WHITE PAPER

Inflection Point: The State of US PV Solar Manufacturing & What's Next

An Assessment of Current US Silicon Solar Manufacturing Capacity and Capabilities, Benefits from Onshoring, and Recommendations to Facilitate the Process

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Executive Summary

Solar generation is essential in transitioning from a fossil fuel-based power generation sector to one that leverages renewable and distributed energy resources. In the US, demand for solar generation capacity is strong across residential, commercial, industrial, and utility sectors. But certain segments of the country's solar manufacturing supply chain remain almost entirely dependent on foreign-sourced materials, primarily from China. In the early days of the energy transition, great effort was devoted to making the cost of renewable technologies like solar comparable to those of dispatchable fossil fuels. After decades of cost declines in solar technology, solar energy now has one of the lowest CAPEX costs of any electricity source across the country. Attention must be shifted toward strengthening the domestic supply chain to produce solar components.

With the demand and production supports embodied in the Inflation Reduction Act (IRA), a robust US solar manufacturing supply chain is within reach. But without a US policy response to the current influx of imports in both components and finished products, resulting in significant oversupply, recent factory announcements will likely not come to fruition. While the groundwork has recently been laid for a strong domestic solar manufacturing ecosystem, significant gaps remain and present a threat to its long-term viability. Following the passage of the IRA, with its provisions to level the playing field for US manufacturers, billions of dollars of intended investments were announced throughout the US solar supply chain. Now, as subsidized overseas - manufacturers in China and Southeast Asia use their outsize market control and questionable trade tactics to undermine those investments, the onshoring progress is stalled as US manufacturers await further support to achieve the promised supply chain independence.

While the groundwork has recently been laid for a strong domestic solar manufacturing ecosystem, significant gaps remain and present a threat to its long-term viability.

Through the IRA and the Creating Helpful Incentives to Produce Semiconductors (CHIPS) Act, the Biden administration embraced industrial and trade policy aimed at charting a course for America's transition to clean energy. However, a whole-of-government approach to this policy has not yet followed, particularly in the area of trade, but also with incentives that do not encompass the full solar supply chain. President Obama faced a similar challenge after the Recovery Act, when significant loans and tax credits were delivered to solar manufacturers but were then followed by a wave of bankruptcies in 2011. The turmoil was largely due to low priced imports of solar materials, components, and modules—whose prices were artificially depressed due to Chinese government subsidies—undercutting the Obama administration's objectives in solar manufacturing. The Biden administration must learn from the Obama administration's mistakes and fully embrace trade policy in its industrial policy planning.

Breaking the US solar industry's dependence on imported polysilicon, wafers, and solar cells and modules would lead to enormous benefits for the American people. Domestic production of solar modules and associated components would insulate the US from the disruptive effects of geopolitical conflicts and other global events on its supply chain, in addition to strengthening the nation's energy security. Producing every core component of a solar module on US soil would create new, stable clean energy jobs and help the US achieve its climate goals, while ensuring the parts are sourced ethically and produced in an environmentally responsible manner. Because the cost of the solar module represents an

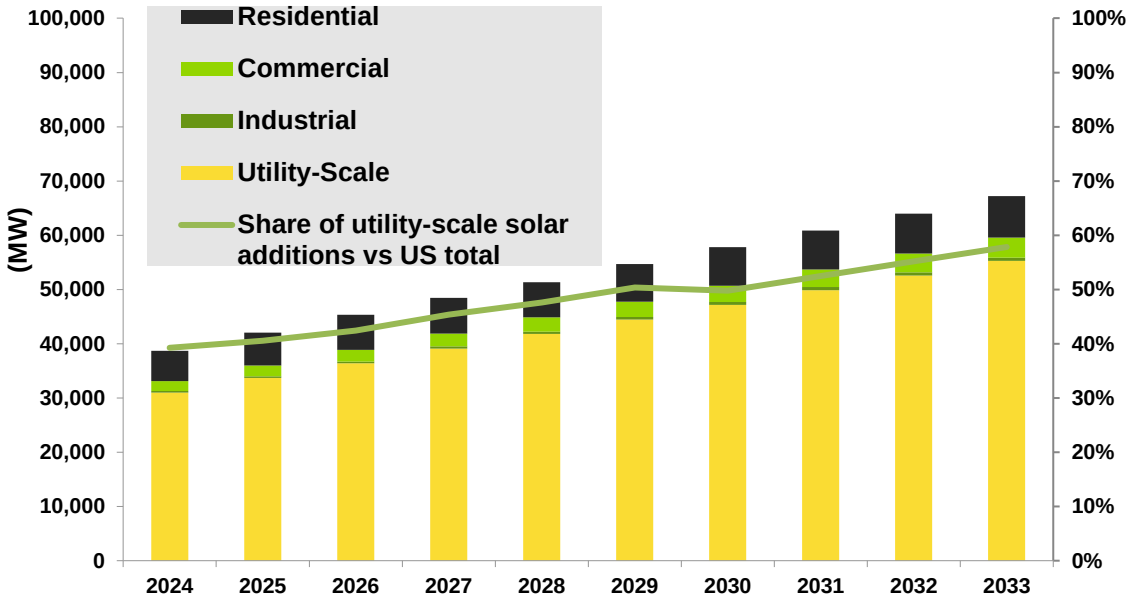
increasingly small portion of the overall cost to install a solar energy system, any slight increases in module cost resulting from domestic manufacturing will not inhibit further consumer adoption of the technology.

To facilitate the transition to a US-based solar manufacturing supply chain, the public and private sectors must work together. Creating and enforcing a supportive federal policy environment for domestic solar manufacturers is perhaps the most crucial piece to enabling a successful transition. This means federal support through tax incentives and loans, but it also means reliable enforcement of US laws to counteract foreign subsidies and prevent products made with forced labor from entering the country. There must also be efforts to support qualified workforce development by procuring or developing the proper expertise in equipment manufacturing as well as noncore activities, so that an increase in manufacturing factory capacity is paired with a corresponding increase in qualified workers to make components and equipment. Policies related to domestic manufacturing must also be structured in a way that allows sufficient time for US manufacturing facilities to ramp up production capacity. Parallel efforts to explore next-generation solar technologies, both within the silicon supply chain and outside of it (e.g., tandem, thin film), will also drive more solar manufacturing capacity onshore.

