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U.S. Solar Photovoltaic Manufacturing

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SUMMARY

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U.S. Solar Photovoltaic Manufacturing

Solar photovoltaic (PV) systems accounted for the highest proportion of new electric power generation capacity in the United States in 2021. Domestic solar power generation has increased over the past decade, enabled by technological advances, government support, state-level policies mandating use of electricity from renewable sources, and improved cost-competitiveness relative to electricity generation from fossil fuels.

Solar PV devices use semiconducting materials, mainly crystalline silicon (CS), to convert sunlight to electricity. The solar CS PV value chain comprises four primary stages of manufacturing, encompassing production of polysilicon, PV wafers, PV cells, and assembled panels. The majority of components needed for the panels that convert solar energy into electricity are sourced from outside the United States. For each major stage of CS PV manufacturing, Chinese companies operating throughout Asia own the majority of global production capacity. Production in the United States has declined due to import competition from Chinese manufacturers benefitting from various factors, including government support and economies of scale.

Domestic output in the first stage of the CS PV supply chain, the production of solar-grade polysilicon, declined by 40% between 2015 and 2018. This decline is largely attributed to antidumping and countervailing duties imposed by China on solar-grade polysilicon imports from the United States and several other countries since 2014. Nearly two-thirds of polysilicon production in China in 2020 came from plants in the Xinjiang region, where allegations of human rights abuses led the United States to place import restrictions in 2021.

In 2012, the United States imposed antidumping and countervailing duties on imports of Chinese-made CS PV cells and panels that contain them, following determinations that U.S. producers were injured or threatened with injury by the unfairly priced and subsidized imports. In 2015, the scope of duties on imports from China was expanded, and antidumping duties were imposed on imports of certain CS PV cells and panels from Taiwan. In March 2022, acting on a petition filed by domestic producers, the U.S. Department of Commerce initiated an investigation into whether Chinese companies are circumventing applicable duties by exporting to the United States through Malaysia, Vietnam, Thailand, and Cambodia.

In 2018, the United States imposed duties on imports of CS PV cells and panels from all countries with CS PV shipments to the United States exceeding 3% of total imports. These tariffs remain in place, although exemptions granted since 2018 have allowed certain volumes of CS PV cells and types of panels from countries other than China and Taiwan to enter tariff-free. These trade actions have not led to greater domestic CS PV cell production. Since 2021, all CS PV panel assembly in the United States has relied on imported cells. Domestic panel assembly supplies a relatively small proportion of domestic demand for solar panels. The domestic solar manufacturing industry employed around 31,000 workers in 2020, accounting for about 15% of total solar-industry employment. Approximately two-thirds of solar jobs are in installation and development, mainly involving residential-scale projects.

Solar power integration into domestic electric transmission and distribution systems is expected to continue, especially with scheduled retirements of coal-fired power plants and increased use of solar systems paired with battery storage. The pace of integration is sensitive to federal tax subsidies, import restrictions, prices of fossil fuels used in generation, and capital costs, among other factors that can impact the cost-competitiveness of solar power. Strategies for expanding domestic output of solar PV system components in a highly competitive global market include improving product performance, lowering costs of production through automation and manufacturing advancements, and developing solar panel recycling pathways. In addition, vertical integration or partnerships among domestic producers of various components may help to address supply chain issues. Performance improvements in solar systems can increase demand by lowering the cost of solar power relative to other types of electricity generation. Examples include recent industry shifts in cell designs and panel packaging, such as large cell sizes that increase the amount of sunlight captured, novel cell architectures that reduce electrical losses, and bifacial panel designs that allow sunlight to enter from both sides of a panel.

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Introduction

Solar photovoltaic (PV) systems now account for the highest proportion of new electric power generation capacity in the United States (**Figure 1**).[1] Domestic solar power generation has increased rapidly in recent years, enabled by technological advances, government support, state-level policies mandating use of electricity from renewable sources, and improved cost-competitiveness relative to generation from fossil fuels.[2]

One way to compare the cost competitiveness of various electricity sources is the levelized cost of energy (LCOE)—a metric that can include operations, maintenance, fuel, financing, tax incentives, and other costs in addition to hardware and installation.[3] Solar energy benefits in the calculation from having no fuel costs but is affected by variable sunlight and weather conditions.[4] According to the International Renewable Energy Agency, the global LCOE of utility-scale solar systems decreased 85% between 2010 and 2020.[5] In 2020, according to the investment bank Lazard, the LCOE of new utility-scale solar in the United States was lower than the cost of conventional sources, such as coal and combined cycle natural gas turbines.[6] The retirement of existing coal-fired power plants with relatively high operating costs has created additional opportunity for new solar capacity in the United States.[7]

Expanding solar generation requires sufficient manufacturing capacity, from the production of polysilicon, the raw material used to convert solar energy into electricity, to the fabrication of solar cells and assembly of panels.[8] Approximately three-quarters of the worldwide production of all inputs to PV systems currently occur in China. While PV panel assembly in the United States has increased since 2018 in the wake of increased U.S. import duties, many of the inputs into those panels are imported. A relatively small proportion of solar products sold in the United States is produced domestically.[9]

[1] In 2021, 23.5 gigawatts (GW) of solar capacity in were installed in the United States. This accounted for 46% of total new electricity generating capacity additions that year. Solar Energy Industries Association (SEIA) and Wood Mackenzie, *US Solar Market Insight 2021 Year in Review*, March 2022.

[2] U.S. Energy Information Administration (EIA), "Electricity Data Browser," at https://www.eia.gov/electricity/data/browser/; and SEIA, "Solar Data Cheat Sheet," December 14, 2021, at https://www.seia.org/research-resources/solar-data-cheat-sheet.

[3] The levelized cost of energy (LCOE) is a ratio of the total costs of a system during its lifetime over the sum of electricity produced. The LCOE typically is measured in dollars per kilowatt-hour (kWh) of electricity produced. Variations in LCOE estimates stem from variations in data sources, assumptions, and the scope of costs included.

[4] The amount of electricity produced in one year depends on how often a power plant is operating and is often represented in LCOE calculations as a capacity utilization factor.

[5] International Renewable Energy Agency (IRENA), *Renewable Power Generation Costs in 2020*, June 2021, p. 83.

[6] Lazard estimates the LCOE to be $30-$41 per megawatt (MW) for new crystalline silicon (CS) solar photovoltaic (PV) utility-scale solar installations, $65-$152 for coal, and $45-$74 for combined cycle gas turbines. These estimates do not consider any tax subsidies. See Lazard, *Levelized Cost Of Energy Analysis, Version 15.0*, October 28, 2021, at https://www.lazard.com/perspective/levelized-cost-of-energy-levelized-cost-of-storage-and-levelized-cost-of-hydrogen/.

