium for nuclear energy.*

Expanding domestic manufacturing capabilities

The United States has been experiencing declining manufacturing capability and employment over the past two decades with several manufacturing activities offshored (Bosworth, 2014; Ramaswamy, 2017). This decline has cost Americans good-paying jobs, made U.S. supply chains less resilient over time, and contributed to a lack of investment in manufacturing innovation that makes the domestic industrial base less competitive. For example, the United States currently lacks certain manufacturing capabilities such as rare earth elements processing, which is essential for clean energy technologies; uranium enrichment capabilities to produce the high-assay low-enriched uranium (HALEU) that is critical for advanced nuclear reactor technologies; and fabrication capabilities for advanced nuclear reactors and advanced nuclear fuels.

Disruptions due to COVID-19 clarified some key weakness in U.S. manufacturing by exposing supply chain risks and vulnerabilities such as shipping logistics, limited access to key products critical to energy and national security (due to closure of manufacturing operations in other countries), and countries choosing to keep critical products for themselves for their own national security. Declines in domestic manufacturing have also been attributed to the cost of labor being higher in the United States relative to other countries (a consideration that is discussed in greater detail later in this section). While some argue that lower labor costs (across the energy sector, as well as other sectors) in other countries do help attract manufacturing activities to those countries, lower labor costs are not the only possible reason for the loss of domestic manufacturing. A range of industrial policies and

planning in other countries have helped secure their domestic manufacturing capabilities, even and sometimes especially where labor rates and worker protections are high, such as in Germany. For example, policies and practices such as heavily subsidizing manufacturing and associated supply chains; streamlining siting and permitting; investing in necessary infrastructure; creating workforce education and training programs; and ensuring procurement with environmental conditions that preference their own domestic manufacturers have encouraged the development of in situ manufacturing needed to support the energy sector. (Head et al., 1999; Bluhm, 2001; Hussinger, 2008).

- *Examples of manufacturing capabilities of concern include neodymium magnets manufacturing for wind and electric vehicle motors; large iron and steel castings for wind turbines, hydropower turbines, and nuclear reactor components; specialized steel plate for offshore wind; grain oriented electrical steel for larger transformers; HALEU and advanced fuels for nuclear energy; and silicon wafers for solar PV.*

Diversify and securing foreign supply chains

While global supply chains are not inherently a vulnerability and can be a necessity in most sectors due to resource availability or economics, for the energy sector, some global sources of materials and components can be considered "insecure." Similar to the 100-day supply chain review report, the DOE one-year energy supply chain review report finds these insecure supply chains may be partly driven by geographical concentration in countries with geopolitical risks due to social instability, unfair trade practices, and human rights issues such as forced labor and child labor jeopardizing national security.

DOE assessments show supply chains of multiple energy technologies are highly dependent on insecure foreign sources. Oil and gas have a long history of insecure supply chains due to geographic resource constraints that have only been reduced in the United States in the last decade due to technological advancements—partly from R&D funded by the DOE. Examples from the technologies reviewed in this effort include, solar PV technology, for which manufacturing capacity is highly concentrated in China, a country with documented human rights violations and forced labor practices as well as national security concerns. In the case of energy storage, 70% of the global supply of cobalt—a key input for lithium-ion batteries—comes from the Democratic Republic of the Congo (DRC), a country linked to unsafe mining standards and human rights issues (Van den Brink et al., 2020).[13] A significant portion of DRC's cobalt production is owned by Chinese companies, with China controlling 72 percent of global cobalt refining (Igogo et al., 2021; Cohen, 2021). China's control of key materials is across the board; China controls roughly 80 percent of rare earths production and refining that are key for components in technologies such as direct drive generators in wind turbines, and China also controls 61 percent of global lithium refining key for battery storage and electric vehicles (Cohen, 2021). China also controls 100 percent of the processing of natural graphite used for battery anodes.[14]

[13] https://pubs.usgs.gov/periodicals/mcs2021/mcs2021-cobalt.pdf

[14] https://seekingalpha.com/article/4361220-graphite-miners-news-for-month-of-july-2020

- *Examples of supply chains of concern for energy dependence include silicon production in China (solar PV), cobalt production in the Democratic Republic of Congo (batteries), lithium and cobalt refining in China (batteries), rare earth element magnet manufacturing in China (wind), and platinum group element mining in Russia (catalysts).*

Creating clear market signals to support deployment

For some energy technologies reviewed, there is a lack of sufficient demand to support domestic supply or manufacturing at a scale to be economic, while some energy technologies lack demand stability. Supply chain investments usually have a long payoff period, and uncertainty in future demand is a challenge in scaling up investment in supply chains in the United States. This lack of demand certainty is a problem for mature technologies like hydropower, offshore wind, nuclear reactors, and electric grid technologies such as transformers, and is particularly acute for emerging technologies such as fuel cells, electrolyzers, and carbon capture. For emerging technologies where the market is not well established yet, this vulnerability can represent an opportunity to address needed cost reductions through economies of scale; policy demand drivers, such as what has been achieved with land-based wind, will be key.

- *Examples of demand concerns include fuel cells, electrolyzers, carbon capture, offshore wind, hydropower, nuclear reactors, and transformers.*

Improving end-of-life waste management

Further capabilities, incentives, and plans on how to handle end-of-life materials are needed. Some materials used in these technologies are hazardous; others have significant value but are difficult and expensive to collect, process, and recover. Recycling energy components could significantly reduce demand for and carbon intensity of new materials. While used nuclear fuel from nuclear energy is currently stored safely primarily at reactor sites, a final disposition solution is still underway. Poor end-of-life management can pose significant risks to surrounding communities and has historically disproportionately impacted overburdened and underserved communities. Concerns about end-of-life management are already a significant issue in land-based wind siting and permitting. The concerns may be partly driven by lack of technologies to close the loop; lack of environmental product standards strong enough to create a market for secondary materials; lack of a social or societal construct whereby recycling is a standard practice; gaps in policies that more aggressively drive end-of-life and waste management; demand for skilled workforce to support end-of-life management; environmental and environmental justice concerns; and lack of urgency for newer technologies (e.g., solar and wind) that will not reach their end of life at scale for another decade or more.

- *Examples of end-of-life management concerns include cadmium in thin-film solar PV, disposition options for used nuclear fuel, safely decommissioning mining and manufacturing facilities, and health impacts on nearby communities.*

Building the workforce to support the energy transition

Workforce-related issues are closely intertwined with the other common vulnerabilities discussed in this section and warrant close attention due to how essential a skilled, trained workforce will be for meeting U.S. climate and clean energy goals. Analysis from the DOE deep dive assessments that accompany this energy supply chain policy strategy report and related input from stakeholders identified numerous skills and types of jobs that will be needed to meet current and future demand. These include technicians; truck drivers to transport materials and goods from ports and warehouses to manufacturing plants; engineers; and manufacturing plant workers. The COVID-19 pandemic has exposed structural opportunities to better support the U.S. workforce. The growing mismatch in demand and supply of workforce across all sectors --including energy-- can partly be explained by social, economic, technological, and demographic changes such as an aging workforce; decline in population growth; training gaps; and changes in workforce preferences (Chini et al., 1999; Dowell, 2020, Judy et al., 2020).

There are also concerns among a range of industry stakeholders about the higher cost of U.S. labor compared to labor costs in other countries affecting the U.S. competitiveness. For example, for solar manufacturing, in the United States, the first line supervisor is paid an average of $23.3—$38.8/hour +35% benefits expense assumed. In China, it costs about $6.2 – $7.5/hour. U.S. labor costs include labor standards and higher costs of living relative to other countries. Foreign direct investment in low-wage economies and export-driven economic growth have historically led to higher worker productivity, higher wages, and subsequent relocation of labor-intensive industries to countries with developing economies (Cutler et al. 2002). Many manufacturers, however, choose to relocate back to the United States from other countries (or "reshore") as wages rise in developing countries, rather than relocate to other low-wage countries. There are many reasons for this, including the total value contribution, which looks at a variety of considerations in making sourcing decisions (Gray et al., 2020). In many cases, productivity gains do offset labor costs: skilled labor in the United States either produces more or higher quality goods. Domestic manufacturing also reduces the complexity of supply chains and reduces risk associated with fluctuations in foreign currencies (Tate et al., 2013).

To ensure a lasting competitive edge, American firms must gain advantages based on innovation, industrial efficiency, and adoption of technologies and processes that reduce the carbon intensity of the goods produced. Successfully rebuilding domestic supply chains will also depend on the ability of employers to attract and retain a skilled, trained, and diverse workforce.

- *Examples of workforce concerns in the electric grid supply chain include matching people with the right skills for large power transformer manufacturing, which is detailed and labor intensive. This applies to jobs at all levels of transformer manufacturing (from engineers to shop floor workers), including operators for new facilities. In hydropower and nuclear technologies, workforce concerns include finding enough early career workers to take the place of retiring workers. In information technology (IT), it is difficult to find sufficient domestic developers for specialized energy systems software.*

Enhancing supply chain data and analytical tools

This review identified limitations in current data and analytical tools to assess and understand holistic and interdependent supply chains. To understand emerging supply chain threats, risks, vulnerabilities, and opportunities, it is important to have access to supply chain data and analytical tools to inform thinking and support decision making in building and maintaining resilient energy sector supply chains. Because the definition

of the Energy Sector Industrial Base as defined by the DOE in this report is new, existing databases and analytical tools to understand and track the energy sector supply chain resilience are inadequate.

The National Institutes of Standards and Technology (NIST) is currently conducting a study to address supply chain data issues in accordance with section 9413 of the William M. Thornberry National Defense Authorization Act (NDAA) for Fiscal Year 2021 (Pub. L. 116-283), which directed NIST to conduct a feasibility study of establishing the National Supply Chain Database. The purpose of this database is to understand the capabilities of American manufacturers and minimize disruptions to the supply chain. If established, this database could be leveraged in building an Energy Sector Industrial Base database which would support analyses of critical energy sector supply chains—such as early identification of risks, dependencies, and single points of failure—to enable proactive mitigation by stakeholders. In addition, specific data needs to support and improve the supply chain of critical energy materials will remain that this proposed database may not address.

- *Example: An Energy Sector Industrial Base database would support comprehensive supply chain tracking, prioritization, analyses, and identification of mitigation needed to manage critical risks. There is a lack of a common framework and nomenclature for understanding critical material content in components such as catalysts used in fuel cells, electrolyzers, and advanced chemical production. These are needed for detailed mapping of the flows of individual critical minerals and materials throughout their lifecycles. The lack of comprehensive view of the Energy Sector Industrial Base impedes analyses of supply chain risk interdependencies, such as those associated with the digital components and virtual platforms and services that increasingly operate distributed energy resources and the modern grid.*

2.2.2 The key technology specific risks and vulnerabilities

Like the common risks and vulnerabilities, most of these technology specific risks and vulnerabilities are well known. DOE has invested heavily in RD&D to address these risks through national labs, universities, and partnerships with industries, and state and local governments. DOE has also worked with other Federal agencies and U.S. allies to address them. For example, the hydrogen plan released by DOE in 2020 offers a strategic framework for the Department's hydrogen RD&D efforts of the Offices of Energy Efficiency and Renewable Energy, Fossil Energy, Nuclear Energy, Electricity, Science, and the Advanced Research Projects Agency-Energy (ARPA-E) to advance the production, transport, storage, and use of hydrogen across different sectors of the economy.[15] Supporting programs include the Million Mile Fuel Cell Truck (M2FCT), H2NEW, HydroGEN, and ElectroCat consortia. [16][17][18][19]

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[15] https://www.energy.gov/articles/energy-department-releases-its-hydrogen-program-plan

[16] https://millionmilefuelcelltruck.org/

[17] https://h2awsm.org/

[18] https://www.electrocat.org

[19] https://h2new.energy.gov/

The BIL allocated approximately $21 billion in funding for clean energy demonstrations and research hubs for next generation technologies of which $8 billion is dedicated for clean hydrogen, more than $10 billion for carbon capture, and $2.5 billion to support advanced nuclear. The BIL also allocated about $700 million to support existing hydropower facilities, $6 billion for the civilian nuclear credit program to prevent premature retirement of existing zero-carbon plants, and $3 billion focusing on investments that improve the flexibility of the grid. including upgrading existing transmission and distribution systems.2 In addition, DOE Loan Programs Office's (LPO) Title XVII Innovative Loan Guarantee Program continues to support the financing of innovative clean energy technologies, including innovative components and manufacturing processes, that can support a domestic clean energy supply chain. LPO supports eligible projects serving offshore wind, transmission, advanced nuclear, and energy storage projects.