US Solar Market Is Strong Yet Overreliant on Imported Goods

The US solar electricity market remains strong, accounting for almost half of all utility-scale generation added to the US power grid. Because US solar energy is a source of electricity with one of the lowest CAPEX in most parts of the country, demand is only expected to accelerate through 2035 and beyond as governmental policies and demand for nonpolluting energy continue to grow. Solar energy today is an affordable, accessible, and viable method for powering the energy transition in the US. As shown in Figure 1, Guidehouse Insights forecasts new annual solar capacity additions across residential, commercial, industrial, and utility-scale applications to grow from nearly 39 GW in 2024 to roughly 67 GW in 2033 at a compound annual growth rate of 6.3%. For utility-scale solar, annual capacity additions now account for about 40% of all new annual utility-scale additions in the US and could approach 60% by 2033.

Figure 1 Annual Solar Capacity Additions and Share of Total US Additions: 2024-2033



(Source: Guidehouse Insights)

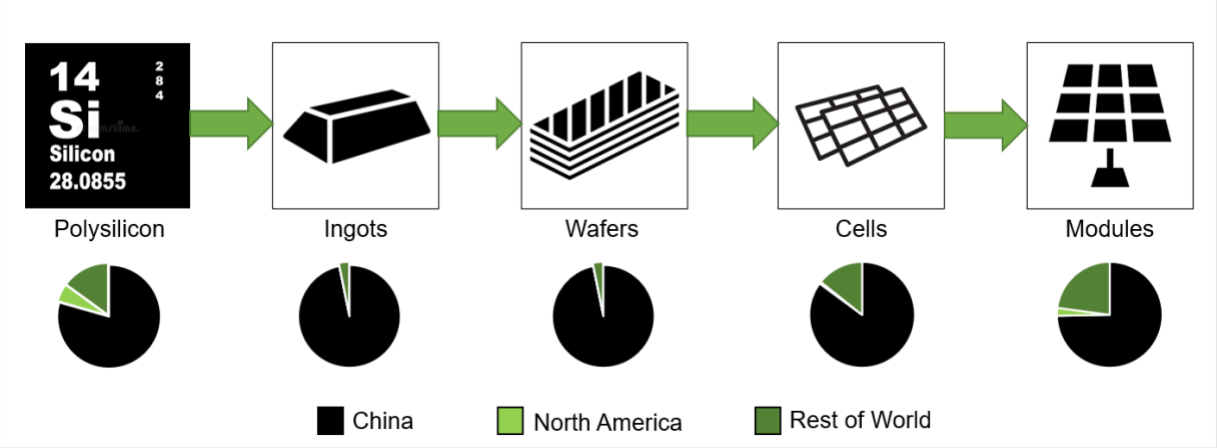
However, US-China geopolitical relations and the attendant implications for American energy security remain a core challenge for the transition to solar as a more integrated part of the US energy grid. The country is in the precarious position of being overly reliant on imported goods—largely from Chinese-controlled companies—to meet its rapidly increasing solar demands. Over the last decade, the Chinese government has heavily subsidized the growth of its own domestic solar manufacturing market, while America's domestic manufacturers have not received comparable levels of support. The US currently has the makings of a strong solar manufacturing supply chain, but increased support is critical to regain solar manufacturing competitiveness. Filling these support gaps is possible, and in doing so, the US can improve its energy security and market leadership as the world increasingly looks to solar PV technology to generate low cost electricity in the face of the continuing climate crisis. Strong, consistent, and unwavering policy support for domestic solar manufacturing can lay the foundation to make the US, the nation that invented solar modules, a leader in modern solar energy manufacturing.

In the early days of solar adoption, technology providers made enormous efforts to lower the CAPEX needed to deploy solar PV systems to make them competitive with fossil fuel sources. Residential solar PV system costs dropped from nearly $9 per watt in 2010 to just over $3/W in 2018. Similarly, utility-scale solar PV system costs went from roughly $6.50/W to $1.35/W in that same period. However, in the years since, the cost decreases to deploy solar have become significantly less dramatic. Demand for solar has continued to increase, while the prices for competing energy sources, such as natural gas, as well as the soft costs associated with the deployment of solar such as transmission queues and permitting, have remained high. Given that solar is and will likely remain the cheapest form of new energy generation, national priority must be given to creating a more sustainable, reliable, and secure solar supply chain.

Supply Chain Analysis Shows Glaring Gaps for US Ingots, Wafers, and Cells

While solar energy technology was invented in the US, domestic manufacturing capacity has only achieved a fraction of what is possible. The US is highly dependent on China for much of the polysilicon PV supply chain, which includes the processing of mined quartz into high quality polysilicon, the pulling of ingots, slicing wafers from the ingots, the production of solar cells, and the final assembly into solar PV modules complete with weatherized housing (see Figure 2). Polysilicon facilities in Michigan, Tennessee, and Washington currently form a foundation for a larger domestic supply chain, but more support is needed to grow domestic manufacturing. The IRA and the CHIPS Act were valuable first steps that will support the opening of multiple new research, development, and manufacturing facilities in the US. While these are positive steps toward a stronger solar manufacturing position, more action is needed to secure a domestic energy future that can withstand international supply chain disruptions.