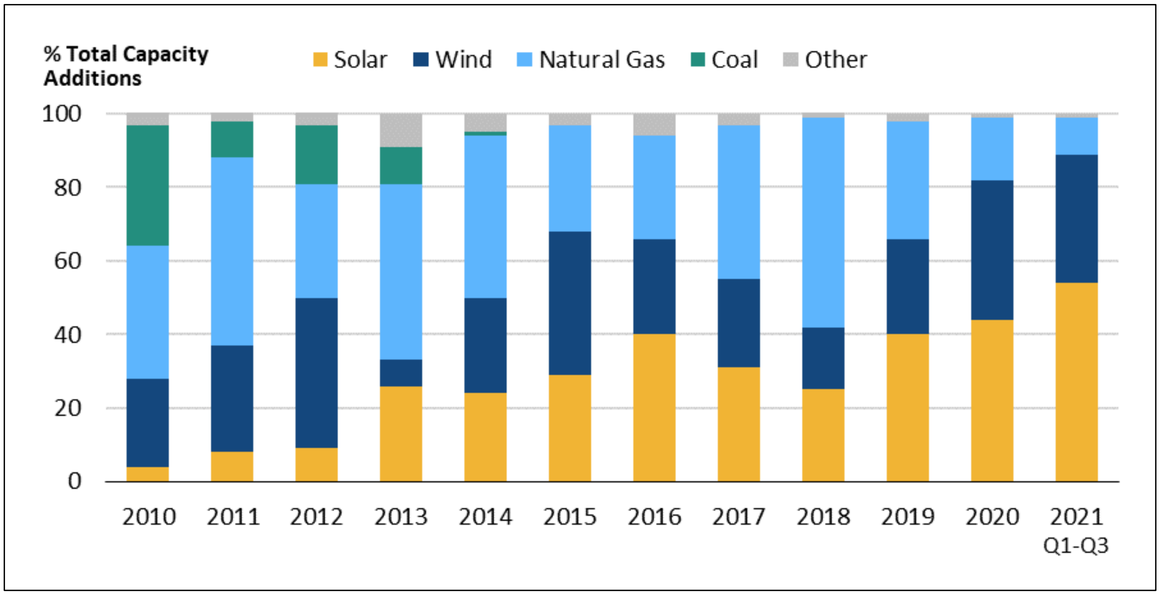
[7] International Renewable Energy Agency, *Renewable Power Generation Costs in 2020* (Abu Dhabi, 2021), p. 18.

[8] Brittany L. Smith and Robert Margolis, *Expanding the Photovoltaic Supply Chain in the United States: Opportunities and Challenges*, National Renewable Energy Laboratory (NREL), July 2019, p. 5. (Hereinafter Smith and Margolis, *Expanding the Photovoltaic*.)

[9] U.S. International Trade Commission (USITC), *Crystalline Silicon Photovoltaic Cells, Whether or Not Partially or Fully Assembled Into Other Products*, Investigation no. TA-201-75, December 2021, pp. 38-39, at https://www.usitc.gov/publications/other/pub5266.pdf. (Hereinafter USITC December 2021 report.)

This report looks at the domestic solar PV manufacturing industry and the downstream value chain for solar power installations. It considers whether market shifts, including new product architectures, improved packaging designs, integration of energy storage into solar systems, and recycling or reuse of components, may create new opportunities for manufacturing in the United States. It also evaluates the extent to which international trade policies enacted over the last decade have impacted each stage of the domestic solar manufacturing industry.

Figure 1. U.S. Electricity Generating Capacity Additions, by Energy Source



Source: Figure created by CRS using data from Solar Energy Industry Association and Wood Mackenzie.

Notes: Represents all new electric capacity added to the national grid.

The Basics of Solar Photovoltaic Systems

Light from the sun can be harnessed to generate electricity using two established technologies, photovoltaics and concentrated solar power. PV technologies use semiconducting materials to absorb sunlight and convert it directly into electricity for use nearby, storage, or for transmission and distribution systems. In concentrated solar power systems, mirrors and lenses focus the sun's rays to heat materials that can produce steam to operate turbines for electricity production. This report does not discuss concentrated solar power and other applications using energy from the sun to heat air or water directly.

The electricity production from any PV system depends on the technology employed and external factors affecting sunlight, such as geographical location, time of day, season, and weather.[10] Conversion efficiency—the percentage of sunlight that is converted into electricity—is one widely used measure to compare the performance of different solar PV technologies. From 2010 to 2020, average conversion efficiency increased from 14.7% to 20% but with variation depending on the specific technology employed.[11] The most efficient installations have

[10] For more information about the factors affecting renewable energy production, see CRS In Focus IF11257, *Variable Renewable Energy: An Introduction*, by Ashley J. Lawson.

[11] IRENA, *Renewable Power Generation Costs in 2020*, June 2021, p. 70.

conversion efficiencies of around 25%.[12] Higher panel efficiencies can reduce both hardware and installation costs by requiring fewer panels to provide a given amount of electricity.[13] Panel capacity ratings typically are presented in watts, the basic unit of power.[14]

Photovoltaic Systems

PV *cells*, usually 5-inch or 6-inch squares of semiconducting materials that convert sunlight into electricity, are the basic building blocks of PV systems. Typically, 60 or 72 cells are wired together and assembled into a rectangular *panel* 5 or 6 feet long and 3 feet wide, also referred to as a *module*. Panels are connected in an *array*, whose size depends on the maximum amount of electricity to be generated.

While several different semiconducting materials may be used in PV panels, crystalline silicon (CS) was used in over 95% of solar panels produced globally in 2020.[15] The remainder of panels were so-called thin-film panels, which typically are less effective at converting incoming sunlight into electricity.

A higher-quality variant of crystalline silicon, *mono*crystalline silicon (mono-CS), is produced using a comparatively expensive process to grow single crystal silicon. Mono-CS has gained market share in recent years and in 2020 was used in 82% of CS PV panels produced. Mono-CS cells convert 20% to 24% of incoming solar energy into electricity, whereas the conversion efficiency of less expensive *multi*crystalline silicon (multi-CS) cells is 18% to 20%.[16] Much new capacity added by silicon wafer manufacturers is to produce the mono-CS type.

Thin-Films

Thin-film panels accounted for 16% of solar deployed in the United States in 2020, a higher market share than global deployment at less than 5%.[17] Thin-film panels are comparatively simple to manufacture relative to CS PV panels, typically using a process in which glass sheets are topped with thin layers of semiconducting materials, such as cadmium telluride (CdTe), and then framed.[18] Although thin-film panels used to be significantly less costly to manufacture than CS PV panels, the declining price of polysilicon and the relatively lower 17%-18% conversion efficiency of thin-films have limited the market growth of these products.[19] The largest market

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[12] Gregory M. Wilson et al., "The 2020 photovoltaic technologies roadmap," *Journal of Physics D: Applied Physics*, vol. 53, no. 493001 (2020), p. 9.

[13] David Feldman et al., *U.S. Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020*, National Renewable Energy Laboratory (NREL), January 2021, p. 82, at https://www.nrel.gov/docs/fy21osti/77324.pdf.

[14] For data presented in watts (W), 1,000 watts = 1 kilowatt (kW); 1,000,000 (one million) watts = 1 megawatt (MW); and 1,000,000,000 (one billion) watts = 1 gigawatt (GW). Based on a typical panel capacity of 320 W, a 1 GW installation would require around 3.1 million solar panels.

[15] G. Masson and I. Kaizuka, *Trends in Photovoltaic Applications 2021*, International Energy Agency, p. 47, at https://iea-pvps.org/wp-content/uploads/2022/01/IEA-PVPS-Trends-report-2021-4.pdf. (Hereinafter Masson and Kaizuka, *Trends in Photovoltaic*.)

[16] Multicrystalline silicon may also be referred to as polycrystalline. Masson and Kaizuka, *Trends in Photovoltaic*, p. 47.

