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Reimagine

Clean Energy Technology and U.S. Industrial Policy

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About the Report

This report is published as part of the U.S. National Industrial Policy Strategy project at the Center for a New American Security (CNAS). The project is developing an intellectual framework for industrial policy in the American context, in an era of strategic competition with technology at its center. The goal of the project is to pave the way for enhanced and sustained American economic competitiveness and technological leadership. This report builds on analysis and insights from prior CNAS publications, including:

"Reboot: Framework for a New American Industrial Policy," by Megan Lamberth, Martijn Rasser, Hannah Kelley, and Ryan Johnson (May 2022).

"Regenerate: Biotechnology and U.S. Industrial Policy," by Ryan Fedasiuk (July 2022).

"Rebuild: Toolkit for a New American Industrial Policy" by Emily Kilcrease and Emily Jin (Forthcoming).

"Rewire: Semiconductors and U.S. Industrial Policy," by Chris Miller (Forthcoming).

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About the Energy, Economics, and Security Program

The Energy, Economics, and Security Program analyzes the changing global energy and economic landscape and its national security implications. From the shifting geopolitics of energy to tools of economic statecraft—such as trade and investment policy and sanctions—the program develops strategies to help policymakers understand, anticipate, and respond. The program draws from the diverse expertise and backgrounds of its team and leverages other CNAS experts' strengths in regional knowledge, technology, and foreign policy to inform conversations at the nexus of markets, industry, and U.S. national security and economic policy.

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Executive Summary

Historically, the United States has been the largest public investor in clean energy research and development (R&D). U.S. research institutions and private firms continue to hold a technological lead in many next-generation technologies that could make the transition away from fossil fuels cheaper and more efficient. Such technologies include next-generation solar photovoltaic technologies, advanced battery chemistries, and software to manage complex energy systems, including those with high penetrations of wind energy.

Although the United States was an early leader in clean energy R&D and continues to make major technological advances, it has, over time, fallen behind in the commercialization and manufacturing of the technologies developed domestically. This study reviews U.S. industrial policy for clean energy sectors and argues that other economies have more frequently used proactive industrial policies to support the development of domestic clean energy technology industries. Too often, the United States has not mounted an equivalent industrial policy response. The U.S. government has instead focused more narrowly on funding the invention of new technologies and, intermittently, supported domestic markets for clean energy technologies through federal and state programs. Such policies have included, for instance, federal R&D grants for universities, research institutes, and the private sector, as well as subsidies and regulations to support the growth of clean energy markets at the federal and state level.

This U.S. approach to encouraging the growth of domestic clean energy industries has assumed that market failures primarily exist in innovation. Since firms cannot in all cases reap all the gains from investments in the development of new technologies, they are likely to underinvest in innovation, creating a need for governments to supplement private-sector investments in R&D. The U.S. approach to clean energy industrial policy also assumes that investments in R&D will eventually spur the growth of domestic industries if combined with sufficient market demand. Yet U.S. industrial policy has not addressed key institutional shortcomings in segments of clean energy supply chains that are not well supported domestically, particularly in scaling new technologies to mass manufacturing. As a consequence, many technologies developed with public R&D funding failed to reach domestic mass production, as firms were unable to make the investments required to bring the technologies to market domestically.

The report develops four recommendations to improve the competitiveness of domestic clean energy industries. First, the United States should establish a state development bank that could fund domestic manufacturing projects in sectors, such as clean energy, that have struggled to raise financing from U.S. financial institutions. The scarcity of capital for clean energy manufacturing has prevented domestic startups from raising the financing required to commercialize and produce their technologies domestically. Second, the U.S. government should ramp up investments in vocational training programs that would meet the workforce needs of growing clean energy manufacturing sectors. Third, the federal government should set stable regulatory requirements and binding targets for clean energy markets as part of a national strategy for competitiveness in clean energy sectors. This would reduce uncertainty injected by the intermittent and fragmented nature of current government support for clean energy sectors and create incentives for the private sector to invest in domestic supply chains for clean energy technologies. Fourth, the United States should limit the use of trade restrictions as industrial policy tools and instead focus on improving the competitiveness of domestic clean energy firms through proactive industrial policies. Trade restrictions can limit the ability of domestic clean energy firms to source materials, parts, and components through global supply chains; may lead to increased prices in ways that can harm domestic clean energy service industries; and obstruct the climate diplomacy needed to meet the goals of the Paris Agreement.

At the moment, geopolitical shifts, strategic competition with China, and the ripple effects of the war in Ukraine provide a political opening for the consistent deployment of more ambitious industrial policies. The United States should use this opportunity or risk falling behind other economies, including those in Europe, that have made the development of domestic clean energy supply chains central elements of their response to climate change.

Introduction

Clean energy sectors—including wind, solar, and battery storage industries that produce the technologies central to decarbonizing the electric grid—have long been subject to government policy. Because these technologies have long been recipients of public subsidies and regulatory support, few governments were content with being consumers of technologies imported from abroad. In the United States and elsewhere, policymakers hoped that public support for research and development (R&D) and domestic clean energy markets would also generate growing domestic clean energy industries that could become new engines of growth and economic development.

Over the past decade, two developments—tensions in the U.S.-China relationship and the war in Ukraine—have further strengthened the focus on domestic clean energy industries in the United States. First, growing tensions between the United States and China have raised questions about the global dependence on China for clean energy technologies, their components, and the raw materials required to produce them. Although the United States placed tariffs on Chinese solar panels as a trade remedy measure nearly a decade ago, China still accounts for nearly two-thirds of global production capacity for solar photovoltaic (PV) technologies and is the largest producer of polysilicon, the core raw material used for the production of solar panels. China is also dominant in the manufacturing of wind turbine components and holds much of the global refining capacity for rare earths and other raw materials required for their production. China is home to more than 75 percent of production capacity for lithium-ion batteries required for on-grid storage and vehicle electrification. Virtually all global lithium refining—the key material input into lithium-ion battery production—currently takes place in China.[1] As the relationship between the United States and China has deteriorated into geostrategic competition, China's central role in clean energy technology sectors has raised energy policy and national security concerns. Policy initiatives to re-shore the production of clean energy technologies have increasingly been justified with the need to decouple from China's manufacturing economy in light of geopolitical tensions.[2]

Concerns about economic interdependence in clean energy supply chains have been further accelerated since Russia's invasion of Ukraine in February 2022 upended global oil and gas markets. Russia's role as the world's largest fossil fuel exporter, increasing energy prices resulting from the war, and associated Western sanctions have made clean energy technologies an attractive alternative to dependence on volatile fossil fuel markets. These developments have also renewed attention on the vulnerability of global supply chains to geopolitical tensions and added to existing concerns about the central role of China—another geopolitical competitor—in clean energy industries.

This case study reviews the industrial policies of the United States—defined here as government measures that intervene in the market to produce economic outcomes in the national interest that markets would not take on their own—to encourage the development of domestic clean energy industries.[3] What industrial policy measures has the United States undertaken to promote domestic supply chains in wind, solar, and energy storage? How do domestic policy efforts compare to those in other economies?

Historically, the United States has been the largest public investor in clean energy R&D. U.S. research institutions and private firms continue to hold a technological lead in many next-generation technologies that could make the transition away from fossil fuels cheaper and more efficient. Such technologies include next-generation solar PV technologies, advanced battery chemistries, and software to manage complex energy systems, including those with high penetrations of wind energy.[4] Although the United States was an early leader in clean energy R&D and continues to make major technological advances, it has, over time, fallen behind in the commercialization and manufacturing of the technologies developed domestically. The central conclusion of this case study is that other economies have more frequently used proactive industrial policies to support the development of domestic clean energy technology industries. The United States has not mounted an equivalent industrial policy response. U.S. government support has instead focused more narrowly on the invention of new technologies and, intermittently, supported domestic markets for these technologies through federal and state policy. Such policies have

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included, for instance, federal R&D grants for universities, research institutes, and the private sector, as well as subsidies and regulations to support the growth of clean energy markets at the federal and state level.