Figure 2 Silicon Solar Module Manufacturing Process Steps and Market Shares by Region of Company Headquarters



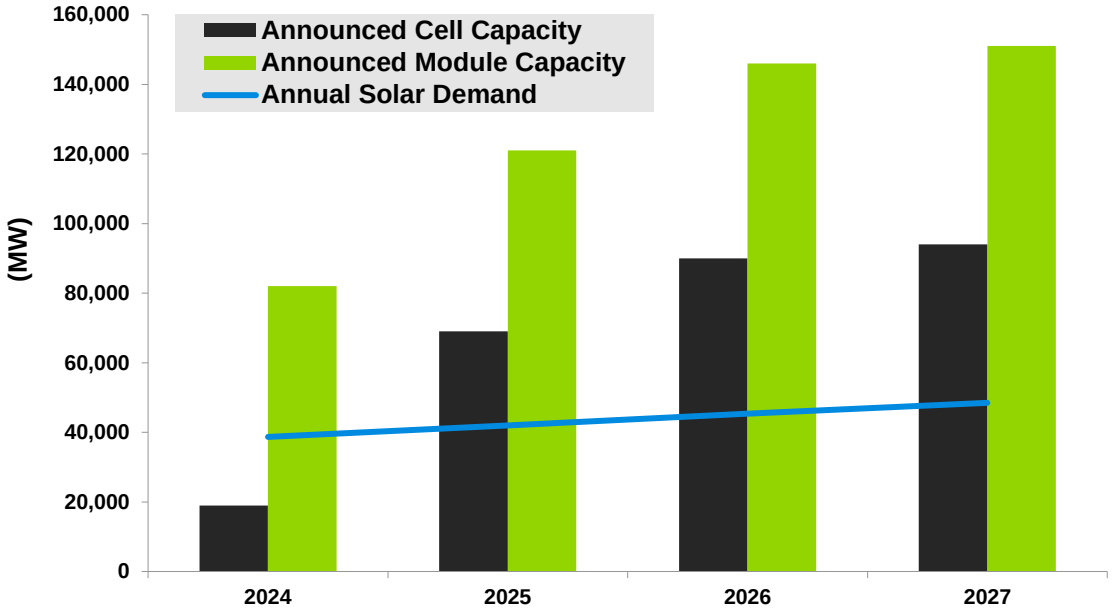
(Source: Guidehouse Insights)

The US currently could produce enough polysilicon to make about 20 GW of crystalline silicon products each year, but the country lacks critical next-step manufacturing facilities for the various refinement and component fabrication steps in the solar cell manufacturing process. The US also lacks capacity to manufacture ingots, wafers, and cells, and therefore is entirely dependent on global suppliers for these components. This is in stark contrast to 2014, when the US had nearly a dozen facilities involved in ingot

and wafer production with a capacity of around 500 MW. These manufacturing steps are the most capital intensive yet among the least incentivized through the provisions in the IRA.

As a direct result of IRA provisions, the US is seeing a significant increase in announced cell manufacturing and module assembly capacity. If even half of this announced capacity comes online, the US could produce enough cells and modules to meet nearly 100% of its new solar demand through 2027. If no new factory capacity came online after 2027, the country could still meet more than 90% of its new solar demand in 2028, dropping slightly to roughly 70% of new demand in 2033. Figure 3 shows projected solar demand and announced cell manufacturing and module assembly capacity across all types of solar PV technologies from 2024 through 2027. While this growth in the final phases of solar manufacturing capacity is a promising start, the US is still overly dependent on large amounts of imports from Chinese-owned companies for upstream materials to meet rapidly accelerating demand. Worse, US-based cell and module manufacturers will face the prospect of having to buy their raw materials (i.e., wafers and polysilicon) from their China-subsidized competitors—a scenario that is unlikely to lead to a sustainable industry over the long term, as it leaves the industry vulnerable to price and supply volatility as well as potential fallout from any geopolitical issues. Furthermore, this reliance represents a marked risk to US solar deployment, as access to internationally sourced solar PV components could be limited through export controls or bans and used as a geopolitical wedge. Market concentration with just a handful of large solar manufacturers outside the US could lead to collusion and price manipulation.

Figure 3 Cumulative Announced US Solar Cell and Module Manufacturing Capacity vs. Annual Solar Demand: 2024-2027



China's Dominance Disadvantages US Manufacturers and Results in Stockpiling

While the US has taken many positive steps in recent years toward bolstering its solar manufacturing capacity, several critical issues must be addressed to achieve domestic market security. In the global market, the US produces only about 5% of global polysilicon supply and final assembled solar modules. By comparison, China possesses 97% of the world's PV wafer manufacturing facilities and controls more

than 99% of global wafering capacity, some through entities located in Southeast Asia. China today produces more than 90% of solar-grade polysilicon, and Chinese-owned companies control 80%-95% of global shipments across the solar supply chain.

Due to longstanding and substantial Chinese governmental support for the solar manufacturing industry, the China's production of solar panels can, and does, exceed current global demand. For ingots, wafers, cells, and modules, the US is forced to rely heavily on suppliers located in Southeast Asian countries like Cambodia, Thailand, Vietnam, and Malaysia; however, most of those suppliers have their main headquarters in China. It should also be noted that polysilicon manufacturing services both the solar energy market (nearly 80%) and the semiconductor supply chain, making the viability of US polysilicon manufacturing critical to multiple economic sectors. While the IRA and the CHIPS Act are positive steps, more support will be required to secure a sustainable and resilient domestic solar PV supply chain.

China's Solar PV Manufacturing Dominance

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Another major threat to building up US solar manufacturing capacity is the stockpiling of cheap imported cells and modules. The Biden administration's decision to declare an emergency moratorium on assessing duties on solar products originating from China and routed through Southeast Asia has resulted in a major increase in the availability of cheap solar imports. Table 1 shows projected cumulative oversupply levels (i.e., module supply that exceeds projected US solar demand for new solar projects) in 2024 under different tariff scenarios. In the current market, imported modules are not subject to tariffs because of the 24-month moratorium issued in June 2022. Should this moratorium be lifted in June 2024, import levels will start to decrease in response to the reinstatement of tariffs, whereas imports will likely continue to rise if the moratorium is continued and imports are not subject to tariffs. An excess supply of stockpiled materials threatens to undercut efforts to scale up domestic manufacturing capacity, as solar developers will not commit to domestic suppliers when they can readily procure cheap components from existing overseas factories with demonstrated ability to price at or below production costs.

Table 1 Projected Oversupply Levels Compared with 2024 US Solar Demand

Scenario	Projected Cumulative Oversupply End of 2024	Projected US Demand 2024	Ratio (Oversupply/Demand)
Tariff moratorium expires June 2024	91,600 MW	38,700 MW	2.37
No tariff scenario	102,400 MW	38,700 MW	2.65

Note: Projected cumulative oversupply refers to module supply that would exceed projected US demand for new solar projects in 2024 (i.e., total supply minus demand).