[17] David Feldman, Kevin Wu, Robert Margolis, *H1 2021: Solar Industry Update*, NREL, June 22, 2021, p. 26, at https://www.nrel.gov/docs/fy21osti/80427.pdf.

[18] Gregory M. Wilson et al., "The 2020 photovoltaic technologies roadmap," *Journal of Physics D: Applied Physics*, vol. 53, no. 493001 (2020), p. 11. (Hereinafter Wilson et al., "2020 photovoltaic.")

[19] Copper indium gallium diselenide (CIGS) is used to make a small proportion of thin-film cells, less than 1% in 2021. Michael Woodhouse et al., *Research and Development Priorities to Advance Solar Photovoltaic Lifecycle Costs and*

segment for thin-film PV installations is the utility sector. Some industry purchasers report that thin-film panels have limitations for residential rooftop applications due to their higher weight, lower output, and use of the hazardous material cadmium.[20]

Some thin-film PV solar panels use perovskites, materials with a specific type of cubic crystal structure, as the active layer to absorb sunlight and convert it directly to electricity. Perovskites can be made from organic and inorganic components and are capable of producing cell conversion efficiencies above 20%. Although costs of production can be low, commercialization of perovskite-based PV panels has not occurred. Challenges in scaling up production and achieving long-term product stability in real outdoor conditions are cited as barriers.[21] Tandem devices with both perovskites and crystalline silicon have demonstrated conversion efficiencies up to 28% in 2021. Such tandem devices may be manufactured more widely should the individual technologies reach their theoretical efficiency limits.[22] This report focuses on CS PV technologies that account for the majority of domestic solar generation.

Bifacial Panels

Traditionally, solar panels have been made to convert sunlight from one side in a monofacial design. More recently, the industry has increasingly shifted to bifacial panels, which can absorb sunlight from both sides and provide higher amounts of power per panel.[23] Bifacial panels use a transparent sheet on the backside to allow light reflected from the surroundings to enter and reportedly can be made on modified monofacial production lines at similar costs per watt of output.[24] Since 2018, global production of bifacial panels has increased from 4% to 51% of all panels (measured by capacity in kW) produced in 2020, according to an investigation by the U.S. International Trade Commission (USITC).[25] Bifacial panels are particularly attractive to the utility sector, as they achieve the lowest cost of energy when combined with a mounting system that adjusts them continuously to face the sun.

PV Manufacturing

Manufacturing CS PV panels has four principal steps: polysilicon refinement, wafer production, cell fabrication, and panel assembly (**Figure 2**).

Performance, NREL, October 2021, p. 12. (Hereinafter Woodhouse et al., *Research and Development*.)

[20] USITC December 2021 report, pp. I-86 and II-23.

[21] Wilson et al., "2020 photovoltaic," p. 18.

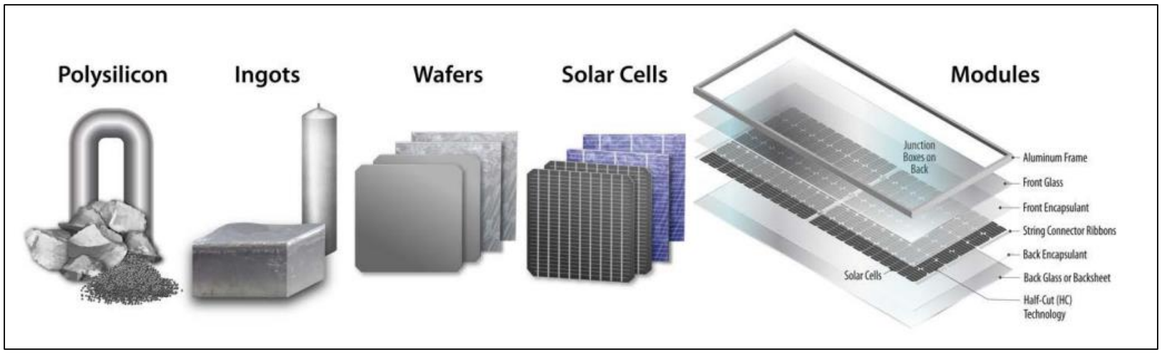
[22] Masson and Kaizuka, *Trends in Photovoltaic*, p. 8.

[23] Bifacial panels are assembled with cells that have high degrees of bifaciality, measured by the ratio of the amount of power generated by the backside versus the front. Popular cell architectures can vary in their degree of bifaciality. Woodhouse et al., *Research and Development*, p. 40.

[24] Woodhouse et al., *Research and Development*, p. 34.

[25] USITC December 2021 report, p. VI-113.

Figure 2. CS PV Panel Production Process



Source: National Renewable Energy Laboratory.

- **Polysilicon Refinement.** The feedstock for CS PV cells is polysilicon, refined from quartz. Such refining plants may cost up to $1 billion to build.[26] Over the last decade, manufacturers have reduced the amount of polysilicon required for each CS PV cell by over 50%.[27] This contributes to the cost-competitiveness of crystalline silicon solar cells versus thin-films, as polysilicon accounts for about one-fifth of the cost of a CS PV panel.[28] Reducing electricity consumption in polysilicon refinement is a key issue in the industry as a way to further reduce manufacturing costs.[29]
- **CS PV Wafer Production.** To produce solar wafers, chunks of polysilicon are melted together with small amounts of another element, known as a dopant, which can provide charges needed to produce electricity.[30] This mixture is crystallized into a cylindrical or rectangular shape called an ingot and sliced into wafers less than 1 millimeter thick. Over the past decade, wafer producers have reduced costs by improving wafer slicing methods and shifting to larger wafer sizes that provide more surface area to absorb sunlight and relatively higher power output.[31] Use of larger size wafers generally yields panels that are larger and heavier, and for U.S. residential applications, the weight of a panel designed for installation by a single worker usually is limited to 50 pounds. Given this practical restriction, some manufacturers seek greater power output by increasing

[26] Debra Sandor et al., "System Dynamics of Polysilicon for Solar Photovoltaics: A Framework for Investigating the Energy Security of Renewable Energy Supply Chains," *Sustainability*, vol. 10, no. 160 (January 11, 2018), p. 4.

[27] From 2010 to 2019, the average mass of polysilicon per watt of output capacity decreased from 6.8 to 3.2 grams per watt, largely due to better methods for wafer slicing leading to less material losses. See Masson and Kaizuka, *Trends in Photovoltaic*, p. 43.

[28] Bernreuter Research, "Why the spot price for polysilicon is going through the roof," press release, April 12, 2021, at https://www.bernreuter.com/newsroom/polysilicon-news/article/why-the-spot-price-for-polysilicon-is-going-through-the-roof/.

[29] Masson and Kaizuka, *Trends in Photovoltaic*, p. 44.

[30] Dopants used are boron or gallium for positive charges in p-type wafers and phosphorous for negative charges in n-type wafers. P-type CS wafers have the biggest market share, but the industry is shifting to n-type for increased efficiency due to lower electrical losses. Gregory M. Wilson et al., "2020 photovoltaic," p. 9.