This approach to encouraging the growth of domestic clean energy industries has assumed that market failures exist in innovation. Since firms cannot in all cases reap all the gains from investments in the development of new technologies, they are likely to underinvest in innovation, creating a need for governments to supplement private-sector investments in R&D. The U.S. approach to clean energy industrial policy also assumes that investments in R&D will eventually spur the growth of domestic industries if combined with sufficient market demand. Yet U.S. industrial policy has not addressed key institutional shortcomings in segments of clean energy supply chains that are not well supported domestically, including in manufacturing. Perhaps most critical among them is the lack of a development bank tasked with funding manufacturing sectors that have been unable to raise funds in U.S. financial markets. Investments in vocational training and stable, long-term regulatory support combined with binding clean energy targets would further improve national competitiveness in these sectors.[5]

This case study reviews how the United States has historically supported clean energy industries, focusing specifically on wind, solar, and energy storage. It then analyses the current state of play in these industries and maps U.S. strengths and weaknesses in clean energy supply chains. The case study provides an overview of policy proposals to address current shortcomings and lessons that could be learned from other economies, particularly in the European Union (EU). Finally, it offers policy recommendations to improve the U.S. competitive position in clean energy sectors in light of growing geopolitical tensions.

U.S. Industrial Policies for Clean Energy Industries

The U.S. approach to supporting clean energy industries through industrial policy has followed a broad postwar consensus on the appropriate role of the state in science and technology policy. U.S. policymaking assumed that critical market failures for new technologies laid in basic R&D, where firms, on their own, underinvest in new technologies. In areas such as clean energy, where new technologies have broad societal benefits but are not yet competitive with the technologies they seek to replace, policymakers in Washington and state governments also saw a role for the state in offering regulatory support and subsidies to create markets for these applications. But public inputs—R&D funding—for the development of new technologies and the existence of domestic markets were assumed to also support the development of new industrial sectors around commercialization, production, and employment. This so-called linear model of innovation—one where inputs into basic research are expected to yield commercializable technologies *and* the industrial capabilities to produce them—has informed U.S. policymaking for the past 80 years.[6]

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One reason for the consistent combination of R&D funding and market support has been a broader problem of political feasibility in a highly polarized system characterized by many veto players. For instance, state intervention in support of innovation, at least until recently, received bipartisan support because of widely perceived market failures in technology development. Other, more targeted industrial policy interventions, including loan guarantees for specific clean energy firms seeking to expand manufacturing or the use of the Defense Production Act (DPA) to accelerate domestic investments in wind, solar, and battery production, often resulted from executive action during periods in which political gridlock made more comprehensive solutions difficult to pass through legislation. Yet the interventions of the executive branch have been narrow and easily reversed by subsequent administrations, making them an imperfect substitute for legislative approaches to industrial policymaking. Even as globalization offered new and often more affordable options for moving domestic inventions to market—for instance, by using global supply chains that took advantage of production locations abroad—the U.S. industrial policy approach remained largely limited to public investments in upstream R&D and regulatory support for the creation of domestic markets, primarily through tax credits. As a result, domestic markets for clean energy technologies often relied on imported technologies, even if the core technological advances behind these products originated in the United States.[7]

The remainder of this section reviews the historical development of industrial policies for clean energy industries, organized along policies encouraging technology push, market demand (technology pull), and state-level policies.[8]

Technology Push

The United States has long been a leader in clean energy R&D. U.S. universities and research institutes remain at the technological frontier for many clean energy technologies, including for advanced solar PV technologies and next-generation battery chemistries. U.S. companies are also global leaders in the development of many climate-related technologies that aim to make decarbonization cheaper and more efficient. Such technologies include advanced battery chemistries, new solar PV technologies, building materials, and software to manage energy systems.[9]

There are, broadly, three factors behind this continued U.S. strength in clean energy R&D. First, the U.S. government has, historically, spent more than any other advanced economy on clean energy R&D.[10] Between 1961 and 2008, the U.S. government spent more than $170 billion on energy R&D. By 2018, the Department of Energy (DOE) alone had dispensed some $28 billion for clean energy research, comprising nearly one-fifth of overall DOE research spending. Such funds were complemented by technology-specific research programs, including programs that, over time, funded work on thin-film technologies, offshore wind, electric vehicle (EV) batteries, and on-grid storage.[11] Even as China began to catch up to U.S. funding levels, the United States continued to lead, albeit with funding levels for clean energy research that differed across administrations and declined since their peak in the wake of the 1970s oil shocks.

In the solar sector, many of the technological advances behind traditional silicon-based solar cells and next-generation thin-film technologies occurred through federally funded R&D.[12] Although the United States was less central in the global development of modern wind energy technologies, federally funded research consortia made important (if ultimately unsuccessful) efforts to rapidly expand the capacity of wind turbines in the wake of the 1970s oil crises.[13] The foundational research that ultimately led to the development of lithium-ion batteries was also conducted at U.S. universities and a number of national laboratories funded by DOE.[14] The Solar Energy Technologies Office, administered by the Office of Energy Efficiency and Renewable Energy within DOE, has supported partners in industry, national laboratories, universities, and research institutes to develop new energy technologies and improve their manufacturability since the 1980s. This office is currently funded at approximately $300 million annually. The Wind Energy Technologies Office has an equivalent mission and is currently funded at roughly $100 million annually.[15]

The U.S. government is increasingly leveraging clean energy technologies to diversify energy sources and reinforce American energy independence. In June 2022, the U.S. Army launched a floating solar panel system at Camp Mackall in Aberdeen, North Carolina. (Melissa Sue Gerrits/Getty Images)

Second, the United States has made it easier to commercialize the results of federally funded research. These legislative and institutional changes are, of course, not unique to clean energy industries, yet they are a central part of the U.S. government's industrial policy apparatus for clean energy sectors: They encourage economic outcomes that markets would not take on their own. Beginning with the Bayh–Dole Act in the 1980s, the United States began passing legislation to encourage universities and research institutes to patent discoveries and license them to the private sector. Subsequent legislative changes further encouraged universities and research institutes to patent discoveries made with the help of federal research support.[16]

These changes are reflected in patenting and licensing statistics of universities and research institutes. In 1965, fewer than 200 patents were granted to U.S. universities. By 1988, that number had increased to more than 1,000 as universities began to commercially exploit their R&D efforts. In the 1990s, after legislative reforms further eased the flow of technology from research institutes to the private sector, many universities began to establish designated technology transfer and licensing offices, setting up thousands of licensing agreements and approaching $500 million in annual royalty income.[17] The institutions and legislative arrangements to support such technology transfers successfully complemented public investments in R&D, including in clean energy industry. Many domestic startups were established to commercialize these technologies, including a number of high-profile firms such as the solar manufacturer Solyndra and the battery producer A123 Systems. Both received additional government aid yet ultimately failed to succeed commercially. Others, such as the Silicon Valley solar startup Innovalight, were acquired by U.S. multinationals once they had successfully found a market for their technologies.[18]

Third, the federal government has directly financially supported firms' R&D efforts to encourage the growth of domestic clean energy sectors. In the broadest sense, a federal R&D tax credit—first passed in 1981 as a temporary measure and permanently codified into tax law in 2015—has rewarded firms' investments in R&D. Firms can claim a tax credit for R&D activities that seek to develop a new or improved product or process through the resolution of technological uncertainty.[19] The tax credit has been the primary way to encourage firms to increase their R&D investments, although smaller firms and those focused on manufacturing innovation have complained about the bureaucratic hurdles to claiming the credit, in particular the difficulty of meeting documentation requirements.[20] In addition to the federal government, the vast majority of states also have R&D tax credits in place to reward corporate investments in technological innovation.[21]

Aside from tax policy incentives for R&D, the federal government, including through the DOE, has also made direct investments in energy innovation in the private sector. Such policy support for clean energy firms has been heavily shaped by the institutional constraints imposed by the U.S. system of government in which there has been little bipartisan support for clean energy industrial policy. Both the Obama and Biden administrations have instead relied heavily on the tools of the executive branch to advance their goals of building domestic clean energy industries. To this end, the American Recovery and Reinvestment Act created a new $60 billion loan guarantee program administered by the DOE to support clean energy projects, including for firms seeking to invest in domestic manufacturing capacity. Advanced Research Projects Agency-Energy (ARPA-E), a federal program to support the commercialization of high-risk energy technologies originally established as part of the America COMPETES Act in 2007, initially invested $130 million in 66 startup firms and research institutes. Its goal has been to support technological discoveries and their commercialization, although funding levels are generally too small to fund investments in manufacturing capacity. More recently, the Biden administration has authorized DOE's Loan Programs Office to provide loan guarantees totaling $40 billion to support clean energy firms both in research and commercialization of their technologies.[23]

Demand Pull

In addition to supporting the development of clean energy technologies, U.S. federal and state governments have long intervened in the economy to create domestic markets for new energy technologies. Three sets of industrial policies tools—regulatory policy, tax incentives, and trade policy—have featured prominently in U.S. support for clean energy markets. Such financial and regulatory support has been and continues to be particularly important for technologies that are not yet cost-competitive with the fossil fuel sources they seek to replace. The role of the state in the creation of market demand declined as technologies became cheaper over time, but solar, wind, and energy storage all relied on the regulatory power of the state to compel utilities, businesses, and customers to switch to clean sources of energy.