(Source: Guidehouse Insights; data from Clean Energy Associates and U.S. Census Bureau)

As supply chain challenges have shown, from the COVID-19 pandemic as far back as the oil embargo of 1973, a strong domestic supply chain is critical to both energy security and establishing America's place in the rapidly growing global solar PV market. The opportunity to achieve this market position comes as the price gap between Chinese and US-made silicon modules continues to close. Domestically produced solar modules can be roughly 30%-50% more expensive to produce than imported ones, but various provisions in the IRA aim to reduce this gap by promoting economies of scale and vertical integration. Focusing investments on developing the cutting-edge equipment, knowledge, and workforce needed for a strong domestic supply chain can further reduce these costs in time.

Onshoring Solar Production Will Aid Industry and End Users

With the volatility of a global solar supply chain as well as mounting geopolitical conflict between major players in the global solar industry, onshoring solar manufacturing is more critical than ever as the US looks to increase its deployments of solar energy to keep pace with growing domestic demand. Building a fully domestic solar supply chain that includes every step of the solar manufacturing process would allow the US to capture more of the workforce and economic benefits of the clean energy transition while ensuring a secure and reliable supply chain. Breaking the reliance on foreign entities for key solar panel components would also enhance US energy independence and security.

Solar PV prices are inherently volatile, even on a 6-month horizon. However, solar module costs are estimated to account for less than 22% of total system costs, depending on the application, meaning module pricing has less impact on overall consumer adoption than it did in the past. Major concerns for scaling adoption are now focused on the labor, siting, and interconnection end of the development process rather than on component costs. Increasing domestic solar manufacturing capacity will not only strengthen the country's supply chain and insulate it from global disruptions but will also help create new, high paying, permanent jobs for skilled workers. Job creation is essential to facilitating the energy transition in the US, and it is imperative to ensure support for such efforts remains high.

Domestic Solar Manufacturing Capability Increases Energy Security and Reduces Global Supply Chain Disruptions

Increasing onshore manufacturing capabilities can help limit module price volatility and availability disruptions, most of which stem from international events (e.g., geopolitical conflicts, pandemics, foreign government trade policies, etc.). Throughout the solar panel supply chain, world events can and often do negatively affect the availability, and therefore the price, of required resources to produce panels. Impacts from COVID-19 led to a 38% decline in the US solar workforce, a 37% decline in forecast US solar installations, and a loss of approximately $3.2 billion in economic investment. Overall, this equated to an approximate 5-year loss of investment within the US solar industry in the first two quarters of 2020 alone. However, companies with more localized and domestic supply chains saw less impact from the global pandemic in terms of manufacturing outputs, job retention, and project deployments than companies with larger dependences on international sources. In addition to the job losses and general difficulties obtaining necessary materials, many US companies have halted expansion plans since early 2020, contributing to domestic supply and demand.

Increasing US solar manufacturing capacity would also make solar components more readily available, in turn reducing US exposure to international competition for these key parts. Because of China's relative dominance in the global solar manufacturing supply chain, Chinese manufacturers exercise a significant amount of influence over the global solar market. For example, if Chinese manufacturers chose to withhold module and component supply or divert it to other markets—as they did in 2021, which resulted in a perceived emergency that led to the tariff moratorium—then US developers would have no choice but to either delay projects or once again call on the US government for support. In contrast, making solar cells and modules more available through a robust US market would allow the energy transition to accelerate nationally with far less risk of supply disruption.

Depending on a global supply chain for key solar components presents an additional layer of complexity and unpredictability for the US solar industry. US utility-scale solar projects can take upwards of 6 years

to develop, including time spent on permitting and interconnection, with the actual construction phase not starting until year 5, after much of the project economics are already analyzed. With this timeline in mind, the fragility of product availability resulting from heavy reliance on suppliers from a single foreign entity can result in uncertainty and inefficiency, which can lead to projects being delayed or canceled. Increasing domestic solar manufacturing capacity further secures the country's energy supply by cutting its ties with foreign component suppliers and allowing the US to dampen pricing volatility and limit project revocation.

Module Cost Has Limited Impact on Customer Adoption

Module cost is a common concern with onshoring solar manufacturing because goods manufactured overseas tend to come at a lower price. This concern is driven by fears that high prices for modules made in the US may lead to slower consumer adoption. However, continued module cost declines will likely have limited impact on customer adoption of solar moving forward. Potential cost reductions in other areas of solar deployment (i.e., permitting, installation/overhead, and balance-of-system operations) are likely to have a larger impact on market growth. An additional potential barrier to adoption not related to cost is a lack of qualified workers and long interconnection queues, which are leading to project delays.

Table 2 shows how the total cost to deploy solar for residential, nonresidential, and utility-scale applications varies when accounting for US-produced solar modules. The data used for average cost of solar PV systems is from the first half of 2023. Because US-produced modules can be 30%-50% more expensive to produce than imported ones, Table 2 uses the more conservative 50% figure when accounting for the change in price between imported and domestically produced modules. In the first half of 2023 alone, the US imported more than 25 GW of solar modules, nearly enough to meet the entire year's demand; therefore, it was assumed that the initial average cost data shown included imported module prices.

Table 2 Module Cost Impact on Average Cost to Deploy Solar: 2023

	Residential	Nonresidential	Utility Scale
Average cost (imported module)	$3.5/W	$2.1/W	$1.2/W
Module cost as % of total system cost	5.4%	9.1%	15.8%
Average cost (US module)	$3.6/W	$2.2/W	$1.3/W
Module cost as % of total system cost	7.9%	13.0%	22.0%
Effective total system cost (US module) with domestic content (tax credit) bonus	$3.24/W	$1.98/W	$1.17/W

(Source: Guidehouse Insights; data from National Renewable Energy Laboratory and U.S. International Trade Commission)

Because the solar module accounts for a relatively small portion of the overall cost to deploy a solar system, the total system cost increases only mildly depending on application when incorporating the higher US module cost. While the module cost represents a larger percentage of the cost to deploy utility-scale solar compared with residential and nonresidential use cases, module equipment cost still accounts for a small portion of the total system cost. Within the utility sector, the contribution of the module could decrease even further as more utilities look to pair energy storage with solar arrays. This trend may also

increasingly become relevant for both residential and nonresidential customers as net energy metering regulations in more states are amended to lower export compensation for excess generation sent back to the grid. Further, when the domestic content bonus (i.e., the Investment Tax Credit from the IRA) is included, the cost to deploy solar with US-produced modules effectively drops to below the deployment cost using imported modules.