[31] NREL reports two shifts in wafer sizes: to the M10 size (~182 mm^2) and G12 size (210 mm^2) in 2020 from the M0 type (156 mm^2) in 2010. Woodhouse et al., *Research and Development*, p. 13.

conversion efficiency and reducing downstream power losses rather than by using larger wafers.[32]

- **CS PV Cell Fabrication.** For solar cell fabrication, CS PV wafers must be partially infused, or doped, with another element to create two different layers of silicon, which together provide electrical activity in a device.[33] The resulting solar cells are typically treated to improve light absorption such as by increasing surface roughness and adding an antireflective layer. To transmit the electricity produced, a thin metallic grid is printed onto the cell primarily using copper and silver. The CS PV cell industry has shifted to cutting cells in half or smaller to reduce electrical losses, thereby increasing output. Half-cut cells were used in over 80% of global production in 2020.[34] Another avenue to increase cell efficiency is improving cell architectures by, for example, adding materials that can reduce electrical losses in the device and improve power output.[35]
- **Panel Assembly.** PV cells are wired together on a glass sheet to form a panel, which typically has 60 or 72 cells (120 or 144 half-cut cells). The assembly is covered on the front and backside with a plastic laminate, sheet of glass, or other material for protection from the environment. Panels typically are framed in aluminum and affixed with a junction box to distribute electricity. In many cases, the panel manufacturer does not produce cells but purchases them from an outside supplier. Panels can be connected in an array whose size depends on power needs; residential systems typically employ around 15-24 panels.[36] Advances in panel assembly include reducing the spacing between cells to increase output, reducing silver usage to lower costs, and varying laminate/backsheet materials to reduce degradation and improve efficiency.[37] Some producers integrate cells into conventional construction materials, such as roof shingles or glass ("solar roof"), to blend the solar PV cells into the roof's overall aesthetic.

PV systems have numerous components not used to generate electricity, including

- **Inverters.** Inverters convert the direct current produced by PV panels into the alternating current used by the U.S. electricity grid.[38] An installation can use

[32] Kelly Pickerel, "Big-wafer solar panels aren't quite ready for their residential debut," *Solar Power World*, August 31, 2020.

[33] Typically, one side is doped to provide positive charges (p-side) during wafer production and the other to provide negative charges (n-side) during cell fabrication. The critical part of a PV device is the interface between both layers, known as the p/n junction. When sunlight illuminates the cell, free electrons are generated around the interface, and if a wire is connected to the device, a flow of electricity is produced.

[34] Using half-cut cells provides lower currents, which lessen electrical power losses and accordingly provide higher cell efficiency and power output. USITC December 2021 report, pp. I-20 and I-61.

[35] Two recent architectures are PERC (Passive Emitter and Rear Contact) and TOPCon (Tunnel Oxide Passivating Contact), which include added layers at the back that can reflect light that did not generate electricity back inside the cell. From 2015 to 2020, PERC technology grew from 10% to 80% of market share and contributed to a 1% improvement in efficiency of CS PVs. Woodhouse et al., *Research and Development*, p. 11.

[36] Andrew Sendy, "How much does a 6kW solar power system cost and how much electricity does it produce?," *SolarReviews*, January 14, 2022, at https://www.solarreviews.com/blog/how-much-does-a-6kw-solar-power-system-cost-and-how-much-electricity-does-it-produce.

[37] Woodhouse et al., *Research and Development*, pp. 33-34.

[38] The power output rating of CS PV panels often is reported in direct current (DC), and electricity operations and sales in the United States are usually reported in alternating current (AC). The ratio of DC output from PV panels compared

microinverters attached to the back of each solar panel, or a larger-capacity inverter can receive all electricity produced by an array from the junction box. Microinverters typically are more expensive than larger-capacity inverters but can increase overall array output (thus warranting the higher upfront cost) in certain cases, such as a partially shaded array.[39]

- **Balance of System (BoS) Components.** Solar PV systems require mounting (racking) systems upon which sit the panels, other structural components, and electrical connections. Racking systems can be configured in a fixed position, or they can track the sun's movement along one or two axes (for example, east-west throughout the day or also north-south to follow the sun's movements throughout the year). Tracking configurations are most popular in large utility-scale systems and were used in 90% of capacity added in 2020 for this sector.[40] In 2020, BoS costs, excluding inverters, accounted for 20%-30% of the total cost of the average utility-scale PV system in the United States. Reducing the cost of these components—which usually are not produced by solar cell or panel manufacturers—thus may affect the overall cost of solar installations.[41]
- **Energy Storage.** Solar electricity generation is inherently dependent on the natural variabilities of weather and available sunlight. Energy storage systems, such as batteries, increasingly are being integrated with solar PV. Such "solar+storage" systems (sometimes called hybrid systems) can store energy during periods of maximum generation (typically mid-day) for use during other times of increased demand or when sunlight is not available.[42] As of December 2020, less than 2% of U.S. utility-scale solar capacity was integrated with battery storage. Declining prices of lithium-ion batteries, the most popular battery technology, likely will increase the number of integrated systems. The U.S. Energy Information Administration (EIA) anticipates that pairing new solar capacity with on-site storage will be a common trend over the next few years.[43]

The Upstream PV Value Chain and Trade Actions

China is the global leader in the production of polysilicon and PV wafers, cells, and panels, accounting for over 70% of worldwide output of each of these products in 2020 (**Figure 3**). The United States accounts for a relatively small share of global production at each stage.[44] The annual revenue of domestic PV manufacturers fell from $5.5 billion in 2010 to $1.5 billion in

with the AC output from the inverter is called the Inverter Loading Ratio. Typically, DC capacities of panels are up to 30% higher than AC capacities. Cara Marcy, "Solar plants typically install more panel capacity relative to their inverter capacity," *Today in Energy*, March 16, 2018, at https://www.eia.gov/todayinenergy/detail.php?id=35372#:~:text=For%20individual%20systems%2C%20inverter%20loading,the%20availability%20of%20the%20sun.

[39] Kerry Thoubboron, "Microinverters: what you need to know," *EnergySage*, August 10, 2021, at https://news.energysage.com/microinverters-overview/.

[40] Mark Bolinger et al., *Utility-Scale Solar, 2021 Edition*, Lawrence Berkeley National Laboratory, Electricity Markets & Policy, October 2021, p. 2. (Hereinafter Bolinger et al., *Utility-Scale Solar, 2021 Edition*.)

[41] David Feldman et al., *U.S. Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020*, NREL, January 2021, p. 101, at https://www.nrel.gov/docs/fy21osti/77324.pdf.

[42] See CRS Report R45980, *Electricity Storage: Applications, Issues, and Technologies*, by Richard J. Campbell.