The technology-specific risks and vulnerabilities are summarized below.

Hydrogen and captured CO_2: Improving infrastructure to support market growth

Hydrogen delivery and storage infrastructure are needed to support market growth. As larger volumes of clean hydrogen are produced and demanded across larger geographic regions, pipeline transmission may become an increasingly more prevalent delivery option. Captured CO2 also requires transportation to storage or usage sites. Due to challenges in establishing new storage and transportation projects, reliance on existing rights of way for pipelines and electricity transmission, as well as rail may prove to be economically promising routes. Incorporating electrolysis, fuel cell, and CO2 capture facilities into this expanding infrastructure network could involve the conversion or redevelopment of interconnection facilities, power stations, brownfields, and land or other assets associated with natural gas and electricity transmission and distribution. Blending hydrogen with natural gas or even conversion of natural gas pipelines to hydrogen may prove feasible under certain conditions. This transition process has technical challenges, is costly, and will require government incentives and regulatory support.

Fuel cells and electrolyzers: Re-envisioning electricity resources and markets

The competitiveness of low-carbon electrolytic hydrogen is highly dependent upon electricity prices, marginal electricity carbon intensities, and average utilization rates. These drivers can be improved by state and local government authorization of innovative or direct utility ownership, the provision of access to wholesale prices, and integrated asset management. Novel ownership structures could be supported through utility reforms that place value on services provided by integrated hydrogen systems, including demand response, increased reliability, and long-duration energy storage. Ideally, these agreement structures will reinforce the supply of ancillary services; be integrated with resource, transmission, and long-duration energy storage planning; and could allow transparent carbon accounting.

Land-based wind turbines: Addressing logistical needs

Land-based wind components are approaching or over road and rail size limits, meaning the number of routes by which components can be transported from ports or factories to deployment sites is decreasing over time.

Permit requirements for transporting such large components vary significantly across state and even county lines, and large components moving from manufacturing to deployment sites may cross multiple states and dozens of counties. As wind components get larger and wind deployment increases, remaining routes are likely to become increasingly congested, and complying with disparate permit requirements more difficult and costly—unless addressed with smart policy interventions.

Offshore wind turbines: Upgrading port and vessel infrastructure

Offshore wind development requires specialized port infrastructure and Jones Act-compliant specialized maritime vessels. The business case for such investments is challenged by lack of certainty in near-term offshore wind demand; uncertainty in demand is exacerbated by the lack of specialized vessels and port infrastructure. Without strong policy interventions, the lack of sufficient specialized port infrastructure and vessels could create significant bottlenecks as offshore wind installations ramp up through this decade and pose a risk both to achieving the 30 GW by 2030 offshore wind deployment goal and to broader supply chain development.

Electric grid, hydropower, and nuclear components: Modernizing aged/outdated infrastructure

The hydropower fleet, the nuclear reactor fleet, and many transmission and local grid distribution systems are aged/outdated. Replacement with modern equivalents requires various levels of system redesign and replacement and is slow due to regulatory governance and funding; many high-risk vulnerabilities remain unpatched. Upgrading these systems is likely to increase pressure on the existing supply chains for materials and components such as specialized steel and turbines. Strategic policy actions are required to support modernizing these systems without creating additional pressure on existing supply chains.

Hydropower: Improving access to large capital and other incentives

Rehabilitation of aged hydropower infrastructure combined with new development, including powering non-powered dams and pumped storage projects, will create competition for investment. Obtaining financing for new hydropower projects and rehabilitation of existing facilities is a challenge since most hydropower projects require large investments with long payoff periods. For example, pumped hydropower storage projects can require an upfront investment of over $500 million, and long-term Power Purchase Agreements (PPA) are rare for this technology. Further, incentives such as investment tax credits are typically limited to powertrain equipment, including turbine generators, but should also apply to total project costs including supporting features of the facilities. These include environmental improvements, enhancements to improve grid resiliency, and dam safety improvements.

Semiconductors: Accelerating focus on energy efficiency gains

The 100-day supply chain report identified eight risks associated with supply chain of semiconductors and policy recommendation to address them which are currently under implementation phase (The White House, 2021b). The DOE one-year supply chain review identifies an additional significant vulnerability in semiconductors: the slowing of energy efficiency gains in each successive generation (typically biennial) of semiconductors and their associated algorithms. As electrification and automation increase, the use of both wide bandgap and conventional semiconductors will continue to increase dramatically. Without a strong energy efficiency focus for both hardware and software, aggregate semiconductor energy demand and associated carbon emissions will increase dramatically. For example, leading algorithms in artificial intelligence are doubling their power use every two months (Mehonic and Kenyon, 2021). In another application of microelectronics—bitcoin mining—semiconductor energy use has increased tenfold in five years, and the electricity used (91 TWh/year) is more than the annual energy use of Finland (Huang et al. 2021).[20] To counter these unsustainable energy use trends, DOE is developing an R&D roadmap to aggressively tackle energy efficiency with a goal of doubling semiconductor energy efficiency every two years or less until semiconductor energy efficiency is 1,000 times greater than it is today. A comprehensive approach can contribute to achieving this thousandfold improvement in energy efficiency by 2040 (Shankar S, 2021).

Grid-scale energy storage: Developing commercial variety to meet broad system requirements

Despite numerous grid-scale energy storage solutions, lithium-ion batteries are by far the current dominant choice due to their cost-effectiveness. However, competition from the transportation sector and the vulnerable supply chain of lithium battery materials underscore the need for further R&D dedicated to other technical alternatives (e.g., flow batteries) manufactured with abundant materials (e.g., low-cobalt alternatives). This need is especially clear when considering the vast number of services and performance requirements that grid storage technologies must meet. Ensuring more than one technology and different chemistries among the options for grid energy storage systems will increase the resiliency of the overall supply chain.

[20] https://energycommerce.house.gov/committee-activity/hearings/hearing-on-cleaning-up-cryptocurrency-the-energy-impacts-of-blockchains

3 Policy Strategies and Actions

Moving to 100 percent clean electricity by 2035 and attaining net zero greenhouse gas emissions by 2050 create opportunities to build supply chains differently and better, create new jobs, strengthen community engagements, and spur U.S. economic growth. To achieve this vision, a combination of policy strategies and actions is needed. DOE's vision for success in the energy sector includes building and maintaining technology supply chains that:

- Promote economic growth and the clean energy transition,
- Are resilient to disruption from natural disasters, cyber or physical attack, economic factors, and dependence on materials or components from unreliable or malicious foreign actors,
- Do not exacerbate issues of disproportionality on certain communities and do advance equity and justice in both the U.S. and global economies,
- Have the potential to scale-up rapidly to meet expanding global demand for clean energy and provide expanded economic value,
- Provide high-quality, family-sustaining jobs and support equitable economic development and prosperity,
- Leverage regional assets, including resources and workforce development, to support the creation and expansion of industrial clusters, and
- Use materials sourced from the United States or reliable foreign partners, and prioritizes materials sourced using the highest environmental, and social standards.

DOE considered a full suite of existing and new U.S. Government policy tools within and outside of DOE authorities. The policy tools include Federal executive actions such as supply chain financing through direct loans, loan guarantees, and grants; government procurement policies; and regulations such as labor standards, and workforce development. The policy tools also include legislation such as tax policies and energy policies; trade policies such as tariffs and import quotas; and state and local government actions and reforms. The policy strategies and actions proposed in this report consider a whole-of-government approach to create new programs and build on existing programs, including the recommendations outlined in the 100-day supply chain review report published in June 2021 (The White House, 2021b). An example of such policy strategies announced with the 100-day supply chain review report is the new DOE policy to support domestic job creation by ensuring that all innovations developed with taxpayer dollars through DOE science and energy programs require awardees to substantially manufacture those products in the United States (DOE, 2021). DOE is implementing this through a Determination of Exceptional Circumstances under the Bayh-Dole Act. The following section describes in detail policies divided into two main groups: policy strategies and actions that will be implemented by DOE and other Federal agencies and entities within the Executive branch, and policy recommendations that will require congressional support. The policy strategies, actions, and recommendations were identified from deep dive analyses of eleven technologies and two crosscutting topics found here: energy.gov/policy/supplychains.

3.1 A Strategy to Secure the Clean Energy Future

DOE and Other Interagency Actions

Some of the risks, vulnerabilities, and opportunities uncovered through the DOE one-year supply chain review reveals new insights about the energy supply chain, while some risks, vulnerabilities, and opportunities have been known for some time but have evolved in recent times. There have been several efforts within DOE and other Federal agencies to address these risks and vulnerabilities, but further government policy support as well as industry and community partnerships are needed to manage these risks and vulnerabilities and build strong domestic supply chains that can deliver on economic, national security, and climate goals. This section presents several strategies and policy actions that will utilize the existing U.S. Government authorities.

Crosscutting Strategies

These are sector-wide policy strategies that will help build resilient supply chains of multiple technologies. These policy strategies and actions are grouped in seven pillars.

Pillar I: Increase Domestic Raw Materials Availability

The U.S. Government is actively pursuing a suite of activities to bolster raw material availability. The 2017 Executive Order 13817, "A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals," led to a Federal strategy on critical materials published by the Department of Commerce in 2019. This was followed by the 2020 Executive Order 13953, "Addressing the Threat to the Domestic Supply Chain from Reliance on Critical Minerals from Foreign Adversaries and Supporting the Domestic Mining and Processing Industries." Building upon these recent executive orders, DOE has developed its own critical mineral and materials strategies for 2021 to 2031.[21] This strategy highlights some of the activities that DOE has been supporting in recent years. The DOE Fiscal Year 2022 budget creates a Critical Minerals and Materials crosscut to elevate, coordinate, and augment DOE's activities for supporting the critical minerals and materials supply chain.[22] For example, the DOE Office of Fossil Energy and Carbon Management (FECM) has created a new Mineral Sustainability subprogram to coordinate activities related to recovery of rare earth elements and critical materials from coal waste and industrial by-products. The DOE Office of Energy Efficiency and Renewable Energy (EERE) funds the Critical Materials Institute (CMI) to diversify the supply, develop substitutes, and drive recycling and reuse of critical minerals and materials. In 2021, DOE announced $30 million to help secure the domestic supply chain of critical materials that build clean energy technologies through 13 national lab and university-led research

[21] https://www.energy.gov/sites/prod/files/2021/01/f82/DOE%20Critical%20Minerals%20and%20Materials%20Strategy_0.pdf

[22] https://www.energy.gov/sites/default/files/2021-06/doe-fy2022-budget-volume-2-v3.pdf.

projects.[23] DOE is also standing up new programs that address critical materials availability in response to the BIL. For example, the BIL establishes a new rare earth elements demonstration program.

DOE also works with other agencies in addressing supply chain risks related to materials. For example, DOE plays a leadership role in the National Science and Technology Council (NSTC) committee on Homeland and National Security tasked with implementing the *Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals* published by DOC in 2019. DOE collaborates and coordinates with other executive branch agencies, including the Departments of Defense, Commerce, the Interior, Homeland Security, Education, State, Justice, Agriculture, and Transportation; Environmental Protection Agency (EPA); National Aeronautics and Space Administration (NASA); International Trade Commission; and National Science Foundation (NSF). As for international partnerships, DOE plays a key role in United States' bilateral critical minerals partnerships, including with key allies such as Canada and Australia, and continues to work with other agencies developing partnerships with the European Union and other likeminded countries to diversify supply chains. In addition, the DOD 100–day supply chain review of critical minerals and materials provides recommendations to increase the resilience of strategic and critical material supply chains that both expands sustainable production and processing capacity and works with allies and partners to ensure secure global security. The actions presented below build on these existing government efforts in critical materials.

1. ***Review and update Federal mining laws and regulations to provide for more efficient permitting while strengthening Tribal consultation and community participation processes and improving environmental performance.*** **(DOI, EPA, USDA, DOE, DOD, DOL)**

The 100–day supply chain review of high-capacity batteries proposed taking action to review and update outdated U.S. mining laws and regulations. Similarly, the one-year supply chain review identified permitting issues, which arise in part from the lack of modern mining laws and regulations, as one of the hindrances to increasing domestic mineral production. In addition, Section 40206 of the BIL directs DOI and USDA to review Federal permitting processes with respect to critical mineral production on Federal land. Reinforcing the 100-day supply chain review recommendations, specific actions will include:

- DOI is coordinating with EPA and USDA to implement the 100-day recommendations to review and update relevant mining laws and regulations, as well as the BIL directive to provide a report on the topic to Congress. Modernizing mining laws and regulations could improve domestic production of critical materials such as nickel, cobalt, and rare earth elements, while also ensuring mining in the United States adheres to the highest environmental, labor, and sustainability standards. The review will explore opportunities to reduce the time, cost, and risk of permitting without compromising strong environmental and consultation benchmarks. The review will include DOE, U.S. Army Corps of Engineers, and stakeholders directly involved in the U.S. mining industries, such as resource and mining companies, local communities, and state, local, and tribal governments.