Onshoring US Solar Manufacturing Will Create More Skilled Jobs

One of the largest benefits of onshoring US solar manufacturing capacity will be the creation of a large number of skilled jobs. Employment at any stage in the solar manufacturing process can offer high wages, full benefits, a steady line of work in a permanent location, and opportunities for career progression, all of which also supports the surrounding economy. The passage of the IRA has already resulted in several announcements of new domestic solar manufacturing facilities, which should lead to a significant increase in solar manufacturing job openings.

A study conducted by the University of Louisiana at Lafayette on behalf of First Solar, a US-based thin-film solar manufacturing company, found that the company's 2023 operations, which totaled 6 GW of operational capacity, supported a total of 16,245 direct, indirect, and induced jobs and nearly $1.6 billion in labor income for the US economy. The company's operations were also estimated to support a total of nearly $2.8 billion in value added and almost $5.3 billion in total output when including indirect and induced economic effects. After First Solar completes the ongoing expansion of its facilities in Alabama, Louisiana, and Ohio, annual operational impacts on the US economy starting in 2026 are projected to grow to more than 30,000 jobs and almost $2.8 billion in labor income. The study estimated that operating at that scale will support nearly $5 billion in value added and over $10 billion in output for the US economy, including direct, indirect, and induced economic effects.

Onshoring solar manufacturing reinforces economic growth and invites qualified personnel and highly educated workers with technical backgrounds to enter the solar job market. However, manufacturing is not the only sector that would see new jobs generated by onshoring the US solar supply chain. As production ramps up, additional R&D jobs in the solar industry may also be created as alternative cell technologies and manufacturing processes are explored to keep pace with demand. These jobs can lead to advances in equipment, technology, and materials that may facilitate sustainable and rapid growth in the solar industry.

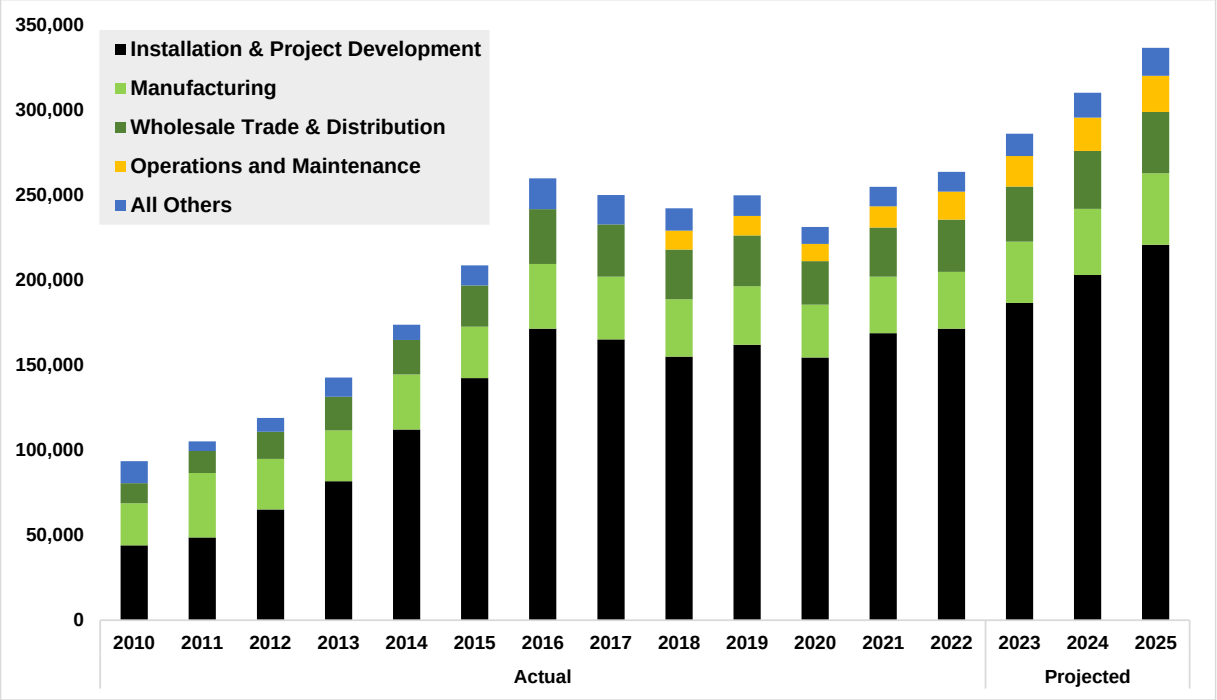
Establishing more domestic manufacturing jobs in the solar sector could also boost national support for clean energy technologies and bolster the clean energy transition. If people are employed by an industry, they may be more likely to support policies related to furthering that industry (e.g., renewable portfolio standards, emissions reduction goals). US jobs created in the solar industry, particularly manufacturing jobs, can counter the often cited argument against transitioning to green energy—that closing fossil fuel plants will eliminate jobs.

While solar manufacturing jobs are increasing, they are increasing at a slower pace than installation jobs in the sector, which creates a false sense of vibrancy. Figure 4 shows that more than 260,000 people were employed in the US solar industry at the end of 2022, but almost two-thirds were employed in the installation and development segment and less than 13% in the manufacturing stage. Between 2010 and 2023, US solar manufacturing jobs grew at an average rate of 2.9% each year, whereas solar installation jobs grew at an average rate of 11.8% each year. Similarly, since President Biden assumed office, solar

manufacturing announcements have totaled 79 projects in 23 states, with nearly 26,000 announced jobs, but the announcements are concentrated in module assembly, which is the least capital-intensive step in making solar modules.