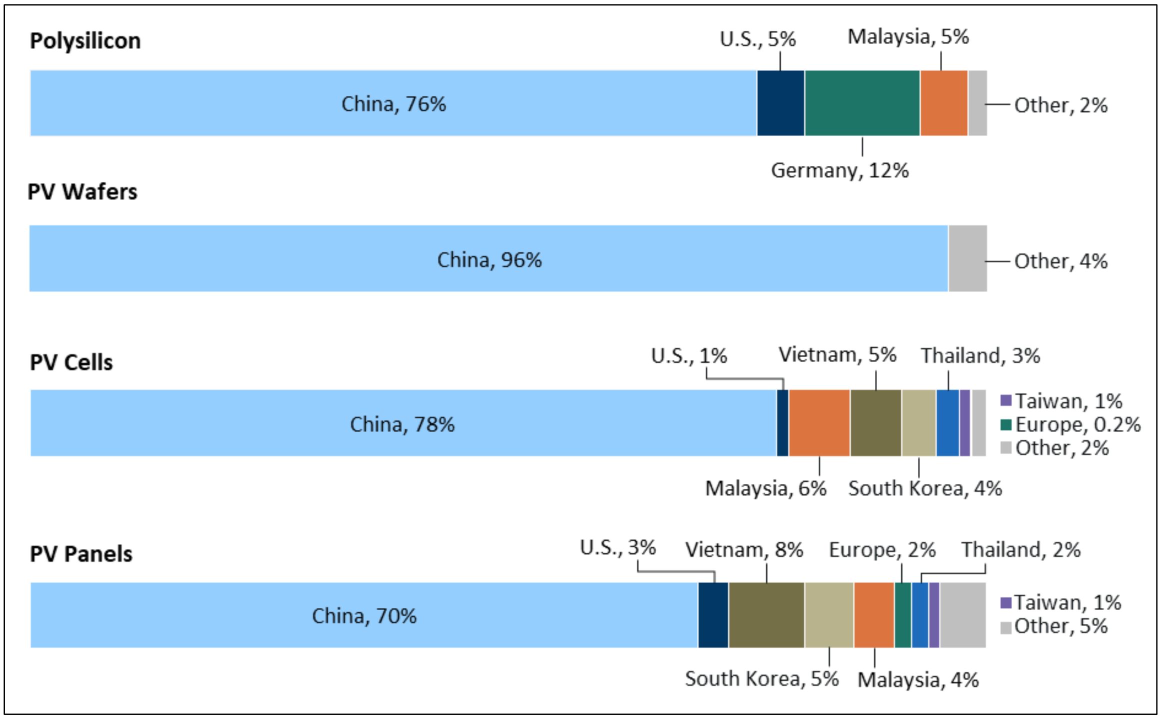
[43] EIA, *Battery Storage in The United States: An Update on Market Trends*, August 2021, pp. 29-30, at https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage_2021.pdf.

[44] Masson and Kaizuka, *Trends in Photovoltaic*, pp. 44-46.

2015 due primarily to import competition from Chinese companies operating throughout Asia. Domestic revenue increased to $3.0 billion in 2021 due to several factors, such as greater domestic demand and restrictions on imports.[45] Within China, government policies implemented over the last decade accelerated corporate consolidation of manufacturers at each stage of the value chain, which may have lowered costs through economies of scale.[46] The majority of manufacturing equipment needed for each stage of the CS PV supply chain also is produced in China.[47]

Figure 3. Upstream PV Value Chain

Share of Global Production by Geographic Area, 2020



Source: Figure created by CRS from Masson and Kaizuka, *Trends in Photovoltaic*, pp. 44-46.

According to one recent study, CS PV manufacturing costs declined an average 15% per year between 2010 and 2020, driven by manufacturing process standardization, increased automation, and more efficient production lines.[48] However, the cost of solar PV manufacturing remains higher in the United States than in China. A cost analysis conducted by the National Renewable Energy Laboratory (NREL) found that as of April 2021, each stage of production in the upstream CS PV value chain would cost 2-4 cents more per watt of capacity in the United States than

[45] Thomas Crompton, *Solar Panel Manufacturing in the US*, IBISWorld, July 2021, p. 11.

[46] For example, in 2013, China's Ministry of Industry and Information Technology required solar companies to meet standards for research and development spending and product performance. Jeffrey Ball et al., *The New Solar System: China's Evolving Solar Industry and its Implications for Competitive Solar Power in the United States and the World*, Stanford Steyer-Taylor Center for Energy Policy and Finance, March 2017, p. 138, at https://law.stanford.edu/wp-content/uploads/2017/03/2017-03-20-Stanford-China-Report.pdf.

[47] U.S. Department of Energy (DOE), *Solar Futures Study*, p. 170.

[48] One example is the development of larger furnaces that can manufacture more wafers per hour. See Wilson et al., "2020 photovoltaic," p. 7.

similar production in China, due primarily to higher U.S. labor costs and costs of importing input materials and components needed in manufacturing, which can be higher due to shipping and duty charges.[49] NREL estimates panels produced completely in the United States would cost 10 cents more per watt than those made in China, without considering tariffs. With tariffs in place on imports of CS PV panels, however, the cost differential in the U.S. market is reversed, such that the consumer cost of a fully U.S.-manufactured CS PV panel would be 2 cents lower per watt than the cost of a similar panel imported from China, NREL estimates.[50]

Polysilicon

The solar industry consumes over 90% of the global output of polysilicon.[51] While the United States and China produced similar shares of global polysilicon output in 2011,[52] production in China has expanded to 76% of global output in 2020, while U.S. production has declined to 5%.[53] New production capacity in China helped lower the global spot price of polysilicon from $20 per kilogram in 2013 to $7 per kilogram in mid-2020.[54] With this change in spot price, many polysilicon producers globally became unprofitable and exited the market or reduced capacity for solar-grade polysilicon; six companies in China accounted for the majority of global polysilicon production in 2020.[55]

In 2012, the Department of Commerce determined U.S. manufacturers had been injured by imports of Chinese solar products sold in the United States at less than fair value and that the products were subsidized by the Chinese government. The United States then imposed antidumping duties ranging from 18.32% to 249.96% and countervailing duties ranging from 14.78% to 15.97% on imports of Chinese CS PV cells and panels containing them, regardless of where the panels are assembled.[56] The Chinese government responded in 2014 by imposing antidumping duties of 53.3% to 57% on imports of solar-grade polysilicon from the United States, as well as on polysilicon from South Korea. China also imposed countervailing duties on solar-grade polysilicon from the United States and the European Union (EU), contending that several federal, state, and local government policies in the United States—such as the federal

[49] NREL estimates labor costs to account for 22% of total CS PV manufacturing costs in the United States compared with 8% in China. DOE, *Solar Photovoltaics*, February 24, 2022, p. 10, at https://www.energy.gov/sites/default/files/2022-02/Solar%20Energy%20Supply%20Chain%20Report%20-%20Final.pdf.

[50] The average price of a PV module imported into the United States before tariffs dropped from $0.39 per watt in 2018 to $0.28 per watt in 2020. David Feldman and Robert Margolis, *H2 2020: Solar Industry Update*, NREL, April 6, 2021, pp. 50-55, at https://www.nrel.gov/docs/fy21osti/79758.pdf.

[51] Masson and Kaizuka, *Trends in Photovoltaic*, p. 42.

[52] Ranmali De Silva, "PV production 2013: an all-Asian affair," *Bloomberg New Energy Finance*, April 16, 2014, p. 3.

[53] Masson and Kaizuka, *Trends in Photovoltaic*, p. 44.

[54] In 2006, China's five-year economic plan included a strategic focus on renewables. Given a global polysilicon supply constraint during this time, prioritization was given in cash grants, loan guarantees, free land, preferential tax rates, and electricity tariff rebates to enable Chinese companies to produce polysilicon and PV products. Dustin Mulvaney, "Breakthrough Technologies and Solar Trade Wars," in *Solar Power: Innovation, Sustainability, and Environmental Justice* (Oakland, CA: University of California Press, 2019).

[55] International Energy Agency, Photovoltaic Power Systems Program (PVPS), *National Survey Report of PV Power Applications in China 2020*, 2020, p. 22, at https://iea-pvps.org/wp-content/uploads/2021/09/NSR_China_2020.pdf.