The first set of clean energy industrial policies used the regulatory power of federal and state governments to accelerate the creation of domestic markets. Foundational to the use of clean energy technologies in domestic electricity markets was the 1978 Public Utility Regulatory Policies Act (PURPA), which required electric utilities to purchase power from third-party generators at the rate it would have cost them to generate the power themselves. At a time when many utilities were regulated monopolies that owned their own generation assets, this opened a pathway for new, independent power generators to sell power to utility companies, including those invested in wind and solar power generation. Passed in the wake of the 1970s oil shocks, PURPA alone was unable to make renewable energy cost-competitive, but it nonetheless paved the way for regulatory interventions that required utilities to begin sourcing clean energy. An early outlier was California, where PURPA and generous state tax credits led to long-term contracts for wind power generation in the 1980s. More than 15,000 turbines were installed between 1980 and 1986, until the elimination of state tax incentives ended this first large-scale experiment with domestic clean energy markets in the United States.[24]

During the early 1990s, when the Gulf War again raised alternative sources of energy as a national security matter, the Energy Policy Act of 1992 made permanent an existing investment tax credit and added a production tax credit for wind power. However, political conflict between Democrats and Republicans over federal support for clean energy technologies throughout the 1990s and 2000s injected a high degree of uncertainty in the availability of such federal support. Between 1992 and 2006, the production tax credit for wind energy was renewed in five separate instances, often only for one or two years. It expired on three occasions before it was renewed, leading to periods during which no federal support was available at all, injecting considerable turmoil into domestic wind power markets. Since 2006, the tax credits have been again renewed as part of the 2009 American Recovery and Reinvestment Act, the 2012 American Taxpayer Relief Act, the 2014 Tax Increase Prevention Act, the 2016 Consolidated Appropriations Act, and the 2018 Bipartisan Budget Act. The 2020 Further Consolidated Appropriations Act extended the tax credits once more. The tax credits also have been revised and extended as part of the 2022 Inflation Reduction Act.[25]

Beyond the uncertainty created by the short-term extensions of these policies, both the investment tax credit (ITC) and production tax credit (PTC) have long been criticized as inefficient tools for supporting domestic clean energy markets. Since most clean energy firms have small or no tax liabilities in their early years due to their ability to write off their capital investments, tax credits can only be monetized by entering complex tax equity swap arrangements with a small number of financial institutions that specialize in offering such solutions to clean energy businesses. In essence, clean energy developers take on financial institutions with tax liabilities as a project partner for the period during which the clean energy project is eligible for tax credits. After this time, the ownership reverts back to the clean energy developer. After taking a cut for their services, the financial institution pays out the remainder of the tax credit value to the developer, who does not have sufficient tax liabilities of their own. Only a share of the subsidy value of the tax credits therefore reaches the developers of clean energy markets. For political reasons, Congress has been reluctant to directly subsidize the deployment of clean energy technologies, relying on tax credits instead.[26] The Inflation Reduction Act seeks to address this issue by offering transferable credits and direct pay provisions.[27]

The volatility of federal policy on the one hand and state jurisdiction over regulation of electricity markets on the other has long made state governments a central force behind industrial policy support for clean energy. Starting in the 1990s, states began to require electricity retailers to source a percentage of electricity from renewable sources by enacting so-called Renewable Portfolio Standards (RPSs). In essence, RPSs require utilities to source a set share of their electricity from clean energy sources, often with specific targets for designated clean energy technologies. The Massachusetts legislature passed the first RPS in 1997; by 2012, the number of states with RPSs had grown to 30. A second policy measure to encourage renewable energy demand, often used in conjunction with RPSs, were Public Benefit Funds (PBFs). By 2005, 23 states had passed legislation to establish PBFs for renewable energy, collecting some $300 million annually to provide low-interest loans, equity investments, and funding for test centers, demonstration projects, and technical support. States also passed net-metering laws, which allow both commercial and residential owners of solar installations to sell electricity back to the grid. By 2005, 38 states had passed such net-metering laws, and an additional three states passed net-metering legislation between 2005 and 2016.[28]

State-level demand-side programs often directly prioritized industrial policy objectives.

State-level demand-side programs often directly prioritized industrial policy objectives. Many programs included local content regulations that aimed to attract economic activity. Particularly when regulatory measures were insufficient and public funds were required to stimulate the creation of demand, government programs often paired regulatory support with the promise of local jobs and economic activity. Measures included, for instance, preferential loans for renewable energy projects that required wind and solar equipment to be manufactured locally. Other states enacted RPSs that required a percentage of renewable energy to be generated in-state. In some cases, to meet RPS requirements, utilities had to use locally manufactured solar panels and wind turbines. A 2015 survey found at least 44 renewable energy programs in 23 states that contained local content requirements.[29]

The second set of industrial policies to support the growth of clean energy markets in the United States targeted customers directly, primarily through the provision of tax credits to subsidize the deployment of clean energy technologies. Tax credits, rebates, and at times cash payments were provided by federal, state, and even municipal levels of government. Although they did not in all cases explicitly pursue the goal of creating domestic industries to commercialize and produce clean energy technologies, they nonetheless supported the growth of market demand for solar, wind, and battery technologies that were not yet competitive with fossil fuels.

A 30 percent solar investment tax credit for residential customers was passed as part of the 2005 Energy Policy Act. Initially set to expire at the end of 2006, the credit was renewed for one year, then extended for an additional eight years as part of the economic recovery measures during the 2008/2009 financial crisis. Starting in 2019, the support began to phase out gradually, reducing the tax credit to 26 percent for systems installed before 2023 and 22 percent for solar PV installations connected before 2024. Similar provisions existed for battery storage installed in conjunction with solar PV installations and (although far less popular) small-scale residential wind turbines.[30]

Most of these initiatives did not include provisions requiring the purchase of domestically made technologies to qualify. An exception is the Inflation Reduction Act passed in August 2022. Central to the bill is a series of tax incentives to encourage a rapid uptick in the sales of EVs and the use of clean energy in the U.S. electric grid. Buyers will receive a $7,500 tax credit for the purchase of a new EV and $4,000 for the purchase of a used one. The bill also revises existing tax credits for investments in and generation of zero-emissions electricity, for instance through solar, wind, and geothermal energy technologies. For the first time, the Inflation Reduction Act (IRA) makes such tax credits eligible based on where the technologies are made in an effort to drastically expand domestic clean energy manufacturing. For example, to qualify for the full EV tax credit, at least 40 percent of the materials used in the battery will have to be mined and refined in the United States or a country with which the United States has a free trade agreement. The battery and its components—the highest value part of an electric car—will also have to be manufactured in North America. Similarly, tax credits for investments in and generation of zero-emissions electricity contained in the Inflation Reduction Act provide bonus credits for clean energy technologies manufactured in the United States.[31]

The tax credits for electric vehicles included in the IRA build on previous tax incentives for alternative-fuel vehicles, which were available initially for hybrid-electric vehicles, then plug-ins, and ultimately full-battery EV's that were able to run solely on electricity. In contrast to the investment tax credits for residential solar installations, the tax credits for vehicles were capped at

In offshore wind markets, the United States trails behind other players. The global wind market is currently dominated by China, the EU, and the United Kingdom. In 2016, Rhode Island's Block Island Wind Farm became the first offshore wind farm in the United States; its turbines—one seen here—are 3.8 miles off Block Island in the Atlantic Ocean. (John Moore/Getty Images)

200,000 qualifying vehicles per vehicle manufacturer. Until the passing of the Inflation Reduction Act in 2022, the credits also ranged from $2,500 to $7,500, depending on battery capacity. As such, the tax credits sought to distribute government support across manufacturers, rather than setting a time limit for eligibility that would have favored those who were first to bring new, battery-powered vehicle technologies to market.