[23] https://www.energy.gov/articles/doe-awards-30m-secure-domestic-supply-chain-critical-materials

- Other Federal agencies support DOI and other regulatory agencies in regulatory processes that pertain to exploration, extraction, processing, reclamation, closure, and remediation relative to critical and strategic minerals and materials, while paying full attention to environmental, tribal, and social justice factors.

2. ***Promote improvement and enforcement of global environmental, human rights, and labor standards for mineral extraction, mineral processing and product manufacturing and advance development and utilization of traceability solutions to enable greater supply chain visibility and standards enforcement.*** **(DOS, DOE, DOC, DOI, DOL, EPA)**

Global standards for mineral extraction, mineral processing, and product manufacturing should be strengthened. The State Department-led Energy Resource Governance Initiative (ERGI) supports reliable, responsible supply chains for the minerals and metals needed for the clean energy transition. Through diplomatic engagement and technical assistance totaling nearly $25 million, ERGI promotes the highest environmental, social, and governance standards in the global mining industry. Specific actions will include:

- DOS in collaboration with DOE, DOC, DOI, DOL, and EPA will continue to engage U.S. allies, established industry, tribal and advocacy groups, and NGOs and international organizations to develop and enforce environmental and social global standards for material extraction, materials processing, and product manufacturing such as best practices for mining waste and tailings management, emissions limits and other environmental, human rights, labor, and safety standards, and an agreed-upon tracking and certification process. The United States will ensure that domestic mining industry is held in the same global standards we expect from other countries.

3. ***Coordinate and expand existing programs, market analysis, and technology commercialization activities for clean energy materials, including secondary/recycled and unconventional sources, that are vital for clean energy manufacturing, across multiple national labs, academia, and in partnership with industry.*** **(DOE, DOC, DOD, DOI, EPA, SBA)**

DOE will work with the Small Business Administration (SBA) and DOD to implement this strategy leveraging existing efforts such as the Critical Minerals Institute, the Minerals Sustainability program, Federal Consortium for Advanced Batteries, Loan Programs Office financing, and Small Business Innovation Research and Small Business Technology Transfer (SBIR/STTR) programs and engage other agencies through NSTC Critical Minerals Subcommittee. Specific actions will include supporting:

- Programs on innovative materials that enable design-for-reuse/recycling structures.

- Innovations in critical minerals and fuel minerals separation, processing and component manufacturing from primary ores, recycled material, and unconventional sources, which will provide U.S. companies with a competitive advantage with respect to existing technologies and intellectual property constraints.

- Alternative and next generation technologies that decrease or eliminate dependencies on rare earth elements, platinum group metals, and other critical minerals and critical materials, with a focus on using more common and lower cost materials with lower or negative environmental and social impacts.

- Next generation materials such as new, fully-recyclable, non-hazardous polymers and resins, and related demonstrations (e.g., for wind turbine blades, fuel cells and electrolyzers).

- Technology development that creates markets for co-products produced as surplus from domestic sources. For example, leveraging incentives for industry to expand usage of aluminum-cerium alloys. Cerium is relatively abundant and low-cost rare-earth element and is generally a co-product of higher demand, higher cost rare earth elements such as neodymium.

In addition, DOE will also work across relevant offices within DOE, with the national laboratory complex, and interagency partners to coordinate building a hub-and-spoke model for conducting market analysis and related analytical work to support technology commercialization efforts. The hub could create end-to-end supply chain analysis capabilities through linking existing capabilities and provide easily digestible resources and tools across the Federal government and to private-sector stakeholders.

4. ***Support innovation for environmentally sustainable and next generation critical mineral and material extraction, processing, and refining activities.*** **(DOE, DOI, DOC, EPA, DOI, DOD, SBA)**

DOE will work with the SBA and DOD to leverage existing authorities such as DOE LPO, SBIR/STTR programs, and new authorities provided under the BIL including approximately $6 billion designated for processing, manufacturing, and recycling of battery materials as well as the $140 million allocated to demonstrate commercial viability of a full-scale integrated rare earth element facility for extraction, separation, and refining. The DOE, SBA, and DOD will engage other agencies through the NSTC Critical Minerals Sub-committee on these programs. Other specific actions will include:

- Providing RD&D grants to support innovation of equipment and methods to support environmentally friendly, minimally invasive, and economic next-generation mining activities from exploration through to processing, refining, and metallization. Priority will be given to novel technologies to locate and identify critical minerals and materials, novel and non-conventional mining, and extraction technologies.

- Funding development and support of novel and innovative engineering solutions to develop sustainable upstream processing. This will include R&D in extraction and refining of raw materials. Prioritization of projects will focus on those with potential for commercialization and scaling; this will take a systems-level, holistic view of the challenges related to clean critical material extraction and refinement, increased material stewardship by incorporating by-production and/or co-production of minerals/materials, and reduction/elimination of waste generation.

- Prioritization of funding projects that emphasize innovations that improve energy efficiency, decarbonization of the mineral extraction and refinery processes, reduced environmental impacts (water usage, emissions, runoff, waste, and tailings), safety standards, workforce development, and commercial pathways. For example, national laboratory and university research projects that partner with the private sector to better understand industry needs and create a commercially viable pathway.

5. ***Consult with stakeholders to create a process under which DOE can specifically recommend or establish critical materials that are vital for DOE's mission areas.*** **(DOE)**

Critical minerals and materials are key to many energy technologies as identified by the DOE strategy on critical minerals and in the DOE 1-year supply chain review.[24] While the U.S. Geological Survey has updated the critical mineral list as a draft document (as of January 2022), there may be materials critical for the clean energy transition that are not included in this critical mineral list. Consistent with authority granted by section 7002 of the Energy Act of 2020, DOE plans to designate certain materials as "critical materials. The basis for inclusion in an official and strategic critical materials list could include, but not be restricted to, the balance of domestic vs non-domestic production or processing, relevance to national security, and potential for future commercial or strategic value.

6. ***Explore establishing multilateral coordination mechanisms on voluntary energy transition-related critical material stockpiling, including through the International Energy Agency.*** **(DOE, DOI, DOD, DOS)**

As part of Executive Order 14017 100-day report related implementation, DOE, DOD, and DOS are currently executing a Memorandum of Agreement on stockpiling. Building on this existing effort, the three agencies will continue to collaborate to:

- Incorporate energy transition and supply chain considerations into the National Defense Stockpile (NDS) to appropriately reflect demand needs associated with domestic decarbonization. Consistent with efforts to recapitalize and modernize the NDS program, expand procurement efforts and inventory of these minerals and materials through the NDS.

- Promote resilience of clean energy supply chains as well as development of a comprehensive approach on maintenance of responsible critical material supply chain transparency and security in multilateral groupings, including through the International Energy Agency (IEA).

- Leverage multilateral opportunities to encourage critical energy material stockpiling by aligned foreign counterparts in support of market development and sustainable sourcing practices.

Pillar II: Expand Domestic Manufacturing Capabilities

To build strong domestic supply chains needed to support the clean energy transition and create jobs for American families, strategic policies and investment will be required. The United States is actively implementing

[24] Critical minerals and materials: U.S. Department of Energy's Strategy to Support Domestic Critical Mineral and Material Supply Chains (Fy 2021–Fy 2031): https://www.energy.gov/sites/prod/files/2021/01/f82/DOE%20Critical%20Minerals%20and%20Materials%20Strategy_0.pdf

policies and programs to support manufacturing for clean energy technologies. Some of these, such as tax credits and RD&D investment in manufacturing innovation, are aimed at creating important market signals. Funding of research for new technologies and manufacturing methods and equipment, development and operations of research facilities, and support to technology incubators need to be part of the approach. For example, the DOE Advanced Manufacturing Office has established a set of advanced manufacturing research consortia to develop domestic manufacturing processes.[25] In highly specific cases, such as SEMATECH, the government has co-invested in new capabilities and facilities, but these have been rare, targeted, and time limited. The actions presented below build on these existing government efforts to support domestic manufacturing.

7. ***Raise awareness, coordinate, and expand manufacturing programs needed to support clean energy transition.*** **(SBA, DOE, DOD, DOC, DOL)**

DOE will coordinate with DOC, DOD, SBA, and DOL to leverage and raise awareness of existing energy manufacturing programs and expand support for manufacturing of machine tools and technologies needed for the clean energy transition. This includes the Manufacturing USA network and the Manufacturing Extension Partnerships. Expanded efforts will include support for manufacturing growth for both Small and Medium Scale Enterprises (SMEs) and large-scale enterprises. DOE has several manufacturing programs that engage government, industry, and national labs to advance manufacturing of clean energy. For example, DOE has partnered with industry to launch High Performance Computing for Manufacturing (HPC4Mfg), which pairs U.S. businesses with DOE national labs that are able to use high-performance computing for new clean energy technologies.[26] SBA can also leverage existing award-based opportunities such as SBIR and STTR programs that encourage domestic small businesses to engage in Federal Research/Research and Development (R/R&D) with the potential for commercialization.

More still needs to be done beyond RD&D to increase domestic manufacturing. DOE already has a Small and Medium Scale Enterprises (SME) program through its Advanced Manufacturing Office but will also leverage loan authority from DOE's Loan Programs Office (LPO) to provide more support to SMEs. DOE will leverage flexibility provided by the BIL amendments to Title XVII authority in order to waive innovation requirements when funding projects that also receive support from state financing institutions. Through this authority, LPO will be able to co-finance or guarantee state-backed projects that have been too small to apply to LPO directly, that utilize commercial (or elements of commercial) technologies, and that benefit from the aggregation of a variety of eligible, smaller projects. In addition, SBA currently offers 7(a), 504, and microloans, which provide businesses with up to $5 million for working capital and major fixed assets, such as for equipment financing. Expanding the 504-loan program to include supply chain financing will provide small businesses with the working capital and longer repayment terms they need to pay suppliers upfront, access discounts, and

[25] https://www.energy.gov/eere/amo/research-development-consortia

[26] https://www.llnl.gov/news/does-hpc-manufacturing-program-seeks-industry-proposals-advance-energy-tech#:~:text=The%20U.S.%20Department%20of%20Energy%27s%20%28DOE%29%20High%20Performance,proposals%20from%20industry%20to%20compete%20for%20%243%20million.

command more attention from suppliers to fulfill orders. Adding a Manufacturing Express loan could support equipment financing, facility upgrades, and capacity building and planning.

Also, DOE and SBA will collaborate across SBA's Office of Government Contracting and Business Development, Office of Investment and Innovation, and Office of Capital Access to enable small businesses (including contractors and manufacturers) to access timely and affordable capital to acquire technology, hire talent, and pay for supplies needed to deliver on a new contract. The SBA is currently assessing strategies to increase awareness of and improve access to affordable upfront financing from qualified U.S. private sector capital providers. Such upfront financing could enable small business government contractors to secure low interest rate loans for working capital or fixed-asset purchases immediately following Federal contract awards. Shortening the timeframe to access capital and lowering interest rates for borrowing could alleviate many of the pain points that small business government contractors face while awaiting the Federal Government's initial contract payment. Specific actions will include:

- Expand funding for RD&D in initiatives such as industrial decarbonization, materials and supply chains, and clean energy manufacturing to enhance the competitiveness of domestic producers. The funding could also include process innovations in steel, cement, and other heavy industrial sectors, manufacturing automation technologies, smart manufacturing, and other advanced and sustainable manufacturing processes across the full range of energy technologies.

- Expand funding for workforce development for the manufacturing sector. Expanded activities could include registered apprenticeships to increase the number of qualified technical employees available to support advanced manufacturing, as well as provide educational resources for community colleges and university curricula for professional and skilled workforce occupations. For example, the Industrial Assessment Centers are expanded under the BIL, to include community colleges, trade schools, and union training programs.