A robust US solar sector would support significant job opportunities across the country. According to a study by Dartmouth University, Princeton University, and the Blue Green Alliance, if all US developers sourced 55% of their manufactured solar goods domestically, the solar manufacturing industry would support 900,000 jobs by 2035. While solar manufacturing jobs are increasing, they are increasing at a slower pace than installation jobs in the sector, which creates a false sense of vibrancy. Clean energy manufacturing jobs are essential to securing a holistic domestic solar supply chain to fuel the energy transition, meaning the US must ensure it facilitates continued and aggressive growth in the solar manufacturing industry.

Figure 4 Cumulative US Solar Workforce by Sector: Historical 2010-2022, Forecast 2023-2025



Note: Prior to 2018, operations and maintenance jobs were included in the "All Others" category.

(Source: Guidehouse Insights; data from Interstate Renewable Energy Council National Solar Jobs Census 2022)

US-Made Solar Materials and Components Are Produced While Adhering to Stricter Environmental and Labor Standards

Onshoring the production of polysilicon, wafers, cells, and modules allows the US to better regulate how the components are produced from end to end. Securing domestic ingot and wafer capabilities is essential to facilitating further investment in more downstream domestic capabilities like cells and modules. Without capabilities at each step in the manufacturing process, US-based cell and module manufacturers would still be subject to Chinese-owned polysilicon and wafer suppliers. Onshoring the solar supply chain means US regulatory agencies would have more control over the material sourcing and manufacturing process of the components themselves, which can result in higher quality and more ethical and environmentally sustainable production than seen overseas, where it can be difficult or impossible to confirm that ethical practices are being observed.

For instance, after the US passed the Uyghur Forced Labor Prevention Act (UFLPA) to prevent the use of goods sourced through forced labor in China, the Forced Labor Enforcement Task Force (FLETF) was charged with developing an enforcement strategy that first established a rebuttable presumption whereby entities are preemptively barred. It is then the responsibility of the importer to produce the proper evidence to refute that presumption about its goods. The UFLPA requires the FLETF to provide annual updates to its enforcement strategy, criteria for barring entities, and the list of barred entities.

In April 2023, after nearly a full year of enforcement, some members of the U.S. Congress argued that U.S. Customs and Border Protection (CBP) was stopping only a small portion of products that should be barred under the UFLPA and urged enforcement practices related to overseas labor be enhanced. The Congressional-Executive Commission on China issued a bipartisan letter with three recommendations related to improved enforcement. The first was a call for greater transparency in the review process and further explanation around why some goods that were stopped based on evidence of violations were cleared without additional reporting. The second was a request for the FLETF to speed up its efforts to expand the entity list and to update the congressional committee throughout the year. Third, the commission's letter asked CBP to detail how it will address challenges related to transshipped goods coming from third countries, including what types of tools and resources CBP will use and what additional resources it may need in the effort.

Because China controls the majority of manufacturing of certain products, such as polysilicon, it is difficult for US consumers of such products to thoroughly ensure their supply chain is free of forced labor. Further complicating the matter is the denial by the Chinese government that forced labor is occurring within its borders. The subsequent issuance of anti-boycott laws by the Chinese government puts Chinese manufacturers in the difficult, if not impossible, position of trying to comply with both US and Chinese law. These challenges will persist, even alongside enforcement improvements, until consumers have access to a domestic market of products that they can be certain upholds US labor and environmental standards.

Public and Private Sector Collaboration Is Needed to Facilitate US Solar Manufacturing Investment and Innovation

Increasing domestic manufacturing capacity, in any field, after it has largely moved overseas is a challenge. In the solar industry, it will require extensive collaboration between the government, investors, and technology companies. The current US solar manufacturing supply chain is fragile and heavily reliant on imported materials from China and Southeast Asian countries; however, the industry's outlook in the US is optimistic. The US has many of the building blocks in place for a strong domestic solar manufacturing supply chain but needs further investment and innovation from a variety of stakeholders to address the gaps.

Create and Enforce a Supportive Policy Environment Long-Term

Perhaps one of the largest drivers for increasing US solar manufacturing capacity is the creation and enforcement of a supportive policy environment. Policies may directly or indirectly affect the economics of domestically manufactured solar components. Among those policies with influence are tax credits tied to production volumes of solar components (e.g., Internal Revenue Service Code Section 45X) and incentives related to upfront CAPEX for the factories producing those components (e.g., Section 48C). These types of policies help offset the higher cost of manufacturing until domestic factories can scale up to become cost-effective.

Among the policies indirectly influencing economics are renewable energy tax credits for end customers and renewable portfolio standards established at the state level. These policies help create new end-customer and utility demand for solar PV systems, which further strengthens the case for increased investment in domestic manufacturing. A supportive policy environment can also address the economics of imported cells and modules directly. Federal trade policy and trade enforcement may increase the price of imported materials through tariffs or may establish domestic content and environmental and labor standards to qualify for incentives, which would help domestically sourced solar components compete on a level playing field with imported ones. In addition to addressing cost, policies like the UFLPA may also seek to ban imported goods that do not meet certain labor or environmental standards.

Domestic Content: Policymakers should set strong standards for domestic content requirements included in tax credits, federal procurement, and other solar incentives for end consumers. To qualify for a domestic content bonus, solar panels and all components used to assemble them must be truly domestic. This means that in addition to solar modules being assembled in the US, every material and core component used in the modules, including polysilicon, wafers, and cells, must be produced in the US. By requiring this, policymakers would be recognizing the manufacturers using domestically produced polysilicon and wafers for their investments in ramping up domestic manufacturing capabilities.

Procurement: Beyond instituting policies related to domestic solar manufacturing practices and economics, the US government could lead by example and require all solar power producers with which it has power purchase agreements to use solar panels with US-made components. In doing so, the government would not only be providing an incentive to solar developers to source domestically made parts but also safeguarding the security of its energy supply by avoiding the use of components coming from US geopolitical rivals.