The clear consideration of battery capacity in the determination of the funding amount also favored advanced battery technologies over those that relied on hybrid-electric drivetrain technologies—those that include *both* a combustion engine and an electric motor. Hybrid technologies were first provided with a tax credit as part of the 2005 Energy Policy Act, with plug-in and battery-electric vehicles receiving such support after the 2008 Energy Improvement and Extension Act. Hybrid vehicles were also subject to a cap of 60,000 vehicles per manufacturer, which Toyota and Honda reached in 2007 and 2008, respectively. Tesla and GM reached the 200,000-vehicle cap for plug-in and battery-electric vehicles in 2019, after which tax credits began phasing out for their models.[32] Such caps were removed with the passing of the Inflation Reduction Act, and tax credits made subject to meeting local content requirements.

A third set of policies used the tools of trade policies to protect firms from unfair import competition. Established primarily in response to China's growing dominance in supply chains for clean energy technologies—including solar, wind, and battery storage—the U.S. government has imposed trade remedies on various imported Chinese products going back to the mid-2000s. The politics around trade in clean energy sectors have reflected both the growing divergent interests among clean energy firms seeking to manufacture domestically and a growing service industry focused on installation and maintenance that remains, for now, deeply reliant on Chinese imports.

In the wind sector, a coalition of U.S. manufacturers filed a trade complaint against wind turbine tower companies from China in 2011, leading the U.S. International Trade Commission to approve antidumping tariffs in 2013. The move was applauded by U.S.-based tower manufacturers; those in the installation and maintenance business warned that tariffs would raise prices and slow the deployment of clean energy technologies in the United States. Similarly, in 2010, a coalition of solar manufacturers successfully petitioned for trade remedies against Chinese solar panels. A "Coalition for Affordable Solar Energy" unsuccessfully sought to stop the imposition of remedies, which took effect in 2012. Over time, Chinese manufacturers shifted their supply chains to Malaysia and Taiwan, leading the U.S. Department of Commerce to increase and expand the geographical scope of the tariffs. The Solar Energy Industries Association began to openly side with installers in opposition to manufacturers in response.[33] Such opposition notwithstanding, remedies were determined to be appropriate and subsequently subject to continuance, being renewed in 2018 under the Trump administration. Tariffs again addressed Chinese subsidies and injury to domestic solar cell manufacturers from artificially cheap imported Chinese solar cells. These measures raised concerns among domestic solar installation and maintenance firms, which expected rising prices to lead to slumping demand. The impact of trade remedies on downstream installation and maintenance industries is not part of the scope of the investigation of the U.S. Department of Commerce and the U.S. International Trade Commission.[34]

The U.S. solar market has been further impacted by a so-called Withhold Release Order (WRO) on solar PV products containing silicon materials produced by the Xinjiang-based Hoshine Silicon Industry Co. and other firms. Roughly 80 percent of the global polysilicon supply, the core raw material for polycrystalline solar PV production, currently comes from China, and half of the Chinese supply is produced in Xinjiang. The WRO was issued by U.S. Customs and Border Protection in response to allegations of forced labor practices in Xinjiang and Hoshine in particular. Panels manufactured by a number of Chinese manufacturers have been held up by U.S. Customs and Border Protection, causing disruption to domestic solar PV markets even if the panels in question are ultimately cleared of containing Hoshine-made silicon.[35]

The Biden administration has since launched a domestic supply chain review for critical industrial sectors with the goal of examining reliance on Chinese inputs for key technologies from both economic and security perspectives.[36] Existing tariffs placed on Chinese clean energy products as a result of previous trade investigations remain in place and could encourage re-shoring or diversification from Chinese suppliers. At the time of writing, however, the full range of proactive industrial policies necessary to increase the competitiveness of domestic firms—for instance, through public investments in vocational training and improved financing for demonstration, commercialization, and manufacturing—have not been passed. The Strategic Competition Act remains stalled in Congress. This legislation would enable the federal government to assist companies financially in their attempts to diversify their supply chains beyond China. It would also authorize infrastructure investments to increase national competitiveness and invest in a global alliance to counter Chinese influence.[37] Some of these provisions have since been included in the CHIPS act, which was signed into law in August 2022 and seeks to bolster U.S. semiconductor manufacturing and science and technology investments. In November 2021, the Infrastructure Investment and Jobs Act passed with bipartisan support. It does not directly target the competitiveness of clean energy firms, but it instead encompasses a number of investments in EV-related infrastructure.[38] The Inflation Reduction Act includes few tax incentives to encourage the domestic manufacturing of clean energy technologies and it does not include proactive industrial policies to help firms meet domestic manufacturing goals.[39]

At the time of writing, the Biden administration has invoked Title III of the DPA, which allows the president to address domestic supply chain risks related to national defense and security. Specifically, the administration has used the DPA to accelerate the domestic manufacturing of five clean energy technologies—including solar—for which the United States is currently highly dependent on global supply chains and in which China is playing a dominant role. The DPA allows the U.S. government to offer minimum order guarantees, provide loans to manufacturers, and put in place domestic content standards to increase domestic manufacturing capacity.[40] The invocation of the DPA was accompanied by a two-year moratorium on antidumping and countervailing duty measures for solar cells manufactured in Southeast Asia, where Chinese manufacturers had been accused of using local subsidiaries to illegally circumvent U.S. tariffs on Chinese imports. The trade investigation into Southeast Asian panel manufacturers had previously injected considerable uncertainty in the U.S. solar installation sector, which heavily relies on imported panels to meet domestic demand.[41]

The State of Play

The United States has long been a leader in the development of clean energy technologies; it has also historically been the largest public funder of R&D efforts to develop alternatives to fossil fuels.[42] In addition to research in universities and research institutes, firms in the U.S. private sector also conduct R&D at the technological frontier in a number of clean energy fields, including in solar PV technologies, batteries, and smart grid technologies.[43] Such long-standing strengths in R&D contrast with the lack of domestic support for commercialization and scale-up to mass production, which has received far less support from the U.S. government so far.

U.S. Manufacturing and the Global Economy

U.S. industrial policies for clean energy sectors have largely assumed that market failures exist in upstream R&D and downstream creation of market demand. They have not equally focused on segments of clean energy supply chains that are not well supported domestically, primarily in manufacturing. Structural shifts in the U.S. economy have increased the difficulty of scaling the domestic production of clean energy technologies. However, few industrial policies have attempted to improve the competitiveness of domestic manufacturing. A shrinking manufacturing economy has long promoted concerns about competitiveness of the domestic economy and the ability of American firms to sustain a lead in innovation without capabilities in commercialization and production. Such concerns first emerged in the 1980s, when the United States feared losing its competitive edge over Japan. While Japan's subsequent economic crisis and the U.S. IT boom in the 1990s distracted from problems in domestic manufacturing, the structural problems underlying a declining share of high-wage manufacturing employment were never fully addressed.[44] China's ascension to the World Trade Organization in 2001 increased import competition, but other factors contributed to a decline of the domestic manufacturing economy and preceded China's rise. Although public (and private) investments in R&D allowed the United States to maintain leadership positions in the invention of new clean energy technologies, three structural changes in the economy undermined the linear innovation model that had once translated such discoveries into domestic industrial outputs.

Structural shifts in the U.S. economy have increased the difficulty of scaling the domestic production of clean energy technologies.