- Expand funding for technical assistance and management consulting in a way that accelerates manufacturing development to support key supply chain efforts. Part of the technical assistance could include supporting manufacturing industry to increased adoption of advanced energy efficiency technologies and wastewater use reduction practices in energy-related manufacturing. For example, in January 2022, DOE announced a funding opportunity of up to $7.5 million for technical partnerships through both Renewably Supplied District Energy Systems and the Regional Smart Manufacturing Pilot Initiative, which aim to accelerate the integration of smart manufacturing and energy management systems.[27] The awards will be given out between June to September 2022.

- Expand research on manufacturing innovations that enable manufacturers to be flexible in production, improve resilience, and reduce lifecycle emissions, while improving economic competitiveness.

[27] https://www.energy.gov/eere/amo/articles/funding-opportunity-announcement-technical-partnerships-foa

- Establish new public-private partnerships and continue to leverage ongoing partnerships to de-risk new manufacturing innovations (e.g., new processes, technologies, materials) through development, demonstration, piloting, commercialization, and scaling of new manufacturing technologies.

- In partnership with industry stakeholders, establish relevant scale RD&D testbeds to accelerate commercial readiness of emerging industrial decarbonization technologies needed to approach zero GHG emissions.

- Expand mechanisms such as competitive grants, direct loans, and loan guarantees that support domestic manufacturing capabilities and job creation. These funding mechanisms will focus on key areas that build on U.S. capabilities and developing markets. Possible topics will include electric vehicles (EVs), rare earth magnets, Grain Oriented Electrical Steel (GOES) – critical for electrical grid, semiconductors, batteries, solar PV processed materials and components, large power transformers, HVDC transmission systems, fuel cells and electrolyzers, nuclear reactor components, and other advanced materials and chemicals key to energy. The funding mechanisms will also focus on other opportunities to strengthen U.S. manufacturing capabilities, including support of casting and forgings, equipment and machine tools, and advanced manufacturing technologies, such as additive manufacturing. An example of an existing program that can be leveraged for these purposes is LPO Title XVII.

8. ***Chart a path forward on how communities, industry, and government envision and should pursue next generation large industrial facilities (e.g., steel mills, processing, and fabrication sites, etc.) necessary for an expanded domestic manufacturing base.*** **(EPA, DOE, DOC, DOL, DOI, SBA, state, local and tribal governments, civil society)**

Siting manufacturing facilities in the United States was identified as a challenge for many technologies. Rather than creating a new advisory committee or taskforce, an existing advisory committee, to be determined, housed within the White House, DOE, DOC, DOL, DOI, EPA, or SBA will analyze and determine a path forward on this important issue. Many communities may not want manufacturing facilities in their neighborhood based on environmental concerns, past experiences, or perceptions of impacts. Specific actions will include:

- Engaging with communities to understand concerns and needs and to identify opportunities to work together and advance next generation expanded domestic manufacturing.

- Overseeing engagement with communities on new rules, regulations, and policies in place that safeguard communities against environmental risks, as well as on ideas to increase the benefits of clean manufacturing to workers and communities. The task force can help build trust between communities, labor, industry, and government and help support domestic manufacturing.

- Outlining and illustrating the opportunity to conduct domestic resourcing and manufacturing using best-in-class standards and with minimal impacts, as compared with an alternative of out-sourcing to international locations, which may have poorer environmental, environmental justice, safety, community development, and economic standards.

- Ensuring that full life cycle impacts, including end-of-facility remediation, are fully addressed.

9. ***Leverage foreign direct investment in U.S.-based clean energy technology manufacturing by using targeted SelectUSA tools.*** **(DOE, DOC, DOD, DOS, states, and local government)**

- DOE in coordination with DOC, DOD, and other U.S. agencies will utilize SelectUSA events and tools to prioritize foreign direct investment in clean energy technology manufacturing in support of capacity geared towards alleviating supply chain bottlenecks and promoting diversification.
- DOE in coordination with the DOC and DOD will collaborate with like-minded foreign partners to attract foreign direct investment into U.S. clean technology manufacturing capacity.
- DOE in coordination with the DOC and DOD will evaluate opportunities to connect foreign critical mineral producers and supply sources from trusted partners with domestic processing and manufacturing companies and projects. This will take a number of forms, including policy and financial tools.

10. ***Coordinate with manufacturers and state, local, and tribal governments to support the establishment of regional clean energy industrial clusters, including providing technical assistance. (DOE, SBA, DOC, EPA, DOD, Congress)***

Regional clean energy industrial clusters have potential to drive innovation, increase competitiveness, and expand domestic manufacturing of clean energy technologies. Establishment of regional clean energy manufacturing clusters will be accompanied by analysis and increasing awareness of available special incentives and programs, identification of geographic locations of industrial brownfield sites available for redevelopment, and research on the local benefits and workforce opportunities created by a cluster. The regional clusters will not only help create quality jobs, attract talent, and drive innovation, but will also help reduce logistical and supply chain issues associated with manufacturing key technologies, such as PV mounting structures, wind turbine components, and hydropower components. There are also opportunities to learn from international industrial clustering policies and approaches. This policy action can be spurred by congressional direction as well as White House leveraging of existing funding. Specific actions will include:

- DOE and SBA will prepare a joint technical assistance plan to support small businesses to expand their role in the U.S. energy supply chain. This plan will include available or proposed budget and programs/activities, analytical capabilities, available or required technical assistance to implement the plan, and a communication and stakeholder outreach to stakeholders (i.e., industry, state/local government, NGOs, unions, community, and workforce groups etc.).
- Engage private sector, community members, and government to leverage existing knowledge on potential clusters in the U.S. such as the U.S. Cluster Mapping Project by the Harvard Business School and U.S. Economic Development Administration, and through a variety of approaches including stakeholder engagement and requests for information with the aim to:
    - Identify the potential geographic locations and number of industrial clusters that will be needed to strengthen U.S. supply chain resiliency for specific clean energy technologies. High potential geographic locations will utilize local assets, including natural resources (e.g., mineral deposits

and water); existing transportation, pipeline, and electric infrastructure; trained and skilled workforce or the potential to foster such a workforce via academic and trade schools; and local connections to existing supply chains that need to be strengthened. State-focused investments in specific technologies that could be leveraged are also a strength in identifying potential geographic locations, such as Connecticut (fuel cells cluster in the Danbury region) or New York (batteries).

- Identify costs and benefits for the prospective locations for these industrial clusters. Factors for consideration will include local economic opportunities and opportunities to reduce local air and water pollution as well as other environmental impacts, especially affecting disadvantaged communities. Additional consideration will include whether the region has been historically reliant on fossil fuel production or fossil fuel-based industries (e.g., the internal combustion engine automobile industry) and what existing manufacturing and supply chain, including workforce and training, resources can be augmented.

- Identify core technology areas of focus for these industrial clusters, drawing on the technologies in this report and leveraging on analytical frameworks such as the one identified in the *Commercialization and Competitiveness of Energy Technologies* deep dive assessment (released in conjunction with this policy strategy report), and future DOE analysis.

- Identify potential levers to mitigate market failures (e.g., mitigate the risk and maximize the reward of investments) to develop these regional clusters from the perspectives of key stakeholders, including the private sector and state and local government.

- Develop environmental standards or recommendations that focus on community revitalization as well as engagement and ensure that regional industrial clusters benefit the members of adjacent communities. **(EPA, relevant agencies, and communities)**

- Fund existing programs and consider whether new authority is needed to enable Federal awards, matching grants, direct loan, and loan guarantees to support creation of these clean energy manufacturing clusters and leverage existing public programs (Federal, state, local) for regional innovation and manufacturing ecosystems. Examples of such public programs include DOE's Energy Program for Innovation Clusters, Clean Hydrogen Hubs authorized by the BIL, SBA's Growth Accelerator Fund Competition, and SBA's Regional Clusters. These programs can more comprehensively support regional ecosystems of entrepreneurs, supply chain partners, labor and community groups, and manufacturing partners to support energy technology commercialization and job growth. **(Congress)**

- The final locations for technical assistance and resources supporting regional clean energy industrial clusters should be determined on a competitive basis. In addition, selection criteria should account for regional comparative advantages.

***11. Enhance coordination of trade policy across the U.S. Government to support fair conditions for the U.S. clean energy industries and its workers (*(DOC, USTR, DOE)**

U.S. manufacturers, particularly in the solar industry, have too often faced unfair—and often illegal—competition from firms that benefit from foreign, non-market practices. In the specific context of the solar manufacturing industry, the United States has responded with trade remedies that protect domestic manufacturing from dumping or competition from companies that use forced labor. The U.S. Government will continue to provide the trade remedies that U.S. firms are entitled to under U.S. law and will engage with experts and relevant stakeholders across the supply chain to review the impact of established trade policies on domestic manufacturing with the aim of ensuring a level playing field across the supply chain both in the United States and around the world.

Pillar III: Invest and Support Formation of Diverse and Reliable Foreign Supply Chains to Meet Global Climate Ambitions

The global market for clean technologies—if we are to meet global climate goals—is simply much larger than the United States can fulfill alone. Supporting global development of the clean energy industrial capacity needed in collaboration with partners and allies and in accordance with principles and standards supported by the Build Back Better World initiative can help secure more resilient, diversified, and sustainable supply chain sourcing to meet global climate goals. U.S. policy has historically promoted open trade through agreements with key partners, such as the United States-Mexico-Canada Agreement (which substituted the North American Free Trade Agreement), that strengthen supply chains essential to meeting larger policy goals. These agreements can also enable requirements for social and environmental standards. Building on the existing U.S. efforts, this strategy presents more policy actions that will be needed to support scaling of clean technologies. The actions presented below build on these existing government efforts to support formation of diverse and reliable foreign supply.

12. ***Increase Federal government financial support to eligible U.S. companies investing in or exporting to foreign countries to secure supply chain inputs that fill challenging domestic gaps and support growth of other domestic segments of the supply chain.*** **(EXIM, DFC, DOD, USTDA, DOC)**

There are various supply chain inputs that the United States is not able to fill for various reasons, including geology, and the U.S. Government can use Federal levers to support companies in securing these inputs. These levers should be deployed to complement viable domestic opportunities to diversify clean energy supply chains. This action builds on current government efforts such as those at EXIM and DFC that support eligible companies to invest in securing American supply chains. For example, DFC focuses on financing private companies in developing countries, such as investing in a graphite mine in Mozambique—a mineral key to lithium-ion battery manufacturing.

EXIM supports eligible U.S. business exports of goods by providing loans, loan guarantees, and insurance. EXIM is launching a new Office of Global Finance Development to enhance its business development capabilities and engage U.S. firms capable of expanding exports of transformational products. EXIM received positive feedback from companies in the energy supply chain to its December 2021 "Information Request on Potential Parameters of Export-Import Bank Financing for Domestic Projects," supporting EXIM providing financing in support of the establishment and/or expansion of U.S. manufacturing facilities and infrastructure projects in the United States that would facilitate U.S. exports. For example, public comments included a lithium

extraction company, "... [I]t is challenging to effectively scale lithium production in the U.S. to the degree demanded for the clean energy transition due to the lack of available government-backed credit enhancement in the U.S.," and a solar panel company, "A program such as this, in combination with the other federal government initiatives proceeding at this time is critical to overcoming the manufacturing barriers that have prohibited the successful deployment of U.S. solar manufacturing capacity to date." EXIM will also begin a process to review how it conducts economic impact analysis to potentially expedite transactions that would result in the production of critical supply chain inputs (provided the transaction does not create domestic competitiveness barriers). Building on these existing efforts, specific new actions will include:

- Provide financial support for U.S. companies to invest in and develop manufacturing of components, particularly those components identified by DOE supply chain analyses, which are not currently economically feasible to produce in the U.S., but face vulnerabilities related to market concentration or single points of failure.

- Leverage the Build Back Better World (B3W) initiative launched in 2021 by G7 countries to support projects that simultaneously advance energy supply chain resiliency and B3W's principles for quality and sustainable infrastructure.

- Accelerate and expand financing and project development tools and incentives to assist eligible companies investing in resource-rich countries. These investments should be leveraged to elevate and expand adoption of sustainability standards, particularly in relation to mineral extraction, processing, and refining.

- Prioritize support for materials mining and processing projects, with a particular focus on projects that feed growth of other supply chain segments in the United States that currently have unmet demand for inputs that cannot be met through domestic avenues at scale or at sufficient pace as identified by DOE supply chain analyses.