[56] Tariff rates varied depending on the specific company, exporter, or producer, and most antidumping tariffs were set at 24.5%. Antidumping: Department of Commerce, "Crystalline Silicon Photovoltaic Cells, Whether or Not Assembled Into Modules, From the People's Republic of China: Amended Final Determination of Sales at Less Than Fair Value, and Antidumping Duty Order," 77 *Federal Register* 73018-73021, December 7, 2012. Countervailing: Department of Commerce, "Crystalline Silicon Photovoltaic Cells, Whether or Not Assembled Into Modules, From the People's Republic of China: Countervailing Duty Order," 77 *Federal Register* 73017, December 7, 2012.

Advanced Energy Manufacturing Tax Credit and local personal property tax exemptions—unfairly subsidize U.S. producers. The countervailing duties on U.S. producers ranged from 0% to 2.1%.[57]

As China was the largest market for polysilicon, U.S. polysilicon producers were adversely affected by these duties. U.S. production declined by 40% between 2015 and 2018.[58] In January 2020, the Chinese Ministry of Commerce extended the countervailing and antidumping duties on U.S. solar-grade polysilicon through 2025. The antidumping duties on polysilicon from South Korea also were extended.[59]

NREL estimates that as of February 2022, the United States had the capacity to produce 74,000 metric tons (MT) of polysilicon annually.[60] In comparison, China had 452,000 MT of capacity as of the end of 2020 and announced plans to add more than one million MT in 2022.[61]

The three companies with U.S. facilities to produce solar-grade polysilicon are U.S.-based Hemlock Semiconductor, REC Silicon of Norway, and Germany-based Wacker Chemie. All three are operating their U.S. polysilicon plants below capacity due to limited demand, as no substantial domestic manufacturing of CS PV wafers or cells exists. Hemlock Semiconductor did not complete an announced $1 billion investment to build a polysilicon plant in Tennessee in 2014; its remaining U.S. plant, in Michigan, produces polysilicon primarily for the semiconductor industry.[62] REC closed its Washington factory in May 2019 and established a joint venture with a Chinese company for production in China; South Korean CS PV cell and panel manufacturer Hanwha Solutions reportedly invested over $150 million dollars into REC Silicon in November 2021 to support the reopening of its Washington plant.[63] Wacker Chemie opened a $2.5 billion plant in Tennessee in 2016 and became the world's largest polysilicon producer through 2019, but the plant reportedly supplies the semiconductor industry.[64]

China is the global leader in polysilicon production, and nearly two-thirds of polysilicon production in China in 2020 came from plants in the Xinjiang region, where some producers have

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[57] World Trade Organization, "Semi-Annual Report Under Article 25.11 of the Agreement: China," January 1-June 30, 2014, Document no. 14-5113, September 15, 2014, at https://docs.wto.org/dol2fe/Pages/FE_Search/FE_S_S009-DP.aspx?language=E&CatalogueIdList=230956,230275,227578,135564,135369,130064,126962,122934,122280,120167&CurrentCatalogueIdIndex=6&FullTextHash=.

[58] Solar Energy Industries Association (SEIA)/Wood Mackenzie Power & Renewables, U.S. Solar Market Insight, 2018 Year in Review, Full Report, March 2019, pp. 58-59.

[59] See Global Trade Alert, "China: Extension of definitive antidumping duties on solar-grade polysilicon from the United States and the Republic of Korea," at https://www.globaltradealert.org/intervention/16490/anti-dumping/china-imposition-of-antidumping-duties-on-solar-grade-polysilicon-from-us-and-the-republic-of-korea. A Chinese Ministry of Commerce announcement (in Chinese) describing the extended countervailing duties is at http://www.mofcom.gov.cn/article/b/e/202001/20200102931616.shtml, and an announcement describing the extended antidumping duties is at http://www.mofcom.gov.cn/article/b/e/202001/20200102931610.shtml.

[60] Communication to CRS from NREL, February 10, 2022.

[61] Johannes Bernreuter, "New polysilicon entrants in China: Nothing learnt from the past," July 15, 2021, at https://www.bernreuter.com/newsroom/polysilicon-news/article/new-polysilicon-entrants-in-china-nothing-learnt-from-the-past/.

[62] Taylor DesOrmeau, "Hidden in the cornfields, Michigan has its own little Silicon Valley," *MLive*, April 6, 2021.

[63] Charles H. Featherstone, "REC Silicon leaders waiting to reopen in Moses Lake," *Columbia Basin Herald*, December 31, 2021, at https://columbiabasinherald.com/news/2021/dec/31/rec-silicon-leaders-waiting-reopen-moses-lake/.

[64] Johannes Bernreuter, "Polysilicon Manufacturers," April 27, 2022, at https://www.bernreuter.com/polysilicon/manufacturers/.

come under scrutiny for alleged use of forced labor.[65] Under P.L. 117-78, enacted in December 2021, all products mined or manufactured in China's Xinjiang Uyghur Autonomous Region are presumed to be produced using forced labor and therefore banned from U.S. entry unless proven otherwise.[66] The act identifies polysilicon as a high-priority sector for enforcement. To support the solar manufacturing industry in navigating the new policy, the Solar Energy Industries Association has published a Solar Supply Chain Traceability Protocol that firms may use to standardize procedures for tracing inputs and auditing supply chain sources.[67]

CS PV Wafers

In 2019, 96% of global wafer production occurred in China, with the two largest companies, Longi and Zhonghuan, accounting for nearly two-thirds of total global output.[68] Companies that formerly made CS PV ingots and wafers in the United States—including SunEdison, SolarWorld, and Panasonic—ceased production between 2013 and 2017.[69] According to the Department of Energy (DOE), the only capacity for wafer production in the United States as of February 2022 was a 20 MW plant in Massachusetts owned by Cubic PV.[70]

CS PV Cells

In 2020, 83% of global cell production occurred in China led by seven companies, many of which also assembled panels.[71] No CS PV cells have been produced in the United States since 2021.[72] South Korea has been the largest source of cell imports into the United States. Two South Korean manufacturers, LG and Hanwha Q Cells, import cells for use in their panel assembly factories in Alabama and Georgia, respectively. Malaysia and Vietnam also have become sources of imports (**Figure 4**).

[65] International Energy Agency, Photovoltaic Power Systems Program (PVPS), *National Survey Report of PV Power Applications in China 2020*, 2020, p. 23, at https://iea-pvps.org/wp-content/uploads/2021/09/NSR_China_2020.pdf.

[66] Effective June 21, 2022, under Section 307 of the Tariff Act of 1930, 19 U.S.C. §1307. For more information, see CRS In Focus IF10281, *China Primer: Uyghurs*, by Thomas Lum and Michael A. Weber.

[67] SEIA, *Solar Supply Chain Traceability Protocol 1.0*, April 2021, at https://www.seia.org/sites/default/files/2021-04/SEIA-Supply-Chain-Traceability-Protocol-v1.0-April2021.pdf.

[68] Masson and Kaizuka, *Trends in Photovoltaic*, p. 45.

[69] Smith and Margolis, *Expanding the Photovoltaic*, p. 6.