Enforcement: Simply instituting policies aimed at increasing US solar manufacturing capacity is not enough on its own; effective enforcement methods should be continually updated throughout the lifetime of the policy. Policies requiring components be manufactured while meeting certain standards (e.g., environmental, labor) should have methods in place to track and verify the manufacturing processes used to produce the components that meet those standards. Tax credits designed to onshore the US manufacturing supply chain with solar manufacturing companies headquartered in the US or allied nations should have processes in place to prevent foreign entities influenced or controlled by US adversaries from claiming those credits. These companies will promote the technology transfer and manufacturing scale at all levels of the supply chain that the US needs to become a leader in solar energy. Furthermore, enforcement practices related to policies around domestic manufacturing should have provisions that set appropriate and high evidentiary standards that importers must meet. Enforcement practices should have guidelines that appropriately punish companies or individuals when they are found to be in violation of the enacted policies, to deter potential or repeated violations. Enforcement mechanisms for any policies supporting domestic manufacturing efforts should also be adjusted periodically to account for new information and other changing conditions that affect enforcement.

Stakeholder Input: To set regulations and enforcement methods that will have the greatest impact, policymakers should solicit input from a variety of stakeholders during the rulemaking process. In addition to US solar installers and developers, stakeholders should include US solar manufacturing companies and industry groups, consumer advocacy groups, and utilities. By including a range of stakeholders during this process, policymakers can ensure the regulations will help address a range of issues while still facilitating market growth. Getting appropriate stakeholder input can shift policymakers' mindset from deploying solar at any cost without regard to the origin of project components to doing so thoughtfully with intent to source components responsibly.

Vigorous Enforcement of US Trade Laws Is Crucial in the Context of Rampant Transshipment, Cross-Border Subsidies, and Duty Evasion

For almost a century, the US has employed antidumping and countervailing duty (AD/CVD) laws as the first line of defense against unscrupulous trade practices. These laws help level the playing field for US solar manufacturers that face competition from heavily subsidized and dumped imports. AD/CVD laws have been particularly important because China has heavily subsidized its solar industry and used its trade laws to block US imports to China. For example, in 2012, the U.S. Department of Commerce found that Chinese solar products were being dumped and duty rates up to 250% were necessary to offset this dumping. AD/CVD laws have also been used when solar products from China are diverted to third countries to avoid duties. In 2023, the Commerce Department found that five large solar producers in Southeast Asia were circumventing US AD/CVD regulations against Chinese companies.

In 2017, an investigation conducted by the U.S. International Trade Commission under Section 201 of the 1974 Trade Act determined that cheaper imports of solar cells and panels were hurting the US solar manufacturing market. In 2018, tariffs were placed on crystalline silicon cells and modules, which provided some relief for solar manufacturers. This modest relief, however, was eroded with the exemption of bifacial modules and certain developing countries in Southeast Asia from the tariff. More importantly, the Biden administration's decision to place a pause on AD/CVD enforcement resulted in a 96% increase in crystalline silicon PV (CSPV) solar modules in 2023, with 81% of those imports coming from countries circumventing duties. The outcome of exemptions to the Section 201 safeguard and the tariff moratorium

was an effective duty rate of 0.4% for solar modules in 2023, down from 9.6% in 2021. Duties must be effectively enforced, and actually collected, if they are going to work. Congress and the White House must work to close gaps in US AD/CVD enforcement efforts for solar.

Without effective trade policy, China's continued dominance in the solar manufacturing market will severely harm the US solar industry. Prices of Chinese-made solar modules have declined by approximately 50% year-over-year—dropping so far below the cost of production that Longi, the world's largest solar producer in China, recently asked the government of China to discourage below-cost production. Market distortion resulting from continued operations in China could drive away investment in US solar R&D, which would, in addition to preventing future growth of the silicon supply chain, inhibit the abilities of US producers to capture future thin-film or other advanced solar technology markets.

Policymakers must aggressively enforce the UFLPA

Despite the Biden administration's concerted efforts to enforce the UFLPA, challenges with the law and China's anti-enforcement laws have made enforcement difficult. According to CBP's own UFLPA enforcement statistics, about $1.1 billion worth of electronics was examined for UFLPA compliance in 2023, but only $200 million worth of those goods were denied. According to Census data, in 2023 the US imported about $14.6 billion in CSPV solar modules (HTS 8541430010) and $660 million in CSPV cells (HTS 8541420010). Even if it were assumed that all electronics examined and denied by CBP were CSPV solar products, that would mean just 1.3% of CSPV solar product imports were denied. According to the U.S. Department of Labor, nearly half of all global solar-grade polysilicon is produced in Xinjiang, China, meaning denials should be much higher than 1.3% of solar imports.

The Biden administration and Congress should enhance UFLPA enforcement to ensure that solar polysilicon supply chains are as traceable as possible and bad actors are held accountable. Currently, detainments are avoidable and may be viewed as the "cost of doing business." Increased UFLPA enforcement should include examining Tier 2 and 3 suppliers; further building out the entity list; preventing importers from reexporting goods multiple times prior to a detainment determination; requiring additional documentation for large, vertically integrated Chinese-owned solar producers; and exploring additional civil and monetary penalties for violations, in collaboration with the Department of Justice.

Promote Workforce and Facility Development

Finding enough qualified workers is critical to the US energy transition, and ramping up domestic solar manufacturing capacity is no exception. Relevant stakeholders like unions, community colleges and trade schools, utilities, developers, policymakers, and solar technology companies should look to enhance opportunities related to education and training for clean energy manufacturing jobs. Providing incentives and resources like on-the-job training, tuition assistance, flexible schedules, and knowledge centers can help potential workers gain the required skills. Some polysilicon wafer and cell manufacturing steps also have the advantage of sharing similarities with existing manufacturing processes in other industries, meaning there could be some skill overlap. Employees working in some sectors of the fossil fuel industry, for example, may already possess skills that can be translated into polysilicon, wafer, or cell manufacturing as well as module assembly. While these workers may have the relevant skills to succeed in the solar industry, they may be hesitant to relocate away from the communities where they have spent much of their lives. Siting new solar manufacturing facilities in states and communities that have historically relied on fossil fuel jobs could minimize the need for fossil fuel employees to relocate. Investing in workforce development by targeting existing manufacturing and fossil fuel sector workers in

addition to recent graduates can help prevent qualified worker shortages from forming and inhibiting the ability of US solar manufacturing companies to increase production.