13. Establish and fund an initiative for expanding clean technology manufacturing capacity globally to achieve the dramatic scale-up in manufacturing of key climate and clean energy equipment associated with meeting net-zero commitments. **(DOE, DOS, DFC, EXIM, DOD, USTDA, DOC)**

More than 130 countries have committed to achieving net-zero emissions. Meeting these goals can avert the worst impacts of climate change—saving lives, driving economic growth, and improving health in communities around the world. Meeting the anticipated explosion in global demand for clean energy products needed to meet these global climate goals will require a buildout in the United States and elsewhere. The strategy described in this report will ensure that much of the clean energy technologies will be sourced and manufactured domestically and from allies where this is not feasible. For example, the United States has supplies of lithium and neodymium that will be supplemented by global supplies to meet expected future demand. The B3W initiative can help secure more resilient, diversified, and sustainable sourcing of climate and clean energy supply chains to supplement what is available in the United States. Specific actions will include:

- Leverage bilateral and multilateral energy dialogues to promote: the expansion of like-minded sourcing and manufacturing capacity; the creation of research partnerships between labs and foreign academic institutions in support of a net zero manufacturing accelerator network; development of relevant

workforce capacity; and the formation of multi-party pilot projects to demonstrate and move toward deployment of carbon neutral clean technology sourcing and manufacturing capacity.

- Examine gaps in domestic sourcing and manufacturing and align with global locations conducive to the development of clean energy technology manufacturing. Additionally, expand technical assistance in partner countries to facilitate development of clean technology supply chain and manufacturing capacity.

14. Promote adoption and implementation of traceability standards to improve global supply chain mapping capabilities, instill integrity of product custody, promote social responsibility, and support carbon footprinting of energy supply chains. **(DOS, DOE, DOC, DOL, EPA, DHS, NASA, DOD)**

There are ongoing efforts within the U.S. Government to promote traceability of supply chains. For example, in February 2021, DOL awarded $8 million to support enhanced tracing of goods made with child labor, forced labor, and other exploitive practices in three countries—India, Pakistan, and the Democratic Republic of Congo.[28] There are also ongoing interagency efforts that include DOS, DOC, and DOE among others to address forced labor issues affecting the input materials used by the solar PV supply chain. In December 2021, President Biden signed the Uyghur Forced Labor Prevention Act into law, which imposes importation limits on goods produced using forced labor in China, especially the Xinjiang Uyghur Autonomous Region.[29] Building on the existing interagency efforts, DOS will work with DOE, DOC, DOL, EPA, Customs and Border Protection, NASA, and DOD to continue to improve and promote implementation of traceability efforts but also expand support to carbon footprinting. NASA will contribute its technical expertise on forensic analysis capability. Specific actions will include:

- Engage bilaterally with producing and importing countries to raise awareness around traceability standards, lifecycle emissions, and their implementation.

- Leverage multilateral dialogues to promote the exchange of data and the development of standards for technology needed to track the movement of critical materials throughout the supply chain.

  Establish a technical capability within the Federal Government to perform forensic analysis on any critical material at all points in the supply chain to determine its source(s).

[28] https://www.dol.gov/newsroom/releases/ilab/ilab20210209-1

[29] https://www.congress.gov/bill/117th-congress/house-bill/6256?q=%7B%22search%22%3A%5B%22Uyghur+Forced+Labor+Prevention+Act%22%2C%22Uyghur%22%2C%22Forced%22%2C%22Labor%22%2C%22Prevention%22%2C%22Act%22%5D%7D&s=1&r=3

Pillar IV: Create Clear Market Signal to Increase the Adoption and Deployment of Clean Energy

There is a need to create and sustain stable future demand for these clean energy technologies, including energy efficiency, to motivate domestic supply chain investments. In addition to the legislative opportunity, described in section 3.2, the executive branch of the Federal Government has several tools to support clear and strong demand signals.

15. Leverage Federal purchasing power to provide a sustained demand signal for both domestic clean energy products and the capability to manufacture them domestically **(DOE, DOD, GSA, SBA)**

DOE will collaborate with GSA, DOD, and SBA to leverage DOD experience and GSA and SBA authority to support strong investment in clean energy. Specific actions will include:

- Incentivize domestic production of energy components on government supported projects:
    - Whenever possible, require domestic content standards for Federal procurement of electronics (including those in electric vehicles), batteries, solar inverters, and grid components such as HVDC converters. Where appropriate, provide specific domestic content incentives.

- Leverage available authority to provide a strong demand signal for domestic clean energy manufacturing. Identify any gaps between actions planned under EO 14057 (Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability) and the demand signal need identified by the 1-year supply chain review reports. The Council on Environmental Quality is working on implementing instructions for EO 14057 that will provide additional clarity.

- SBA will leverage small business financing tools e.g., SBIR to support small business. SBIR is a competitive awards-based program that enables small businesses to explore technological potential and provide the incentive to profit from its commercialization. By including qualified small businesses in the R&D process, the Federal government can stimulate demand and help meet R&D, and production needs. In addition, recent changes to the Category Management program will facilitate increased purchasing from small businesses contributing to a sustained demand signal.

- Strengthen Federal purchasing program tracking and reporting on the purchase of recycled content products as required by the Federal Acquisition Regulations (FAR) Part 23 and through Federal Affirmative Procurement Programs (APP) for EPA designated items.

16. Develop a preference list of materials that will be used for Federal procurement and as a basis to engage U.S. industry and foreign governments to secure capacity. **(DOE)**

As part of the deliverable for the response to Executive Order 14017, DOE will develop a "preference list" list of critical materials and components that have been identified by the one-year supply chain review and updated yearly thereafter. This proposed list will be informed by analysis and input from private and government engagement. The list will provide a basis for Federal procurement and financial assistance to send clear demand signals to domestic manufacturers and foreign allies in building resilient domestic supply chains. This list will

identify critical materials and components that may receive time-limited financial incentives in Federal procurement to foster domestic manufacturing and strengthen the supply chain. This list will be shared with key Federal agencies such as DOS and DOC to help them identify foreign ally engagement as well as domestic business needed to help the United States secure needed critical materials and components. The list will also be shared with funding agencies such as SBA, EXIM, and DFC to help with their strategies in investing in supply chains. Additionally, the list will be available for any Federal agency, state and local governments, and industry to support strategic investment and Federal procurement.

17. ***Identify and advance activities to grow and sustain the demand signal for sustainable transportation fuels and associated supply chain industries.*** **(EPA, DOE, DOT, DOD, USDA, TPCC)**

This policy strategy is already being implemented by DOE, DOD, EPA, and USDA. For example, DOE, DOT, and USDA jointly launched the Sustainable Aviation Fuels Grand Challenge, a comprehensive Government-wide strategy for scaling up new technologies to produce sustainable aviation fuels (SAF) on a commercial scale.[30] The effort aims to supply sufficient SAF to meet 100 percent of aviation fuel demand by 2050, with a near-term goal of 3 billion gallons per year in 2030. DOD activities to provide demand signals for sustainable fuel are funded through budgetary processes. Examples for hydrogen include DOE's ongoing RD&D activities as well as the BIL funding for electrolysis, manufacturing, and hydrogen hubs. Ensuring there are strong and sustained demand signals for sustainable transportation fuels and related supply chain industries are key to securing private sector investment and domestic manufacturing scale-up. Further actions will include:

- The EPA, DOE, USDA, DOD, and DOT in consultation with other relevant agencies will engage with industry, states, utilities, energy companies, and other key stakeholders to identify additional next steps, including policy frameworks, to drive demand for domestic sustainable transportation fuels and supply chains.

18. ***Ensure that implementation of the U.S. Government clean technology competitiveness export strategy harnesses the clean technology demand pull of international markets in a way that supports domestic manufacturing.*** **(Trade Promotion Coordinating Committee (TPCC) agencies)**

DOC has been coordinating the ongoing interagency efforts through TPCC to engage foreign allies in securing supply and supporting U.S. clean energy manufacturing. As part of the response to Executive Order 14008, "Tackling the Climate Crisis at Home and Abroad," DOC is developing the U.S. clean energy technology export competitive strategy.[31] The strategy is being finalized, and interagency discussions are underway to develop an integrated project implementation plan. Specific actions will include:

[30] https://www.energy.gov/eere/bioenergy/sustainable-aviation-fuel-grand-challenge

[31] https://www.federalregister.gov/documents/2021/08/30/2021-18637/request-for-comments-on-us-clean-technologies-export-competitiveness-strategy

- Align existing U.S. competitive advantage and planned DOE investments to position U.S. clean energy manufacturing capacity for exports to international markets and do so in ways that will help meet growing net-zero climate commitments.
- Utilize the TPCC to continue to prioritize clean technology competitiveness as part of the National Export Strategy process and to monitor success of the clean technology export strategy.

19. Examine and analyze costs and benefits of authorizing federal agencies to sign utility service contracts and power purchasing agreements that extend beyond the current 10 year maximum for power procurement from clean energy technologies. (DOE, GSA, OMB)

DOE will engage other Federal agencies, utilities, and clean energy developers to examine and analyze costs and benefits of amending 40 U.S.C. § 501 to extend the authorized contract term beyond the current 10 year maximum for utility service. This proposal does not seek to change the treatment of capital leases under the scorekeeping rule as detailed in Circular A-11 Appendix B. Federal agencies can enter into power purchase agreements (PPAs) for the multi-year purchase of power. PPAs can be a significant incentive for the deployment of clean energy technologies. Long-term PPAs may reduce the financial risk for the deployment of clean energy technologies. However, a long-term PPA increases the risk that it could be scored as a capital lease, which requires agencies to pay the full estimated net present value of the Government's total estimated obligations in the first year of the contract.

Pillar V: Improve End of Life and Waste Management

Recycling has a long history in the United States but largely as a means of waste management and typically incentivized at the state and local level. Metals with high value to industry, such as aluminum and steel, have high recovery rates and in many cases feed a domestic metals processing supply chain that is highly electrified further reducing GHG emission especially when electricity is sourced from clean energy sources. Hazardous waste management, such as for lead acid batteries, is regulated for both minimizing waste in landfills and for materials recovery. The U.S. does not yet have strong product responsibility requirements to recover valuable materials from consumer and other distributed products. DOE will leverage funding authority provided by the BIL to support end of life waste management. The BIL allocated more than $320 million to support battery recycling—including RD&D as well as $200 million to support electric vehicle battery recycling, including second life. Part of the $750 million allocated from section 40209 of the BIL is also designed to support recycling facilities of advanced energy projects. The actions presented below build on existing efforts to engage government and the private sector on end-of-life waste management.

20. Leverage U.S. Government's purchasing power and demand to support supply chains of recycled content products, market development, and sustainable sourcing practices

Federal agencies purchase recycled content products in accordance with RCRA section 6002 and Federal Acquisition Regulation (FAR) part 23. The BIL also supports efforts to advance Federal purchase of recycled content products. EPA and GSA will continue to collaborate to:

- Increase awareness of Federal affirmative procurement programs and requirements for agencies to purchase recycled content products.

- Explore opportunities to encourage and support agencies' procurement of recycled content products to promote a transition to a circular economy.

Pillar VI: Attract and Support a Skilled U.S. Workforce for Clean Energy

21. Convene multiple agencies and workforce stakeholders to advance energy workforce development. **(DOL, ED)**

The Department of Labor (DOL) in coordination with the Department of Education (ED) will develop targeted sector-based plans that will include convening Federal agencies, regional employers, state and city governments, labor unions, training partners, and NGOs to advance skill-adjacent training and registered apprenticeships that will support the large-scale training needs of energy workers and employers. This builds on existing activities underway with DOL and DOE.

22. Embed strong labor standards and support for organized labor in Federal funding for the Energy Sector Industrial Base. **(DOL, ED, DOE)**

Cultivating and maintaining U.S. jobs for critical parts of the energy sector is a priority. The DOE 1-year reports identified several workforce demand and training gaps across supply chains. Importantly, this workforce demand is not limited to the energy sector supply chains, and affects other sectors such as defense, agriculture, and service (including information and technology industries). Thus, a Government-coordinated approach is needed to address these multi-sector workforce issues and should cover the entire supply chain from raw materials and manufacturing to end-of-life and recovery. DOL and ED will work with other agencies and key stakeholders to identify labor standards that will need to be upheld and will set strategic nationwide plans to encourage the creation of safe jobs with competitive wages and benefits. This will lead to a stronger ability to attract and retain a qualified and competitive workforce. Additionally, The DOE 21st Century Energy Advisory Workforce Board directed by section 40211 of the BIL can be leveraged to support interagency efforts in building the workforce that is needed for the Energy Sector Industrial Base. Specific actions will include:

- Using Federal and state policy and procurement levers to support unionized, family-sustaining employment in the manufacturing sector.