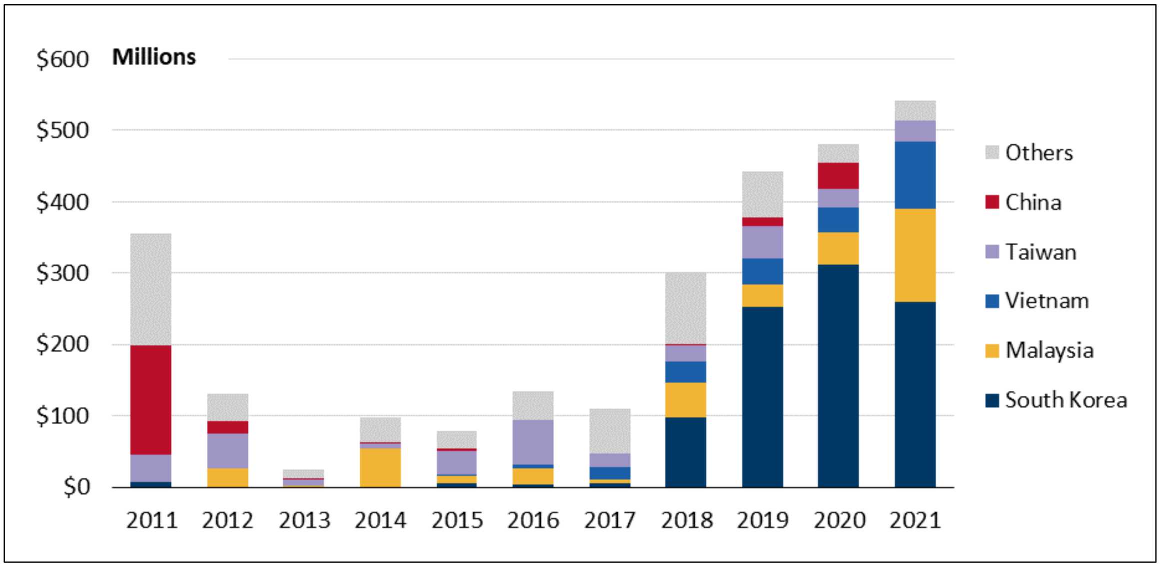
[70] DOE, Office of Energy Efficiency & Renewable Energy, Solar Energy Technologies Office, "Solar Manufacturing," at https://www.energy.gov/eere/solar/solar-manufacturing.

[71] International Energy Agency, PVPS, *National Survey Report of PV Power Applications in China 2020*, 2020, pp. 23-24, at https://iea-pvps.org/wp-content/uploads/2021/09/NSR_China_2020.pdf.

[72] David Feldman and Robert Margolis, *H2 2020: Solar Industry Update*, NREL, April 6, 2021, p. 43, at https://www.nrel.gov/docs/fy21osti/79758.pdf.

Figure 4. PV Cell Import Value

2011-2021, by Country



Source: Figure created by CRS using data from the U.S. Census Bureau.

Note: Based on Harmonized Tariff Schedule (HTS) codes 8541406030 and 8541406025.

Effective February 2015, the United States expanded the scope of duties on CS PV cells and panels from China[73] and added antidumping duties to cover imports of CS PV cells and panels from Taiwan after a U.S. Department of Commerce investigation determined that Chinese companies had shifted production there to avoid, or circumvent, the duties.[74] The duties on Chinese products have been extended through 2024;[75] duties on Taiwanese products have been extended through 2025.[76]

Table 1. Chronology of Trade Rulings Affecting Domestic CS PV Value Chain

Date	Products	Action
December 2012	Cells and Panels	U.S. Department of Commerce imposes antidumping and countervailing duties of 15%-250% on imports of all products with CS PV cells made in China (extended in March 2019 until next five-year review).
January 2014	Polysilicon	China imposes antidumping and antisubsidy duties exceeding 50% on U.S. solar-grade polysilicon (extended in January 2020 for five years).

[73] International Trade Administration, "Certain Crystalline Silicon Photovoltaic Products From the People's Republic of China: Antidumping Duty Order; and Amended Final Affirmative Countervailing Duty Determination and Countervailing Duty Order," 80 *Federal Register* 8592-8596, February 8, 2015.

[74] Department of Commerce, "Certain Crystalline Silicon Photovoltaic Products From Taiwan: Antidumping Duty Order," 80 *Federal Register* 8596-8597, February 18, 2015.

[75] Antidumping: Department of Commerce, "Crystalline Silicon Photovoltaic Cells, Whether or not Assembled Into Modules, From the People's Republic of China: Continuation of Antidumping Duty Order," 84 *Federal Register* 10300, March 20, 2019. Countervailing: Department of Commerce, "Crystalline Silicon Photovoltaic Cells, Whether or Not Assembled Into Modules, From the People's Republic of China: Continuation of Countervailing Duty Order," 84 *Federal Register* 10299, March 20, 2019.

[76] International Trade Administration, "Certain Crystalline Silicon Photovoltaic Products From China and Taiwan," 85 *Federal Register* 55319, September 4, 2020.

Date	Products	Action
February 2015	Cells and Panels	U.S. Department of Commerce imposes antidumping duties from 11% to 27% on CS PV cells and panels from Taiwan and extends 2012 tariffs on imports from China to include panels made in China, including panels with cells from other countries (extended in September 2020 until next five-year review).
February 2018	Cells and Panels	President Trump imposes tariffs on imports of CS PV cells exceeding a 2.5 GW annual quota and on solar panels from all countries with significant production. These "safeguard" tariffs, authorized under Section 201 of the Trade Act of 1974, were imposed after a finding by the United States International Trade Commission that increased imports were a substantial cause of serious injury to U.S. manufacturers. The duties started at 30%, decreasing five percentage points yearly for four years, and came on top of the antidumping and antisubsidy duties on imports from China and Taiwan.
June 2019	Bifacial Panels	U.S. Trade Representative excludes bifacial panels from 2018 Section 201 tariffs.
October 2019, April 2020	Bifacial Panels	U.S. Trade Representative attempts to withdraw the June 2019 exclusion of bifacial panels but is blocked twice by the U.S. Court of International Trade based on the agency's failure to meet procedural requirements.
October 2020	Bifacial Panels	President Trump revokes bifacial panel exclusion from Section 201 tariffs and increases the duties in effect from 15% to 18%.
November 2021	Cells and Panels	Department of Commerce rejects anonymous petition claiming certain companies have been circumventing tariffs on Chinese CS PV products by importing from Thailand, Malaysia, and Vietnam.
November 2021	Bifacial Panels	U.S. Court of International Trade reinstates the June 2019 exclusion of bifacial panels and the 15% Section 201 tariff rate.
February 2022	Cells and Panels	United States extends Section 201 tariffs on imports of CS solar cells exceeding a 5.0 GW annual quota (doubled from 2018 rate) and all CS PV panels of 14.75% for the first year, decreasing 0.25% each year for four years.
March 2022	Cells and Panels	U.S. Department of Commerce initiates countrywide inquiry to determine whether imports of CS PV cells and panels from Cambodia, Malaysia, Vietnam, and Thailand are circumventing antidumping and countervailing duties on China in response to a petition submitted by Auxin Solar.

Source: Compiled by CRS.

Note: CS PV = crystalline silicon photovoltaic; GW = gigawatt.

In 2018, the United States—acting under Section 201 of the Trade Act of 1974[77]—responded to an industry petition by imposing tariffs of 30% on imports of CS PV cells exceeding a 2.5 GW annual tariff-free quota and on all CS PV panels. For imports from China and Taiwan, the Section 201 tariffs were additional to antidumping and countervailing duties. That action followed a finding by the USITC that imports had risen so rapidly as to be a substantial cause of injury to U.S. manufacturers. These Section 201 tariffs, sometimes referred to as "safeguard" tariffs, were to decrease five percentage points annually through February 2022.[78] The tariff rates and scope of coverage have subsequently been adjusted several times.