First, broad shifts in the composition of the domestic economy sharply reduced the number of manufacturing firms that had capabilities in the scale-up and production of new products and technologies. The decline in manufacturing establishments began in the 1970s and accelerated in the decade after China's World Trade

Organization ascension, when the number of manufacturing firms in the United States declined by 14 percent. Losses were particularly strong in industries adjacent to clean energy sectors (i.e., in industries with skills that could be used to bring homegrown clean energy technologies to market). Although the United States remained one of the world's largest manufacturers, by the time clean energy sectors became sizable global industries, growth in technology- and resource-intensive industries such as pharmaceuticals, medical devices, and petrochemicals masked declines in other sectors. Where a domestic manufacturing ecosystem had once been able to commercialize technologies developed through public investments in research, structural changes in the domestic economy made manufacturing capabilities difficult to come by.

Second, U.S. multinationals increasingly relied on outsourcing and offshoring of noncore production activities. Beginning in the 1970s, U.S. financial markets rewarded large firms for focusing on core competencies just as falling tariffs and trade barriers opened new opportunities to shift production to other parts of the world. U.S. manufacturing firms had difficulty adjusting to this global reorganization of production, particularly since state institutions often offered little support to adjust. Despite R&D funding programs for early-stage research on new technologies, little public support was available to help existing manufacturing firms seeking to upgrade their technological capabilities enter clean energy sectors. For instance, the accounting procedures necessary to claim R&D tax credits favored research conducted in traditional R&D departments over manufacturing innovation. Firms in emerging clean energy sectors also struggled to find qualified manufacturing staff trained to handle increasingly complex machinery. Smaller firms with demand for workers with complex manufacturing skills reported difficulty filling vacancies. Existing vocational training institutions and community colleges did not meet the needs of clean energy sectors.[45]

A third, and perhaps most consequential, shift in the domestic economy was the growing difficulty of manufacturing businesses to secure financing to move technologies from research to production, particularly in emerging sectors such as clean energy. Few banks were willing to finance investments in manufacturing capacity in the absence of order guarantees or were able to meet the capital needs of firms trying to scale their products to mass production. Although policymakers and startups both hoped that venture capital (VC) might be able to fund the commercialization of new energy technologies, VC funds only briefly invested in clean energy sectors. In 2011, U.S. VC firms invested $11 billion in U.S. clean energy technology firms, compared to $9 billion globally. Yet VC investments dropped to $2 billion by 2013 as the number of clean energy startups that were able to secure VC funding fell from 75 in 2007 to 24 in 2013. VC instead focused on later-stage technologies and was unable to bridge the valley of death—the gap between publicly funded, early-stage R&D and technologies ready for mass production—to meet demand in growing clean energy markets.[46]

In clean energy industries, U.S. startups are often unable to finance the construction of manufacturing plants or to find domestic commercial partners that can. Private equity and VC industries are frequently unwilling to finance capital-intensive projects that cannot easily be liquidated. Many firms resort to collaborations with foreign firms. Others are bought up by multinationals.[47] The United States has not translated its leadership in the invention of new clean energy technologies into an equally strong position in commercialization and manufacturing. This is not the case in other parts of the world, such as the EU, where the competitiveness of clean energy manufacturing is a central policy priority. Europe is increasingly framing climate policy as economic policy and investing in domestic competitiveness of clean energy sectors. China, meanwhile, is ramping up its R&D spending and closing in on the U.S. leadership position in R&D.[48] In the United States—where considerable partisan disagreement exists about the urgency of addressing climate change, the appropriate role for the state in the economy, and the future growth potential of global clean energy industries—growing markets for wind, solar, and energy storage have not yielded similarly comprehensive efforts to improve the competitiveness of domestic clean energy supply chains.[49]

U.S. Clean Energy Sectors Today

The United States is one of the largest global markets for solar PV technologies, wind power, and EVs. In cumulative solar installations, the United States now trails only China and the EU. In 2021, the United States was the third-largest global market for new solar PV installations. The situation is similar in the wind industry, where the United States is the third-largest global market behind China and the EU. Owing to the gradual phase-out of federal tax credits, which prompted a rush of installations before a reduction in federal support, the United States has been one of the largest global markets for new installations.[50] The United States is also the third-largest market for EVs, the highest value component of which are lithium-ion batteries.[51]

However, aggregate market figures mask weaknesses in the U.S. market position, including far higher shares of renewable energy penetration in individual European economies and sizable markets for clean energy technologies in places with far smaller economies, such as Germany. These figures also obscure the dismal competitive position in offshore wind markets, where the United States trails behind far smaller economies like Finland and Taiwan in global markets dominated by China, the EU, and the United Kingdom.[52] Given the level of political polarization around the clean energy transition in the United States, the development of domestic markets for clean energy technologies is nonetheless noteworthy, owing to decades of federal and state market support and rapidly decreasing costs of wind, solar, and battery technologies.

The United States has been far less successful at translating its position in global clean energy markets into domestic industrial outcomes beyond the sizable service-sector industries required for installation and maintenance. These problems have not gone unnoticed. The Biden administration in 2021 launched a comprehensive investigation into domestic supply chains for 10 sectors critical to national security and national competitiveness. The review revealed significant gaps in domestic industrial capabilities and highlighted high levels of import dependency for key materials and components.[53] Despite public investments in R&D and support for clean energy markets, wind, solar, and batteries are no exception.

In clean energy sectors, the United States is best positioned in the wind industry. The United States is one of five economies that can manufacture the six main components of a wind turbine domestically. A modern wind turbine is generally made up of six components—the nacelle, which is the housing for all the components and the frame the rotating blades attach to; the blades themselves; the bearings that make sure that the blades rotate smoothly; the gearbox that shifts gears according to wind speed; the generator that generates electricity; and the tower on which the nacelle is mounted. Global and domestic manufacturers have sited production facilities in the United States to produce close to end-user markets. Particularly for heavy components, such as the nacelle that houses the other components, shipping costs are a strong incentive to produce in the United States. Nonetheless, the U.S. competitive position is not as strong as it could be given the sizable domestic markets. In 2019 alone, the United States imported some $2.6 billion of wind turbine equipment, of which wind turbine blades and hubs made up the largest share. Blades were primarily imported from Brazil, China, and India. Towers, which have long been subject to trade conflict with China, were primarily imported from India, Indonesia, and Vietnam, where labor costs are lower. Estimates suggest that roughly half of the overall value of a wind turbine comes from domestically produced components, far less than for similar turbines in Europe or China, which reach local content rates (the share of the product materials and components sources domestically) of over 90 percent. The United States also exports less wind turbine equipment than the EU and China and has largely left markets beyond Canada and Brazil untapped.[54]

Export volumes of wind turbines have been falling since 2015, and, as noted in the DOE review of domestic wind turbine supply chains, local content rates for domestic turbines have also been declining from their peak around 2015. A key factor identified behind declining competitiveness for the U.S. industry is significant uncertainty over future demand, which prevents firms from investing in retooling their existing manufacturing facilities to keep pace with technological innovation. Particularly in the production of wind turbine blades, domestic uncertainty has prevented the construction of new facilities, with firms sourcing blades from Europe and Mexico instead. As the industry shifts to larger turbines with significantly larger and more complex components, upgrading and retooling domestic production capabilities are essential to avoid losing market share to foreign competitors. Although the three main firms serving the U.S. market—GE, Siemens Gamesa, and Vestas—all have sizable domestic manufacturing facilities, they source components and material inputs through global supply chains. Unless domestic firms enter supply chains and keep up with changing technological requirements, these manufacturers are unable to switch to U.S. suppliers.[55]

The United States is one of the largest global markets for solar PV technologies, wind power, and EVs.