- Strengthening the manufacturing workforce by requiring or incentivizing job creation and job quality commitments by manufacturing firms working on projects funded with public dollars.

- Engaging in outreach to communities that identify effective methods to retrain displaced workers who are interested in transitioning to new clean energy careers. Additionally, support unionization across technologies to facilitate the ability of workers to switch jobs without losing union benefits or taking wage or benefit cuts.

- Consistently including prevailing wage requirements and apprenticeship utilization goals on construction projects that are funded or subsidized with public dollars and encourage the use of project labor agreements and construction career policies to increase access to construction jobs for local and marginalized workers.

Pillar VII: Augment Supply Chain Knowledge and Decision-Making

Broader analytical capability is required to fully understand drivers and dynamics across all clean energy technology supply chains on a proactive, ongoing basis. Supply chain policy and investment decisions should continue to be grounded in an understanding of risks, dependencies, material availability, supply chain dynamics, market dynamics, unit economics, and total cost of ownership. Integrating tools that can assess these interactions can help guide development of environmentally, socially, and economically sound solutions. But many available structured data resources are not adequately designed to perform such supply chain analysis. The significant increase in the use of clean energy technologies in the United States and global economies requires a commensurate increase in the ability of the U.S. Government and its national labs to collect, standardize, compile, validate, analyze, and distribute economic and market data to inform public and private decision-makers across the clean energy economy and assess results on improving energy sector supply chain resilience. This will require a scale-up in the capacity of multiple Federal and quasi-Federal entities to handle an increasing amount of data and analysis in these growing markets and industries. Taking advantage of existing Federal authorities, DOE will work with other agencies to implement the strategies highlighted below to ensure that moving forward, DOE will build energy supply chain knowledge and analytical capabilities not only useful to the DOE mission, but also for other federal agencies and the U.S. economy at large.

23. Create and maintain a manufacturing and energy supply chain office as well as database and analytical modeling capabilities. **(DOC, DOE, DOD, DOS, DHS, NASA)**

Given the broad and increasing interdependency of risks to supply chains in the ESIB, a comprehensive approach is needed to strengthen and secure energy supply chains and galvanize domestic manufacturing. DOE will create a new manufacturing and energy supply chain office that will help implement the strategies described in this report and coordinate closely with multiple offices within DOE and across the interagency. This office will focus on strengthening and securing energy supply chains needed for energy transition. Building upon the National Institute of Standards and Technology (NIST)'s study for the proposed national supply chain directed by Section 9413 of the NDAA for Fiscal Year 2021, and existing DOE authorities in coordination with DOC, DOE will create the ESIB Database. There are already supply chain capabilities in DOD, NASA, and USGS that DOE can build upon. USGS has supply chain models to track critical minerals. DOD has the critical materials economic models under the stockpile program supported by USGS and DOC. NASA has multiple databases that address supply chain information and is working on interoperability within the Agency. DOE is planning for a comprehensive and holistic database and analytical capabilities to support the ESIB and will look to collaborate with DOC, DOI, USGS, DOD, and NASA to build on existing supply chain capabilities. The database and the analytical capabilities will be designed to enable:

- Identification and understanding of sources, risks, and consequences of supply disruptions.

- Examination of the availability of raw materials and the viability of establishing domestic supply chains while accounting for other hidden costs of offshoring (e.g., carbon emissions, reduced future innovation potential, risks of long supply chains).
- Exploration of possible outcomes of actions taken by government or market players and the effect on clean energy supply chains of new or emerging energy generation and supply technologies and applications.
- Evaluation of clean energy technology supply chain factors to identify and address concerns that may limit commercialization or competitiveness of these technologies.
- Identification of critical products with a limited number or a monopolization of suppliers.
- Forecasting of material flows, productions, and pricing under various scenarios including demand growth/shrinkage, technology change, trade policies, and new supply sources.
- Prediction of points of failure in supply chains to proactively address them through redundancy in supply chains.
- Economic analyses across technology supply chains on an ongoing basis and under varying scenarios in the short, medium, and long term.
- Development of an evaluation of integrated technology and commercialization roadmaps for priority technologies and markets that include technology commercialization and market adoption data, analysis, and strategies. The roadmaps can be updated on a regular basis to ensure they are relevant to fast-moving market dynamics.

Specific actions will include:

- DOE will establish a new Manufacturing and Energy Supply Chain Office to help strengthen and secure strategic supply chains needed for the energy sector. This office will also house supply chain analytical capabilities that will help inform the department decision making including investment decisions to support commercialization and scaling of technologies, and growth of domestic manufacturing sector. This office will work in close coordination with the proposed Critical Supply Chain Resiliency Program (CSCRP) at DOC.
- DOE will leverage existing DOE authorities such as those provided by Energy Policy Act of 2005 and Energy Act of 2020 to create the ESIB database as well as leverage the NIST study on a proposed National Supply Chain Database per the National Defense Authorization Act of 2021. This supply chain database and assessment will be updated periodically as determined by the Secretary of Energy and shared with other Federal agencies that are in charge of promoting domestic manufacturing, such as the interagency Made in America Council announced in 2022 as well as the Manufacturing Extension Partnership.
- DOE, in coordination with DOC and Customs and Border Protection, will build analytical decision models to track and assess the global trade of key energy-related materials and components and to assess market dynamics.

- DOE will create standard definitions and frameworks to characterize and synthesize status and dynamics across clean technology supply chains and to encourage use of these definitions and frameworks, where appropriate, by Federal agencies and state and local governments.

- DOE requires open data access provisions in DOE-funded demonstration projects; learning from these projects will accelerate commercial adoption and deployment and maximize public benefit.

In addition:

- DOE will work across the agency, including with the Energy Information Administration (EIA), building on the BIL to expand EIA analysis activities that will include upstream clean energy critical materials. EIA will integrate upstream critical material data and analysis into its analytical activities and reports, such as the Short-term Energy Outlook and the Annual Energy Outlook, where appropriate and feasible.

- DOE will coordinate output and findings from DOE economic analyses and roadmaps with interagency partners to develop integrated commercialization strategies that dovetail with global market opportunities and export strategies.

- DOE will continue to work on advanced manufacturing and how supply chain work can support the next generation of manufacturing.

24. ***Support studies that assess and quantify the economic, environmental, social, and human rights impacts of different aspects of the energy supply chain for all clean technologies.*** **(DOE, EPA, DOC, DOS, DOI, USGS)**

As mentioned earlier, the transition to a clean energy economy provides the opportunity to build supply chains differently and better. Knowledge of potential risks and opportunities related to economic, environmental, social, and human rights factors within the global clean energy supply chains are needed for government and private sector strategic planning and decision making. This knowledge will not be limited to understanding these impacts in the United States but will extend to engaging allies to examine the environmental and social footprint of industries in other countries so that U.S. companies are not uniquely spotlighted, especially in cases where negative impacts are identified.

- Fund detailed analyses of collection and recycling rates among different technology types and metals in the United States, including projections for at least 10 years and the impact of recycling investments on recycling rates. Included in this analysis should be an assessment of what types and parts of the technologies are being collected and recycled, by whom, from which sources, and the destinations of these technologies for recycling. Additionally, the end use or stockpiling of the recovered material from waste streams should be explored. Analysis should include determination of optimal feasible recycling rates for clean technologies and let those inform national targets for recycled content and collection rates. This type of study will help gain a deeper understanding of recycling in the United States so that informed decisions may be made about targets and enforcement.

- Conduct an analysis and design requirements for corporate responsibility for products at end-of-life and waste generation across the supply chain, with emphasis on those containing critical or key materials

that could be valuably recovered and the recyclability of inputs to processing and manufacturing processes.

- Conduct an analysis of impacts to jobs in upstream industries that support clean energy manufacturing, as well as increases in value added and changes in household spending.

***25. Support actionable, deep dive analyses that build on The Long-Term Strategy of the United States in a way that informs high-priority decarbonization and American economic leadership strategies.* (DOE, DOC, DOL, SBA, EOP)**

The Long-Term Strategy of the United States[32] lays out pathways to reach net-zero greenhouse gas emissions economy-wide no later than 2050 and identifies the clean energy deployment and scale up in supply chains needed to meet this target. The Strategy shows how driving down GHGs will spur investments that modernize the American economy, address the distributional inequities of environmental pollution and climate vulnerability, improve public health in every community, and reduce the severe costs and risks from climate change. Additional analysis that builds on *The Long-Term Strategy of the United States* will further explore the clean energy transition, including policy actions and technologies that consider economic, environmental, and social dimensions. Specific actions will include:

- Studies to examine U.S. resources, manufacturing infrastructure, supply chain resiliency, workforce needs, energy and environmental justice and equity, while targeting value-added steps and accelerating technology development and adoption. For example, further exploration is underway on the impacts of the transition to electric vehicles, including the associated shifts in manufacturing, operation, maintenance, and end-of-life management and recycling, while considering changes in communities, workforce, and education needs.

- A study to identify and examine the role and impacts of small businesses in the U.S. clean energy supply chains. Small businesses are a large part of the American economy and have potential to create high quality jobs for many Americans. Identifying their role in the energy transition and particularly in the supply chains will be key.

***26. Engage government and private sector to develop a secure digital component supply chain strategy for the Energy Sector Industrial Base.* (DOE, DOC, DHS)**

As the energy sector has become more globalized and digitized with increased use of smart systems, the supply chain risks for digital components has evolved and expanded. The list of digital components in U.S. energy sector systems includes software, virtual platforms and services, and data. The supply chain risks have grown in recent years as increasingly sophisticated cyber adversaries have targeted and exploited vulnerabilities in these digital assets. Key cyber vulnerabilities include reliance on untrusted foreign suppliers and software developers;

[32] https://www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf.

reliance on opaque and highly dynamic global supply chains for digital goods and services; high and often unrecognized reliance on certain ubiquitous key digital components in energy sector systems that have the potential for cascading effects if concurrently compromised; and fragmentation and inconsistent oversight of interdependent of cyber supply chains. Key cyber threats include national security threats from adversary nations with sophisticated intelligence collection and cyber capabilities and threats from criminal actors (both independent and state-sponsored) employing ransomware attacks via digital supply chains. Cyber supply chain risks are present in all systems within the U.S. Energy Sector Industrial Base, namely those systems operated by asset owners and third-party contractors across energy subsectors (e.g., electricity, oil and natural gas, and renewables) and the systems operated by a worldwide energy industrial base. In general, supply chain risks for digital components in energy sector systems are consistent with those identified for information and communications technologies (ICT), and all stakeholders in the Energy Sector Industrial Base operate some form of ICT. More on cyber supply chain risks and vulnerabilities is covered in the deep dive assessment on *Cybersecurity and Digital Components* that accompanies this strategy report (energy.gov/policy/supplychains).

Overall, supply chain risks for digital components in energy sector systems will continue to evolve and likely increase as these systems are increasingly interconnected, digitized, and remotely operated. DOE strategy addresses parts of security for interdependent digital supply chains across the Energy Sector Industrial Base (ESIB). Because cyber supply chain risks are shared among interconnected energy systems, a more holistic approach is needed to effectively increase resilience and digital supply chain security. Building on the ESIB database to be created per *Policy Strategy 22* of this document, DOE will leverage DOC and DHS Information Communication Technology supply chain efforts to develop a secure digital component supply chain strategy for the ESIB. In developing this strategy, DOE will partner with industry in mapping critical digital supply chains and creating a security strategy to mitigate risk and threats throughout the ESIB. The secure digital component supply chain strategy for the ESIB will identify actions to address the supply chain security of critical digital components including software, virtual platforms, services, and data used by key subsectors and companies in ESIB that are critical to U.S. energy security. The strategy will be developed with input from ESIB industry stakeholders. Efforts will be aligned to any similar initiatives underway within the defense, IT, and communications sectors, as appropriate. This strategy will leverage activities funded by section 40125 of the BIL. Specific actions will include:

- Establish a secure digital component supply chain strategy for the ESIB based on a prioritized assessment of risks and challenges to energy sector digital supply chains (modeled on 10 U.S.C. §2501) to include:
    - defining and prioritizing critical digital supply chains for ESIB;
    - establishing a required baseline and tiered security controls for hardening digital supply chains in ESIB;
    - funding to support hardening priority digital supply chains in ESIB; and
    - requiring use of Federal purchasing power (under the Buy America Act) to support hardened digital supply chains for ESIB.
- Assess the installed base of digital components in critical energy systems to determine prevalence and prioritize cyber supply chain risks and mitigation actions.