Workforce development is not just related to personnel, however; the US also needs to invest in manufacturing equipment that allows US solar companies to manufacture all aspects of the solar cell and module supply chain. This means domestic facilities capable of producing solar-grade polysilicon and assembling solar modules are not sufficient on their own for the US to lead global production of solar technology. There must also be facilities with equipment that can produce ingots, wafers, and cells. If it is not possible to procure the necessary equipment for those facilities, additional research and investment to develop the technology within the US may be required. As demand for more US solar manufacturing capacity increases, so too does the need to invest in the necessary equipment required for solar cell manufacturing and module assembly.

Allow Sufficient Time to Build Out Manufacturing Infrastructure

Manufacturing facilities require time to scale up production such that they can become cost-effective. Each step in the solar manufacturing supply chain has a different threshold at which that effectiveness is achieved. This means it is essential that any policies and incentives put in place to encourage the growth of domestic solar manufacturing capacity must allow for a ramp-up period. This may mean enabling a slow phaseout of imported materials such that current and projected solar demand can be met while simultaneously increasing the manufacturing capacity at each step in the solar supply chain of domestic suppliers. Any such policies should also ensure there are safeguards in place to prevent imported materials from undermining the ability of US factories to expand and scale production (e.g., stockpiling).

Pursue Next-Generation Technologies in the Solar Supply Chain

Diversity in supply chains is essential to ensure industries can withstand disruptions and mitigate negative impacts stemming from changes to the status quo. This white paper is focused on outlining the benefits of onshoring more of the crystalline silicon solar supply chain. Within this supply chain are numerous next-generation technologies that could be investigated to help introduce technological diversity. New technologies could include different types of ingots and wafers, wafering techniques (such as kerfless wafering), or cell structures. The future of US solar technologies will also likely incorporate both CSPV products as well as thin-film products. Thin-film panels can not only be cheaper to produce but also offer the advantage of already being produced entirely within US borders; however, there is a tradeoff on efficiency compared with silicon PV panels. The coming transition is also spurring exploration by the domestic solar industry in developing innovative tandem technology, such as layering of thin-film products, like perovskites or cadmium telluride, on silicon substrates. These efforts would be pursued in parallel with the efforts to ramp up traditional crystalline silicon solar component manufacturing capacity in the US.

A notable recent example of supply chain disruption that was exacerbated by a lack of technological diversity came in 2021 when the auto industry faced significant manufacturing challenges because of a semiconductor chip shortage. The shortage caused automakers to drastically reduce production volumes and increase production times, which led to lost revenue. Some estimates place production volume losses at 12.5 million units globally between 2021 and 2022. While not as severe as in 2021/2022, automotive production losses directly related to the semiconductor shortage were still present into 2023.

Diversity can apply to not just the sources of materials but also the technology produced using those materials. Part of the reason the production issues in the auto industry persisted into 2023 was the high demand in the automotive industry for chips produced using the 90 nanometer (or larger) process, a mature process in the semiconductor manufacturing industry. Auto manufacturers had little incentive to investigate using chips produced with alternative node sizes, as that would have required additional research, design, development, and qualification, leading to increased costs. The automotive industry is not the only industry that needs semiconductor chips, meaning a semiconductor manufacturer may shift to focusing on smaller node sizes if the bulk of its sales are to an industry that requires those. That means automakers could encounter future supply chain disruptions if semiconductor manufacturers shift to focusing on smaller node sizes.

If care is not taken to further develop US solar manufacturing capabilities, the solar industry could find itself in a similar situation as the automotive industry experienced a few years ago, significantly inhibiting the country's ability to break its dependence on fossil fuels. Remaining entirely reliant on a single foreign entity for materials and components essential to facilitating the energy transition places the US in a precarious position. A strong domestic solar manufacturing supply chain that utilizes silicon, thin-film, and tandem technologies generates significant value for all stakeholders in the solar industry and ensures the nation can preserve its energy security, independence, and future.

Scope of Study

Guidehouse Insights has prepared this white paper, commissioned by the Solar Energy Manufacturers for America (SEMA) Coalition, to outline the benefits of onshoring US solar manufacturing in pursuit of improving its energy security and reaching the country's climate goals. It provides an overview of the current US silicon solar PV manufacturing supply chain and the competitive landscape of US suppliers compared with global suppliers. It then describes and quantifies some of the additional benefits that could arise from increasing US solar manufacturing capability. It closes by providing recommendations for stakeholders in both the public and private sectors to facilitate that transition.

Sources and Methodology

Guidehouse Insights' industry analysts use a variety of research sources in preparing research reports and white papers. The key component of Guidehouse Insights' analysis is primary research gained from phone and in-person interviews with industry leaders including executives, engineers, and marketing professionals. Analysts are diligent in ensuring that they speak with representatives from every part of the value chain, including but not limited to technology companies, utilities and other service providers, industry associations, government agencies, and the investment community.

Additional analysis includes secondary research conducted by Guidehouse Insights' analysts and its staff of research assistants. Where applicable, all secondary research sources are appropriately cited within this report.

These primary and secondary research sources, combined with the analyst's industry expertise, are synthesized into the qualitative and quantitative analysis presented in Guidehouse Insights' reports. Great care is taken in making sure that all analysis is well supported by facts, but where the facts are unknown and assumptions must be made, analysts document their assumptions and are prepared to explain their methodology, both within the body of a report and in direct conversations with clients.

Guidehouse Insights is a market research group whose goal is to present an objective, unbiased view of market opportunities within its coverage areas. Guidehouse Insights is not beholden to any special interests and is thus able to offer clear, actionable advice to help clients succeed in the industry, unfettered by technology hype, political agendas, or emotional factors that are inherent in cleantech markets.

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