In the solar PV industry, the United States currently has no production capacity for any of the components of crystalline silicon solar PV modules, which are the dominant technology today and are predicted to remain the key solar technology through 2035. Crystalline solar PV modules are made up of silicon, the main raw material, which is then turned into ingots (essentially silicon blocks) that are cut into thin wafers, turned into cells, and then mounted into a module. The small amount of manufacturing capacity that the United States once possessed for these components has long ceased production. Although the United States used to be a large exporter of silicon, China placed import tariffs on American silicon in retaliation for U.S. trade sanctions and has since built up a sizable industry of its own. The United States possesses some domestic manufacturing capacity for thin-film modules, which make up 16 percent of domestic markets but only account for 4 percent of global solar PV markets. One-third of thin-film modules installed in the United States were manufactured domestically.[56] The U.S. solar industry employs more than 230,000 people, primarily in service-sector jobs in installation and maintenance. These jobs are highly dependent on imported technologies, despite almost a decade of anti-dumping/counterveiling duty tariffs on Chinese modules. Some 97 percent of silicon wafers—the thin plates cut from silicon blocks that become the primary input for the production of solar PV cells—are currently manufactured in China. DOE estimates that 75 percent of silicon solar cells used in the production of solar PV modules for U.S. markets are made by Chinese firms in Vietnam, Malaysia, and Thailand. Even for the small share of modules that are produced domestically, nearly two-thirds of value accrues in China due to the need to import raw materials and core components.[57]

The lack of domestic manufacturing capacity and the high share of imported products, particularly from firms with ties to China, have led to divergent economic interests in the domestic solar PV industry. Domestic installation and maintenance industries, however, are reliant on trade and open borders to source solar PV modules and take advantage of lower cost modules produced primarily in Asia. As a result of trade remedies, U.S. solar installations are approximately 30 percent more expensive than in other parts of the world.[58] Startups seeking to commercialize new types of solar PV technologies—often developed with federal research support in U.S. universities and research institutes—frequently file antidumping complaints with the federal government to minimize import competition. Despite U.S. government support for the development of these technologies—for instance, through DOE funding through the ARPA-E program—U.S. startups face an uphill battle to succeed in domestic markets. They compete against cheaper, established technologies and have difficulty financing domestic production facilities, yet need to reach scale economies before their technologies become competitive.[59]

Like the solar industry, the energy storage sector also relies on technologies that were at least in part originally developed in the United States but are now primarily produced elsewhere. Encouraged by a portfolio of industrial policies, Chinese battery manufacturers have progressively improved their technological capabilities and expanded their command of production capacity, particularly for lithium-ion batteries now used in EVs and on-grid storage. Lithium-ion batteries are assembled from battery cells, which contain cathodes, anodes, a separator, and electrolyte. Cathodes themselves contain different materials that determine the cell chemistries and, ultimately, the performance characteristics of the batteries.[60] China controls much of the raw material production and refining capacity for core material inputs into battery production but is even more dominant in the production of subcomponents for battery manufacturing. The United States has less than 1 percent of global production capacity for cathode and anode materials, 3 percent of production capacity for separators, and 7 percent of electrolyte production capacity. China, by comparison, controls 63 percent of cathode manufacturing, 84 percent of anode materials production, 66 percent of separator production, and 69 percent of electrolyte production. Although the United States now has 13 percent of the world's lithium-ion cell manufacturing capacity—not least because of Tesla's investments in domestic manufacturing—domestic production is highly dependent on imported subcomponents. Domestic production remains far smaller than China's battery industry, which controls more than 75 percent of global lithium-ion cell production.[61]

Today, none of the top five lithium-ion battery producers are American, and domestic mining projects, particularly for lithium, have been halted for environmental reasons. Domestic firms, including the EV manufacturer Tesla, are increasingly betting on non-cobalt, lithium-iron alternatives to current lithium-ion technologies to reduce supply chain bottlenecks and shortage in global mining capacity. However, this research does not place them ahead of global competition: The Chinese battery manufacturer CATL, among others, is working on cobalt- and nickel-free batteries, so the United States does not have a clear intellectual property (IP) advantage. Moreover, China's aggressive expansion of manufacturing could eventually lead to persistent overcapacity in global battery markets for batteries, further shrinking margins that may eventually affect the ability of U.S.-based manufacturers to set aside sufficient resources for the development of next-generation battery technologies.[62]

Current Developments and Domestic Policy Responses

The United States was long able to rely on global supply chains to meet growing domestic market demand for clean energy technologies. The gap between public investments in clean energy R&D and relatively modest domestic industrial outputs was primarily a political problem that surfaced, for instance, as calls for trade protection from U.S. clean energy startups. However, shifts in domestic climate goals and growing geopolitical tensions make such a reliance on global supply chains to meet domestic demand increasingly risky. Three developments in particular make this an opportune moment to ramp up industrial policy efforts and build domestic clean energy supply chains.

First, domestic climate goals set by the Biden administration—if implemented as planned—will require a rapid increase in both the pace and scale of domestic clean energy deployments. Cutting emissions by 50 percent by 2030, decarbonizing the power sector by 2035, and reaching carbon neutrality by 2050 will entail dramatic increases in the use of renewable energy technologies in the power sector, electrification of the national transportation sector, and, eventually, decarbonization of hard-to-abate sectors in heavy industry. The United States is not the only large economy with ambitious climate targets; meeting the goals of the Paris Agreement will require the global economy to reach net-zero emissions by 2050 and substantial reductions before then. Emissions must peak by 2030 and begin declining among major industrialized economies, given the limited remaining carbon budget.[63] Consequently, major economies around the world are expected to rapidly accelerate their deployment of wind, solar, and battery storage, straining existing supply chains that may no longer be able to meet U.S. demand. Already in 2021, the cost of solar PV modules increased after decades of falling prices, owing primarily to supply chain constraints. Domestic alternatives to global supply chains for clean energy technologies could make sure that at least some of the economic benefits from necessary capacity additions would accrue domestically, and domestic alternatives could also help prevent cost increases by helping prevent supply shortages and removing the threat of import tariffs. Ultimately, increased domestic production could help ensure that climate goals can be met.

China is home to more than 75 percent of production capacity for lithium-ion batteries required for on-grid storage and vehicle electrification, which makes Chinese EV producers highly competitive. Here, an EV show in China features 30 domestic brands out of approximately 80 total participating brands. (Getty Images)

Second, rising tensions in the U.S.-China relationship and bipartisan calls for economic decoupling from China are threatening to undermine existing clean energy supply chains, which are, for now, dominated by Chinese firms. While an anti-globalization sentiment in Washington is affecting trade policy beyond the clean energy industries discussed in this case study, few sectors have more to lose in these battles than those producing the energy technologies needed to meet climate goals. China's share of global PV production increased from less than 1 percent in 2001 to over 60 percent today. China makes one-third of global wind turbines and a far higher share of wind turbine components. It is home to nearly three-quarters of global production capacity for lithium-ion batteries. It is also because of China's enormous nonmarket-based investments in manufacturing capacity in these sectors that prices for clean energy technologies have fallen sharply over the past two decades.[64]

While the Biden administration has reopened conversations with China on climate goals, not least to urge China to step up its commitments under the Paris Agreement, the economic and political relationship between the two nations remains tense. For instance, China temporarily halted communication on climate after House Speaker Nancy Pelosi's visit to Taiwan in 2022. Domestic investments in clean energy industries are now increasingly framed in the context of a competitive relationship with China and explicitly justified with the need to re-shore American jobs. The development of renewable energy sectors relied on collaboration in global supply chains, including between firms in the United States and China with complementary skills in innovation and manufacturing. Yet growing tensions in the U.S.-China relationship have begun to undermine such collaborations, which in turn affect the ability of global clean energy industries to commercialize and deploy new technologies at the necessary speed and scale to meet climate goals. While it will be difficult to replace China in global clean energy supply chains in the short run, stepping up efforts to improve domestic competitiveness in segments of clean energy supply chains that are not well supported domestically is important to creating alternatives to the current reliance on China.[65]

While the Biden administration has reopened conversations with China on climate goals, not least to urge China to step up its commitments under the Paris Agreement, the economic and political relationship between the two nations remains tense.

Third, the COVID-19 pandemic has exposed the vulnerability of global supply chains and accelerated a widespread pushback against globalization. The vulnerability of the world's economic supply chains to external shocks was further highlighted after Russia's invasion of Ukraine in the spring of 2022, which not only wreaked havoc on global energy markets but also disrupted supply chains in industries from automobiles to energy. Building up domestic supply chains for clean energy technologies would not only allow the United States to insulate itself from increasingly volatile markets for fossil sources of energy but would also improve its control over the commercialization and production of clean energy technologies in the face of an adverse geopolitical climate.