- After baselining activities are completed, the strategy will develop recommendations to improve the security of ESIB digital supply chains and address the threat of malicious compromise of critical software in terms of development and maintenance for critical software, virtual platforms, services, and data services.

27. ***Engage government and private sector to create national standards, guidelines, and requirements for the security of energy-related software, firmware, virtual platforms and services, and data.*** **(DOE, DOC/NIST, DHS, DOT, DOD)**

To address fragmented and inconsistent oversight of supply chain risks for digital components in critical energy systems, DOE, in consultation with other Federal agencies including DOC/NIST, DHS, DOT, and DOD, will undertake steps to develop consistent standards and guidelines to manage shared cybersecurity risks more effectively in digital supply chains for the ESIB. These efforts will leverage and build upon actions directed in Executive Order 14028, "Improving the Nation's Cybersecurity," and on efforts completed by the Securing Energy Infrastructure Executive Task Force pursuant to Fiscal Year 2020 NDAA section 5726, as well as incorporate new initiatives directed under section 40122 of the BIL, the Energy Cyber Sense Program. Specific actions will include:

- Leverage existing sources of standards and guidance within the energy sector, from other applicable sectors, and from global standards bodies to develop additional guidelines for the ESIB for critical digital supply chains that secure software, virtual platforms, datasets, and digital components. This will leverage the existing work of the Securing Energy Infrastructure Executive Task Force on evaluating the standards used to secure industrial control systems mandated under Fiscal Year 2020 NDAA section 5726.

- Identify, characterize, and assess global supply chains for critical digital components (including software, virtual platforms and services, and data) in ESIB systems, to include the bulk electric system, to inform cyber supply chain analyses. Characterization of information should include factors such as foreign provenance, ownership, control, and influence for prime and sub-tier suppliers.

- Develop guidance on the use of software and hardware bills of materials to illuminate risk in critical software supply chains and virtual platforms used in ESIB. This work will build on existing efforts underway at DOE and expanded under section 41022 of the BIL, the Energy Cyber Sense Program.

- Establish a technical R&D program to further develop capabilities to automate generation of software and hardware bills of materials for energy system components to illuminate software supply chain risks in commercial transactions at scale.

Technology-Specific Strategies

This section presents technology-specific strategies that the Federal Government can take to supplement cross-cutting strategies.

Table 5. Technology-Specific Strategies

S/N	Technology	Strategy	Actor(s)
		Energy Infrastructure	
28.	Fuel cells and electrolyzers	Engage government and private sector to explore the idea of a hydrogen reserve.	DOE, EPA, DOT
29.	Nuclear	Develop an integrated waste disposal strategy, with an initial focus on consent-based siting process for the siting of Federal facilities for the temporary, consolidated storage of spent nuclear fuel.	DOE, NRC, EPA
30.	Energy storage	Engage government and private sector to deploy long duration (10-plus hours) energy storage projects that utilize a structured framework for meeting cost feasibility goals and supply chain sustainability metrics.	DOE
		Electricity Grid and Market	
31.	Energy storage	Provide technical assistance to design and support an "energy storage subscription" financing model, hosted by utilities or third parties to provide a financing option for storage.	DOE, FERC
32.	Fuel cells and electrolyzers	Engage government and private sector to develop novel utility ownership structures and regulatory support, including a novel power purchase agreement structure for long−term contracts with electrolyzers and fuel cells.	DOE, state and local governments, public service commissions
33.	Energy storage	Conduct a study to evaluate the impact of second life grid applications for which parties own the batteries in a high EV-deployment scenario.	DOE
		Manufacturing and Innovation	
34.	Semiconductors	Engage government and private sector to: • Expand RD&D on high voltage (up to 10 kilovolt) silicon carbide wide bandgap semiconductors for high-power and high-voltage electrification applications needed for decarbonization. • Invest in advanced packaging RD&D to expand U.S. capacity for conventional semiconductor supply chain and promote competitive advantages for U.S. manufacturers.	DOE, DOD, DOC
35.	Semiconductors	Engage government and private sector to embed energy efficiency improvement efforts into research, development, demonstration, and commercial application investments to improve the energy efficiency of microelectronics over the next 20 years	DOE, DOC, DOD, NSF, DHS
36.	Nuclear	In coordination with NRC, will support deployment of advanced nuclear reactors in a timely manner. Specific actions include: • Fully implement NEICA (Nuclear Energy Innovation Capabilities Act) to enable private sector partnerships with national labs to	DOE, NRC, DOD

S/N	Technology	Strategy	Actor(s)
		demonstrate novel reactor concepts and share technical expertise with NRC. • Fully implement NEIMA (Nuclear Energy Innovation and Modernization Act) to ensure successful and efficient licensing of the next generation of technology in the near term. • Implement DOE programs for advanced reactor demonstration projects and for HALEU availability to support timely deployment of these new technologies by private sector	
37.	Magnets	Engage government and private sector to lead efforts to utilize the Defense Production Act to develop the domestic rare earth magnet market across multiple supply chain stages. Congressional appropriations would be required.	DOD, DOE, DOC, DOI
38.	Electric grid	Engage government and private sector to expand RD&D to improve modularity, create flexible designs, improve efficiency, and lower manufacturing costs of Large Power Transformers (LPTs) and related materials.	DOE
39.	Wind	Engage government and private sector to expand RD&D to address logistical limitations for land-based wind, including modularization and onsite assembly and manufacturing of large components such as blades and towers.	DOE, DOT
		Aged/Outdated Infrastructure	
40.	Hydropower	• Increase the domestic content of hydropower components in the Buy American Act in accordance with trade agreements. • Consider how to maximize Buy American Act provisions to support rehabilitations and upgrades of federal hydropower plants.	Made in America Office, DOE

3.2 Recommendations: Congressional Actions

The BIL provides DOE authority to address supply chain risks and manufacturing. A significant portion of that authority and funding is tied to battery supply chains—about $7 billion. Additionally, $1.5 billion is tied to support clean hydrogen manufacturing and advancing recycling RD&D, and $750 million is for a grant program to support a wider range of advanced energy technology manufacturing and recycling specifically in coal communities. The BIL amends DOE LPO authority to support supply chains and manufacturing that will cover a wider range of supply chains technologies. However, currently there is no funding tied to this extension of LPO authority to support these supply chain efforts. The DOE one-year supply chain review reveals several supply chain opportunities that will require additional authority and funding in the next 10 years. Therefore, this section identifies recommendations that will require congressional support to provide DOE and other Federal agencies additional authority needed to expand support for energy supply chains.

Crosscutting Congressional Actions

These are sector-wide policy actions to help build resilient supply chains of multiple technologies that will require congressional consideration and support.

41. ***As part of Executive Order 14017 100-day report-related implementation, expand the National Defense Stockpile inventory and/or strategic offtake agreements for priority critical minerals and materials, thus enabling the clean energy transition for civilian and industrial purposes and accounting for future demand needs.*** **(Congress, DOE, DOD, DOS)**

Specific actions should include:

- Incorporate an evaluation of the need for stockpiling of select, high priority critical minerals and materials that will be essential to domestic decarbonization efforts, both current and future, into DOD's implementation efforts related to Executive Order 14017's 100-day report. Consistent with efforts to recapitalize and modernize the National Defense Stockpile (NDS) program, expand procurement efforts and inventory of these minerals and materials through the NDS.
- Promote strategic commercial or offtake agreements involving domestic companies that conduct mining operations, separation, and processing, refining or production of clean energy component materials from refined products.
- Develop coordinated market engagement plans for critical minerals and materials used in clean energy technologies, which could couple stockpiling with the development of domestic reserves and offtake agreements with domestic producers of raw and processed materials.

42. ***For certain critical supply chains, broaden the innovation requirement under Title XVII of the Energy Policy Act 2005 to better support supply chains for innovative clean technologies.*** **(Congress)**

The Department's Title XVII Innovative Energy Loan Guarantee Program provides access to low-cost financing for the first deployments of a technology, including a range of supply chain and manufacturing technologies. Among other program criteria, Title XVII requires projects to avoid, reduce, utilize, or sequester emissions and employ new or significantly improved technologies. Waiving this latter criterion in certain cases if a project meets the definition of a critical supply chain for a clean energy technology, as determined by the Secretary, would enable LPO to support some manufacturing projects that may not currently qualify under Title XVII, but which could have material impact on technology adoption. Congress should amend section 1703 of the Energy Policy Act of 2005 to provide the Secretary of Energy with authority to consider the strategic importance of the supply chain in lieu of innovativeness for such projects.

43. ***Enact legislation to provide tax incentives to support domestic clean energy manufacturing and deployment, including incentives for building new facilities and for the ongoing operation of those facilities.*** **(Congress)**

Tax incentives are needed to provide a clear demand signal and help U.S. manufacturers build and maintain a competitive edge in clean energy technologies such as solar, wind, fuel cells and electrolyzers, nuclear energy, CCS, energy storage, and others. These incentives should cover equipment manufacturing, processing of materials needed for manufacturing components, as well as certain logistics equipment. Refundable tax credits could enable access by a wide spectrum of entities. Specific actions recommended to Congress include:

- Extend, expand, and revise eligibility for advanced energy manufacturing tax credits (48C) to include material processing facilities such as those for battery materials processing, casting and forging, manufacturing of grain oriented electric steel, materials for advanced nuclear reactors, rare earth element separation and processing, and catalyst manufacturing as well as equipment manufacturing facilities such as manufacturing equipment/machines key for energy manufacturing, solar polysilicon, wafers, cells, modules, grid components, components for advanced nuclear reactors, and other components.

- Establish investment-based and production-based manufacturing tax incentives specifically targeting critical aspects of the domestic supply chain for clean energy and decarbonizing industry, inclusive of materials, components, and logistics. The combination of investment-based and production-based tax credits can help ensure the build-out and ongoing success of domestic manufacturers.

- Extend and revise tax credits, such as the Production Tax Credit (PTC) and Investment Tax Credit (ITC), for both clean energy deployment and continued operation of clean energy assets to provide stronger incentives for clean energy projects that support domestic manufacturing and a major increase in family-sustaining jobs.

- To provide demand certainty, policy stability, and clear signals to support domestic manufacturing investment, these tax credits should be in place for at least 10 years and should not phase out until significant progress has been made towards decarbonizing the overall sector.

44. Appropriate additional RD&D funding to DOE to further accelerate domestic manufacturing in a way that addresses supply chain vulnerabilities and promotes resilience for clean energy domestic manufacturing. (Congress)

The DOE one-year supply chain technology reports revealed a number of issues that will require more investment in the next 10 years beyond what is appropriated in the BIL supply chain provisions, to enable a strong, resilient domestic manufacturing sector that creates high-quality jobs and helps the nation meet emission reduction goals. Investments should accelerate the progression of innovation from research through development and demonstration to deployment and commercialization. Specific actions recommended to Congress include:

- Establish an interagency taskforce that will develop criteria for Determination of Exceptional Circumstance findings under the Bayh-Dole Act to ensure that RD&D funding awardees for clean energy technologies from the Federal Government substantially manufacture in the United States.

- Fund research, development, demonstration, and deployment of innovative, next-generation manufacturing technologies and processes toward industrial decarbonization—including key pathways of energy efficiency, industrial electrification, low carbon fuels, and carbon capture, utilization, and storage.

- Fund innovative research, development, and demonstration of advanced materials and their supply chains, with consideration in designs for recyclability, that are needed for industrial decarbonization and clean energy manufacturing. Key areas for increased investment include high performance materials, sustainable materials and products, and critical materials and fuel minerals.

- Fund innovative research, development, and demonstration to enable clean energy manufacturing—including advanced processes and energy technology manufacturing. Advanced processes will provide key foundational capabilities required across the manufacturing sector necessary for U.S. competitiveness and enabling sector-wide decarbonization. Energy technology manufacturing includes power generation, clean fuel production, and energy storage component and system manufacturing; rare earth element magnets used in electric vehicles and wind turbines; nuclear reactor materials and component manufacturing including HALEU and advanced nuclear fuels; and semiconductors needed for power electronics, computing, and controls.

- Link funding to other DOE place-based programs such as the industrial clusters, RD&D activities, Communities Local Energy Action Program (LEAP), and more, so new manufacturing is developed with full community engagement and in recognition of local needs and opportunities, while leveraging other public and private investment.