Recent policy proposals to reduce U.S. dependence on imported technologies in growing clean energy markets have focused on manufacturing, in many ways picking up from the advanced manufacturing initiatives first put forward during the Obama administration. To date, however, few policies and policy proposals specifically target the underlying structural problems that have prevented public investments in R&D and domestic markets from translating into a competitive clean energy manufacturing sector in the United States.

Perhaps the largest exception to this trend is a 2021 proposal to create a domestic industrial finance corporation to address the inability of the U.S. financial sector to meet the needs of the manufacturing economy. Domestic clean tech firms have faced great difficulty in trying to raise capital for investments in manufacturing because the U.S. financial sector has shunned manufacturing in favor of sectors that yield higher returns, such as software.[66] American VC firms and financial institutions have frequently failed to meet the capital needs of manufacturing businesses due to low returns and long investment periods, particularly in sectors such as clean energy that are dependent on favorable regulatory environments to thrive.[67]

On August 12, 2021, a group of Democratic senators introduced the Industrial Finance Corporation Act to address this issue. The proposal entailed the establishment of a government-owned organization—Industrial Finance Corporation of the United States (IFCUS)—that would finance high-tech manufacturing in the United States. The announcement argued that large injections of

EVs are one of China's many strategic emerging industries under heavy state guidance and development. Pictured here is a BIRO City EV, which features Italian design and components. (VCG/Getty Images)

public and private capital had once allowed the United States to lead in the development of new technologies, but the nation was not equipped with the right financial institutions to commercialize and produce these technologies domestically. Large upfront capital expenses, long investment horizons, and high risks associated with the commercialization of new technologies have prevented financial institutions from funding manufacturing, even in clean energy sectors that are central to national efforts to decarbonize the economy.[68]

According to the proposal, IFCUS would be funded with a one-time capitalization of $50 billion, which could in turn generate hundreds of billions of loans and equity investments. Structurally, it would be a government-owned but independent organization tasked with supporting domestic supply chains in critical industries, including in clean energy. Although IFCUS was initially included in $3.5 trillion infrastructure package of 2021, the proposal ultimately failed to gain sufficient political traction and was written out of the bill in September 2021. Nonetheless, the proposal presents the first concrete industrial policy attempt to resolve a long-standing gulf between political promises of green manufacturing jobs and the economic reality in the United States.[69] In China, state-owned development banks were central to the expansion of clean energy manufacturing. In Germany, the state-owned KfW bank offers preferential loans for strategic sectors and underfunded businesses in the economy. The creation of such an industrial finance corporation in the United States would level the playing field in clean energy sectors.[70]

Considerably less targeted is the CHIPS and Science Act passed in August 2022.[71] A central element of the bill is a $52 billion subsidy program to support the establishment of domestic semiconductor manufacturing, which could have a positive impact also on clean energy supply chains. Although the bill is meant to set up a U.S. industrial policy response to China's growing competitiveness, it falls short of addressing underlying structural obstacles to increasing U.S. manufacturing in critical new industries. The bill increases public research funding for critical technologies, a strategy which has in the past led to U.S. technological breakthroughs but has also often failed to translate into domestic industrial development. Such proposals fall short of providing a long-term financing institution to support domestic manufacturing, structural support for vocational training programs for the workforce needed for clean energy supply chains, and stable regulatory backing for the growth of new economic sectors.

More narrowly, a number of recent bills seek to address U.S. dependence on China for critical minerals, which are central to many global supply chains, including those in clean energy. While some versions focus on easing permitting to jump-start domestic exploration and production of rare earths and other critical minerals, other bills propose new international alliances that could be funded to create alternative supply chains to those in China.[72] While such bills, if passed, have the potential to ease raw material shortages and increase supply chain resilience in the face of geopolitical tension, they do not affect the regulatory environment or the institutional obstacles affecting domestic manufacturers.

A key government intervention in domestic clean energy supply chains took place in June 2022, when the Biden administration invoked the DPA to boost domestic manufacturing of clean energy technologies, including solar panels, heat pumps, and transformers.[73] The DPA allows the federal government to pay firms to jump-start domestic production of clean energy technologies and offer an advance market commitment as an incentive for firms to invest in domestic production. Importantly, the DPA invocation was paired with a two-year moratorium on solar antidumping and countervailing duties (AD/CVD) tariffs for cells and modules from Southeast Asia. The moratorium offers a window of opportunity to increase domestic manufacturing capacity before potential tariffs could increase prices and lead to supply issues for imported clean energy technologies.[74] While the DPA allows the White House to intervene instead of waiting for bills to meander their way through bipartisan negotiations in Congress, it is also inevitably narrow in impact.

The passing of the Inflation Reduction Act in August 2022 created perhaps the most ambitious incentives for the creation of domestic supply chains by making tax credits for EVs conditional on rapidly increasing local content requirements. It also introduced bonus credits for clean energy projects qualifying for investment and production tax credits that use domestic manufacturing technologies. These are important signals that the federal government is willing to intervene in domestic markets to create domestic supply chains through demand incentives. However, such demand-side policy alone is unlikely to rapidly create a thriving manufacturing ecosystem that can support the domestic commercialization and production of clean energy technologies in the long run.

Other Countries' Strides in Industrial Policy for Clean Energy Development

While U.S. industrial policy approaches have primarily addressed market failures in upstream R&D and the creation of domestic markets, other economies, including in the EU and China, have launched broad industrial policy initiatives to improve financing and vocational training to support domestic firms in taking key positions in clean energy supply chains. The United States could learn from European and Chinese approaches, which the subsequent sections review in turn.

European Clean Energy Initiatives

The European Battery Alliance (EBA) is an example of a proactive industrial policy initiative that seeks to strategically position Europe as a competitive global producer of advanced battery technologies needed for decarbonization. A key target of the alliance is to not only ensure the presence of domestic firms in battery assembly and production but also to ensure that European firms take strategic positions in the supply of raw and processed materials, cell component manufacturing, cell manufacturing, battery pack manufacturing, battery-electric vehicle production, and raw material recycling.

The alliance brings together the European Commission, the European Investment Bank (EIB), and EU national governments and development banks, as well as vocational training institutions, research institutes, and more than 500 industry actors along the entire battery supply chain. In collaboration with industry partners, EBA established a strategic action plan that sets a number of targeted measures to develop secure access to raw materials and refining capacity, to establish manufacturing capacity along the battery supply chain while reducing its environmental footprint, to train a domestic workforce by overhauling curricula in existing vocational training institutions, and to support R&D to both advance existing lithium-ion batteries and build European IP for next-generation disruptive technologies.

EBA relies on different financial instruments to reach its targets, including loans from the EIB, R&D funding from the EU Innovation Fund, and direct support from the European budget. It also calls on EU national governments to align their industrial policy strategies with EBA targets, and EBA established a novel funding mechanism for cross-border industrial policy initiatives. For so-called "important projects of common European interest" (IPCEI), such as the establishment of a battery industry, the European Commission exempted national governments from the usual restrictions regarding state support to the private sector. Two EU-wide battery initiatives were approved under the IPCEI framework in 2020 and 2021 and funded with €3.2 and €2.9 billion to support R&D collaborations between industry partners and research organizations along the battery supply chain. As such, EBA coordinates national industrial policies and industrial actors along the battery supply chain and provides financing instruments to meet investment targets.

By 2021, public funding had led to the construction launch of some 15 lithium-ion plants across Europe. For instance, with €1.3 billion of public funding from France and Germany, Automotive Cells Company—a joint venture between the oil company Total and the automaker Groupe PSA—began building two giga factories in France and Germany. Several projects received loans directly from the EIB. The Swedish startup Northvolt, established in 2016 to commercialize a low-cobalt lithium-ion technology, was able to use an EIB loan to secure additional investment from financial institutions and automotive companies. The EIB also backed the construction of a factory for cathode materials in Poland by the Korean manufacturer LG Chem.

Europe's industrial policy approach is, of course, itself a response to state support for the growth of clean energy industries in China. As noted in detail in the supply chain review conducted by the Biden administration, Chinese firms are not only key global players in the production of wind turbines, solar PV modules, and batteries, but they also make the components required to manufacture these technologies and control the supply chains to mine and refine the raw materials for clean energy sectors.[75]

Chinese Clean Energy Efforts

At least since 2006, the Chinese central government has implemented strategic industrial policies to promote the goal of "indigenous innovation"—shorthand for a reduced reliance on imported technologies through increased domestic R&D and commercialization. To this end, the central government has used a series of R&D programs to support firms' efforts to develop homegrown clean energy technologies. Dependent on tax revenue from the manufacturing economy, however, subnational governments have continued to support mass production, at times in outright defiance of the goal to consolidate clean energy industries and avoid overcapacity. They have brokered bank loans and provided land, facilities, and tax incentives to manufacturers, including in clean energy sectors. According to press reports, the China Development Bank alone has extended at least $29 billion in credit to China's largest solar and wind turbine manufacturers.[76] Similar manufacturing loans have since been extended to China's rapidly growing lithium-ion battery industry.

State industrial policies were further magnified in "High-Technology Zones"—areas set aside for the development of critical technologies in key industrial sectors. National industrial policies designated strategic technologies and provided funding for R&D in these zones. Local government industrial policies supported firms in these industrial parks in their investment in mass production, including by helping firms secure loans for manufacturing expansion and by setting up vocational training for a manufacturing workforce.[77] Although

The global transition toward clean energy could intensify competition for access to materials necessary for clean energy applications, such as the lithium mined here in Utah. (Doc Searls/Wikimedia Commons) much speculation in the United States has focused on the question of whether China's clean energy manufacturers were able to secure below-market interest rates in loan deals obtained from China's state development bank, the key critical ingredient to China's rapid expansion of its domestic supply chain in wind, solar, and batteries was that it was able to obtain financing at all. Neither European banks nor U.S. VC funds and financial institutions were willing to fund the expansion of domestic clean energy manufacturing when China began making strides in becoming the world's largest clean energy technology producer.

In the transportation sector (today the largest consumer of lithium-ion batteries manufactured in China), the state also used technological benchmarks—including range requirements, battery density targets, and other measures—to encourage domestic producers to catch up with the technical standards of their global competitors. China's domestic subsidy system for EVs, first piloted in select cities in 2009, had detailed eligibility rules based on technical criteria and manufacturing locations that largely discriminated against foreign battery producers. To qualify for the subsidy, EV models were required to use batteries included on a list of government-selected manufacturers based on technical criteria and production location. In addition to technical requirements for drive motors, safety measures, and energy consumption, vehicle batteries also had to meet battery density requirements, which further narrowed the battery chemistries manufacturers were able to choose from.[78]

After a period during which green industrial policies for China's EV sector targeted government-chosen technologies and firms, the government switched in 2017 to a dual-credit system that required auto manufacturers to sell a specific share of EVs as part of their overall sales in China. Once domestic firms began to meet the technological standards of their foreign competitors, benchmarking became both more difficult for the state and less productive for the development of a domestic industry, as consumer adoption of EVs now relied on far more complex choices about what types of cars to sell. The dual-credit system therefore sought to maintain a stable domestic market for EV and fuel-cell vehicles as direct subsidies were being phased out. It also provided a financial advantage to manufacturers that exclusively produced EVs, most of which were Chinese brands. Importantly, it let firms choose their vehicle portfolio, their business models, and make technological choices, for instance on which battery technology to use.[79]

Recommendations to Reimagine the U.S. Clean Energy Landscape

The United States has failed to mount a similarly comprehensive industrial policy strategy for clean energy sectors, even if the recent Inflation Reduction Act has now created strong incentives to increase the domestic production of clean energy technologies. Four recommendations would increase the competitiveness of domestic clean energy sectors.[80]

Establish a state development bank—akin to the IFCUS proposal—to finance domestic manufacturing projects that the U.S. financial system has been unwilling to fund.

The scarcity of capital among clean technology firms has prevented domestic startups from raising sufficient funds to provide capital for shoring up domestic manufacturing capacity, as American financial institutions have prioritized sectors—including software—that have historically yielded better returns.[81] Beginning with a one-time capitalization through the U.S. government, a politically independent, not-for-profit manufacturing bank should aim to be self-sustaining and strive to maintain and grow its capital base. With its revenues, it should prioritize support for domestic supply chains in critical industries, buttress the commercialization of U.S.-developed technologies, and provide for the capital needs of manufacturers in traditionally underfunded industrial sectors, such as clean energy technologies.[82] Such an institution could complement provisions in the Inflation Reduction Act, including a tax credit for clean energy manufacturing and funding for investments in clean energy infrastructure.

Ramp up federal investments in vocational training programs to meet the workforce needs of a growing clean energy manufacturing industry.

The federal government should take an active role in improving and expanding vocational training programs for a growing clean energy workforce. Such support could take the form of grants for vocational schools and community colleges that seek to establish clean energy manufacturing curricula together with partners from industry. The federal government could also help solve problems that have prevented the establishment of manufacturing apprenticeship systems similar to those in place in European economies. U.S. companies are currently often reluctant to invest in training out of concerns that trainees will eventually be poached by their competitors. Public support for vocational training is especially important in areas that depend heavily on fossil fuel industries for employment and that are likely to suffer economic losses from a clean energy transition without such programs for a just transition.[83]

Set stable regulatory requirements and legally binding targets for growing markets for clean energy technologies to incentivize domestic manufacturing investments.

Manufacturing firms often co-locate with the sources of demand, but less so if that demand is volatile. This has historically been a problem particularly in the U.S. wind industry, where a political tug of war over federal production tax credits has led to below-average U.S. local content rates. Such volatility deterred domestic manufacturers from retooling their plants for emerging renewable energy sectors, even when they in principle had the necessary capabilities. Many industrial policies for clean energy sectors originate in the executive branch due to gridlock in Congress. Unfortunately, such executive actions are limited in their ability to create a stable long-term market for domestic clean energy technologies that would encourage domestic investments in manufacturing. The Inflation Reduction Act has begun to create strong support for the growth of these domestic markets over the next decade. Subsidies and tax credits, such as the investment and production tax credits, could be tied to clear deployment targets to give the industry certainty over future support. A version of California's policy to mandate vehicle manufacturers to sell a specific share of their fleet as EVs should be adopted at the national level. Setting minimum standards for the use of renewable energy by utility companies would offer additional incentives for manufacturers to move production to the United States. The central goal is not to use federal legislation in all cases to set more ambitious goals than what the market, states, and consumers would already do on their own, but to set binding minimum standards to reduce the uncertainty created by the fragmented approach currently used to support these sectors.

Limit the use of trade remedies and instead support the competitiveness of domestic clean energy firms through proactive industrial policies.

Trade restrictions can limit the ability of domestic clean energy industries to source materials, parts, and components through global supply chains—and increase prices in ways that may harm domestic clean energy service industries focused on installation and maintenance. Restrictions can also obstruct the climate diplomacy urgently needed to meet the Paris Agreement goals of limiting the destructive impact of climate change. Even with more robust industrial policy efforts, it is unlikely that entire value chains for complex energy technologies would ever lie entirely within U.S. boundaries. This does not mean that there are never cases where anti-dumping tariffs are necessary or appropriate. Including a net economic benefit to the U.S. test in such determinations could broaden the scope of trade investigations to consider the interests of clean energy industries as a whole. Trade disputes have focused on low-value-added assembly of final products, which has harmed domestic installation businesses without improving the competitiveness of domestic manufacturing. European industrial strategies, particularly in the battery sector, offer instructive lessons on how to improve national competitiveness in clean energy industries through proactive industrial policy measures while maintaining market access.

Conclusion

Owing to the lack of bipartisan consensus on the appropriate role of the state in directing economic activity, U.S. policy interventions in support of clean energy industries beyond R&D funding have been fragmented and intermittent. But geopolitical shifts, strategic competition with China, and the ripple effects of the war in Ukraine could provide a political opening for the consistent deployment of more ambitious industrial policies. The United States should use this opportunity or risk falling behind other economies, including those in Europe, that have made the development of domestic clean energy supply chains central elements of their response to climate change. The United States must recognize the economic benefits from—and national security imperative in—public investments in clean energy industries, as governments in other parts of the world have begun to strategically support their domestic clean energy sectors in the pursuit of world market share.

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