- Provide direction to award funding with consideration given to employers that offer competitive wages and benefits, training in transferrable skills, the free and fair choice to join a union, and strong labor, safety, and environmental standards.

45. Ensure national energy policy aligns with U.S. climate policy goals. **(Congress)**

The 2021 *Long-Term Strategy of the United States* lays out how the United States can reach its goal of net zero emissions no later than 2050 (The White House, 2021c). Congress should consider aligning this policy goal and pathways with national energy policy and energy sector investment, including how to stimulate demand for the technologies and generation sources that will provide the certainty for investments supporting the growth of domestic manufacturing for clean energy. This alignment will ensure energy policy and investments deliver results consistent with our climate goals and build on the BIL supply chain investments.

46. Appropriate funding to DOE for use of Title III of the Defense Production Act to support domestic critical material supply. **(Congress)**

Congress should consider appropriating adequate funding specifically for the purpose of enabling DOE to utilize Title III of the Defense Production Act to support the production of critical energy technologies, buy products in certain circumstances, and take other actions as needed to support and maintain a secure Energy Sector Industrial Base for civilian use.

47. Amend Buy American Act to support clean energy technologies by extending the purchasing mandate to the equipment generating the electricity and storing the energy for new facilities. (**Made in America Office, DOE)**

The Buy American Act requires that goods purchased for the U.S. Government with taxpayer dollars contain at least 55 percent American-made content; there is a proposed rule change to raise this requirement to 75 percent by 2029.[33] At present, electricity generated for use by the U.S. Government (1.5 percent of total U.S. consumption) is considered domestic if the generating facility is in the United States, regardless of whether the generating facility utilizes domestic equipment, hardware, and/or software. Congress should consider amending the Buy American Act and maximize Buy American Act benefits to clean energy technologies by extending the purchasing mandate to the equipment generating the electricity and storing energy (to include hardware, software, and virtual platforms) supplied to the U.S. Government under any utility service contract or power purchase agreement.

48. Enact a comprehensive set of policies to create the infrastructure for enabling reuse and recovery of key components and materials through the circular clean energy economy. (Congress)

Congress should consider enacting a comprehensive set of policies to create the infrastructure for recovering key materials through the circular economy and creating a robust market for secondary materials by incentivizing/helping to make it more economical to use secondary components and materials. The BIL has an extensive funding program to improve recycling and circular economy. However, most of the funding is allocated to support recycling of battery materials—over $3 billion—with only $750 million to re-equip, expand, or establish a manufacturing or recycling facility for the production or recycling of advanced energy property, and to re-equip an industrial or manufacturing facility designed to reduce GHG emissions of that facility substantially below current best practices (section 40209). This $750 million prioritizes projects that have higher net impact on avoiding/reducing GHG emissions, higher level of job creation, and higher potential for innovation and commercial deployment, lower levelized cost of generated/stored energy or reduction in energy consumption or GHG emissions, along with minority ownership. Finally, this funding is for census tracts where a coal mine has closed, a coal-fired power plant has been retired, and adjacent tracts. Congress should consider specific actions, including:

- Allocate RD&D grants for innovation in design for reuse and recycling methods across all stages of the supply chain, techniques, and end-of-life management for energy technologies, including batteries.
- Increase RD&D for innovative second-life solutions for systems at the end of their usable life. For example, economic and technical challenges exist for the widespread adoption of EV batteries at the end of their usable life for safe use in stationary grid applications. However, such batteries may represent a significant market share as EVs greatly increase in number and investing in solving these challenges may significantly benefit the supply chains of both sectors. Automotive fuel cell stacks and hydrogen storage tanks have similar second life opportunities in stationary grid applications.

[33] https://www.federalregister.gov/documents/2021/07/30/2021-15881/federal-acquisition-regulation-amendments-to-the-far-buy-american-act-requirements

- Appropriate additional funding for the advanced energy manufacturing and recycling grant program established under section 40209 of the BIL. This additional funding should be dedicated to supporting domestic materials recovery companies or companies that use recovered materials. Congress should also consider funding new advanced energy technologies that use low-cost common materials, especially those recoverable in a circular economy.

- Condition energy investment and production incentives on or provide bonus incentives to support commitments for full decommissioning and end-of-life management of energy projects, such as decommission bonds, and material re-use (such as wind turbine repowering), recycling, and recovery requirements, particularly for critical materials.

- Examine and analyze possible tax credits to support the use of recycled components and materials and zero-to-little waste manufacturing to determine how they could benefit the U.S. supply chain efforts.

- Examine possible incentives to support industrial rental programs for and recovery of high value critical materials used in decarbonization technologies (such as those already in place for platinum group metal catalysts) to maximize material recovery.

- Fund DOE in partnership with EPA, DOS, and DOC to engage stakeholders and allies to develop national and international standards for the reuse and recycling of structures and components of clean energy technologies and establish modularity or consistency of design standards up-stream of major infrastructure and electronic products that enable end of life options across key industries.

49. Support disposition of hazardous materials critical for clean energy deployment. **(Congress)**

Specific actions Congress should consider include:

- Direct EPA to establish management, processing, recovery, and disposal guidelines/requirements for hazardous and non-hazardous waste from clean energy technologies.

50. Appropriate funds to establish regional and state-level sector partnerships and Registered Apprenticeships to recruit, train, and place workers into careers needed for domestic supply chains. **(Congress, DOL)**

Ensuring a robust workforce is one of the main concerns across technologies and the cause of multiple vulnerabilities throughout the Energy Sector Industrial Base. In particular, the training gaps of skilled workers is a persistent challenge cited by industry stakeholders in many technology sectors. The high cost of U.S. labor relative to labor costs in countries with lower wages and fewer worker protections is seen as a barrier to U.S. competitiveness. Congress should consider the following strategies to develop skilled and sustainable talent pipelines across energy technologies should receive priority:

- Expand scholarships for associate degrees and other technical certificates as well as advanced degrees in mining, energy economics, software development for operational technology/industrial control

systems, and engineering, with requirements to work domestically for five years after degree completion.

- Support the expansion of Registered Apprenticeships, youth apprenticeships, and pre-apprenticeships by directing agencies to require the use of Registered Apprenticeships and providing funding for a new start-up program to build up the manufacturing and technology labor force across the supply chain. Stakeholder engagement for this initiative should highlight sectoral partnerships and should include unions, worker groups, employers, and trade associations.

- Examine incentives and funding to support state and regional sector partnership that bring together employers, industry associations, educational stakeholders, community organizations, and labor groups that work in partnership with each other to provide career awareness and readiness, job training, work-based training, work-based learning and apprenticeships to U.S. students (including high school and transitional students), retiring military personnel, dislocated workers, and disadvantaged workers in fields that support U.S. energy supply chains.

51. Fund and expand supply chain analytical capabilities across DOE, the national labs, and in conjunction with partner agencies. (Congress, DOL, DOI)

Specific actions Congress should consider include:

- Appropriate funding to establish an end-to-end supply chain research and analysis consortium to address crosscutting supply issues of national importance by bringing together multidisciplinary teams with diverse approaches to address long-term, immediate, and multi-scale energy supply chain challenges. Such a consortium might follow the model of the National Virtual Biotechnology Laboratory, in which DOE national laboratories, academia, and the private sector worked together with a systems-level approach to a complex and rapidly evolving landscape. The consortium could incubate novel analytical approaches, address, and overcome data deserts, identify current research gaps, and supply chain vulnerabilities, support economic development, and contribute to building the future supply chain workforce. It can also directly support industry by sharing validated data sets and analysis tools and models. The consortium could also build out distributed capabilities across the U.S. Government such as embedded within applied programs where constant reassessment of technology supply chains is warranted.

- Direct agencies to incorporate economic analysis into taxpayer funded innovation, demonstration, test beds, scale-up, technology transfer, and manufacturing to identify gaps, risks, opportunities, trade-offs and implications of policy and investment decisions. This analysis should include identifying overlaps between sectors and shared technical skills, particularly where important domestic or allied capabilities are in decline.

Technology-specific recommendations

This section presents technology-specific recommendations that require congressional consideration and support.

Table 6. Technology-Specific Congressional Actions

S/N	Technology	Policy	Actor(s)
		Energy Infrastructure	
52.	Wind	Prioritize financing of offshore wind ports and vessels utilizing existing DOT Maritime Administration (MARAD) programs and DOE LPO programs.	Congress, DOT, DOE
53.	Wind	Encourage intrastate and interstate transportation permit harmonization through research initiatives, competitive grant applications, and state programming of Federal-aid funding, and explore multimodal infrastructure investment to alleviate bottlenecks. Given such bottlenecks and different permitting rules varying by state or county, it is sometimes difficult to move large wind components from one location to another.	Congress, DOT, DOE, state and local governments
54.	Fuel cells and electrolyzers	Examine and analyze possible tax incentives for fuel cells in emergency backup power and primary power applications, such as data centers, as well as incentives for hydrogen pipelines.	Congress
55.	Fuel cells and electrolyzers	Amend the Buy American Act requirement to include clean hydrogen and extend the purchasing mandate to hydrogen generation, delivery (including pipeline systems and liquefaction production and delivery systems), storage (including geologic storage), dispensing and end-use technologies (including fuel cells for emergency and backup power), with a requirement of domestic content over 55 percent for all components, subsystems, and systems.	Congress, DOE
56.	Carbon capture storage and transport	• Further RD&D to address technical challenges and costs of carbon capture, storage, and transport. • Building on the BIL, incentivize infrastructure projects (pipelines and storage), including providing investment and permitting support.	Congress
57.	Hydropower	Examine and analyze possible incentives to support modernization of the existing hydropower fleet, powering of non-powered dams, and development of pumped storage hydropower through investment tax credits for total project costs, including for supporting features of the facilities. These include fish passage, spillways, or debris/sediment mitigation.	Congress
58.	Nuclear	Continue funding critical gaps in R&D infrastructure, including a fast neutron irradiation reactor or Versatile Test Reactor.	Congress
59.	Nuclear	Amend the Nuclear Waste Policy Act (NWPA) to allow DOE to implement an integrated waste disposal strategy (addressing Federal interim storage, permanent disposal, and related transportation).	Congress
		Electricity Grid and Market	

S/N	Technology	Policy	Actor(s)
60.	Nuclear	Support RDD&D funding to agencies (DOD, NASA, and DOE) for the development and accelerated deployment of innovative nuclear energy systems.	Congress
		Aged/Outdated Infrastructure	
61.	Electric grid	Fund investment of upgrades and expansion of historical grid systems and undergrounding as appropriate.	Congress
		Manufacturing and Innovation	
62.	Semiconductors	Fund semiconductor research, design, and manufacturing, which will be critical to accelerate the domestic semiconductor industry and assert global leadership.	Congress, DOE, DOC, DOD

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Appendix I

Technology Selection Criteria

DOE works on supply chain analysis for many energy technologies over time. The following selection criteria were used to identify critical energy technologies for assessment in the timeframe of the one-year review:

- *National security:* Is the technology critical to national security?
- *Exposure to supply chain risks:* Is the technology subject to supply chain risks stemming from limited domestic production and/or limited availability of raw materials, or malicious risks from foreign adversaries?
- *Importance to other critical infrastructure*: Are other critical infrastructure and energy systems reliant on the technology in a way that would compound supply chain vulnerabilities?
- *High quality jobs:* Is there a significant opportunity to create sustained new high-quality jobs?
- *Decarbonization:* Is the technology a big contributor (e.g., new capacity additions) to U.S. decarbonization pathways? Can it reduce emissions by a certain target through Federal deployment?
- *Leverage of U.S. capabilities:* Could the manufacturing process leverage existing processes/capabilities where U.S. has technical leadership or a cost advantage, or where U.S. has ongoing research investments (e.g., DOE's Manufacturing USA Institutes – Power America, IACMI, CESMII, RAPID, REMADE)?
- *Stage of commercialization:* Is domestic manufacturing near cost-competitive today or projected to be within five years given sufficient R&D or U.S. industrial policy?
- *Market size:* Is the projected global market for the technology big enough to support supply contributions from multiple economies? Is domestic demand alone sufficient to support a significant level of domestic manufacturing?
- *Global trade potential:* Is the supply chain for the technology subject to high shipping costs or other barriers that support domestic production (e.g., wind blades)?
- *Value add:* Does increased domestic production provide a significant increase in value added to the U.S. economy in comparison to existing manufacturing footprint (using Benchmark Report methodology and most recent data)

For more information, visit:
energy.gov/policy/supplychains

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