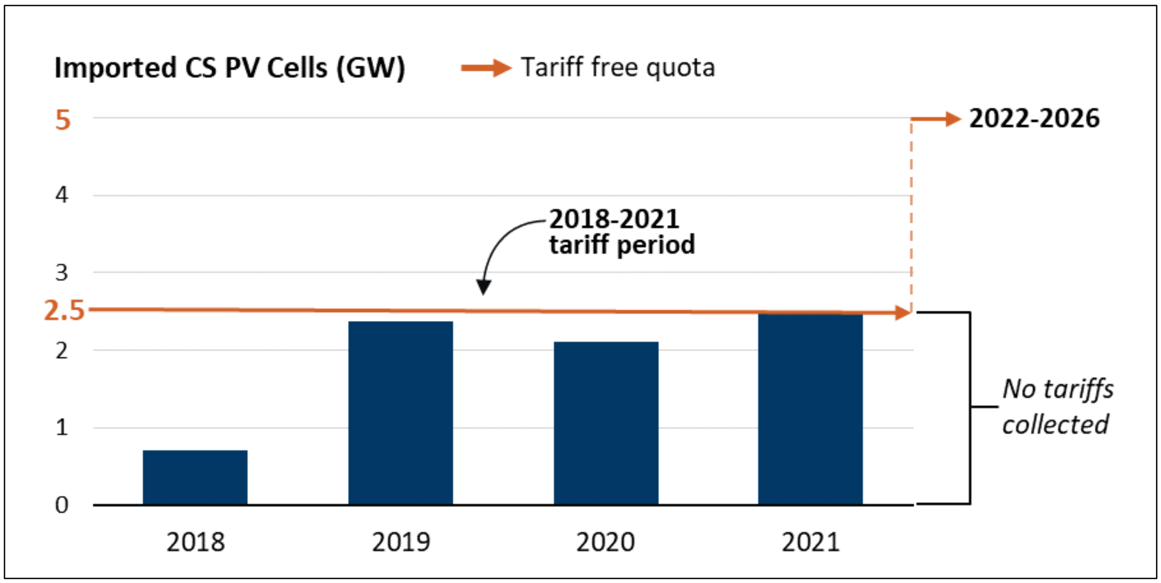
[77] 19 U.S.C. §2251.

[78] Executive Office of the President (Biden), "To Facilitate Positive Adjustment to Competition from Imports of Certain Crystalline Silicon Photovoltaic Cells (Whether or Not Partially or Fully Assembled Into Other Products) and

Since the Section 201 tariffs were imposed on CS PV cells and panels, almost all domestic CS PV cell production facilities have closed. Suniva, one of the two companies that petitioned for tariffs in 2018, has asserted it did not benefit from the tariffs because the 2.5 GW of cells exempted from tariffs each year allowed too many imports to enter the country duty-free.[79] The other petitioner, SolarWorld, sold its Oregon cell and panel factory in 2018; the current owner, Convalt Energy, shipped the equipment to New York State and announced plans to start 200 MW of panel assembly there by 2023.[80] A Canadian panel producer, Ubiquity Solar, has announced plans to produce 350 MW of CS PV cells in New York State in 2022.[81] Maxeon Solar, based in Singapore, has applied to DOE for a loan guarantee to finance a 3 GW CS PV cell and panel factory that would open by 2023.[82]

Figure 5. CS PV Cell Imports

Section 201 Tariff Period 2018-2021



Source: Figure created by CRS using data from U.S. Customs and Protection Commodity Status Reports.

Notes: Annual tariff period begins February 7 of each year, and tariff period 2018-2021 covers February 7, 2018, through February 6, 2022. The only period in which the 2.5 GW quota was surpassed and duties were collected was from December 30, 2021, to February 6, 2022.

On February 4, 2022, President Biden extended the Section 201 tariffs on CS PV cell and panel imports for another four years at a 14.75% rate and doubled the amount of CS PV cells exempt from tariffs to 5 GW annually.[83] This action did not follow a USITC recommendation to maintain

for Other Purposes," 83 *Federal Register* 3541, January 23, 2018.

79 USITC December 2021 report, pp. 27-28.

80 Anne Fischer, "Convalt Energy's plans for solar panel manufacturing plant in New York slowed, but not deterred," *PV Magazine*, February 7, 2022, at https://pv-magazine-usa.com/2022/02/07/convalt-plans-for-solar-panel-manufacturing-plant-in-new-york-hits-some-snags/.

81 Plamena Tisheva, "Ubiquity Solar to set up manufacturing operations in New York," *Renewables Now*, September 23, 2021, at https://renewablesnow.com/news/ubiquity-solar-to-set-up-manufacturing-operations-in-new-york-754977/.

82 USITC December 2021 report, p. I-25.

83 The tariff rate is to decrease 0.25 percentage points annually through 2026. Executive Office of the President (Biden), "To Continue Facilitating Positive Adjustment to Competition from Imports of Certain Crystalline Silicon Photovoltaic Cells (Whether or Not Partially or Fully Assembled into Other Products)," 87 *Federal Register* 7357,

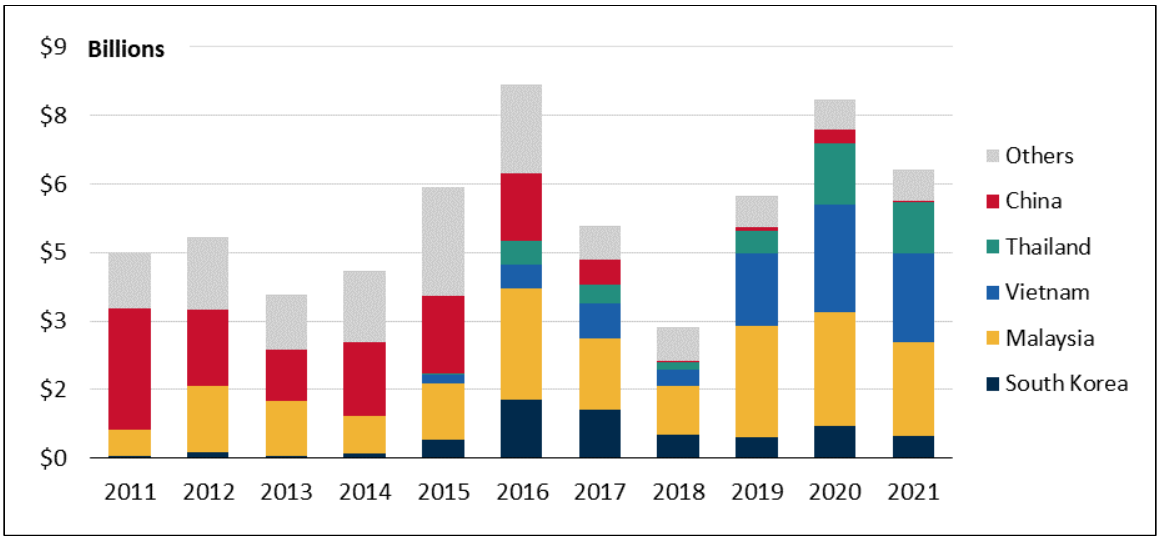
the duty-free quota at 2.5 GW. The USITC had asserted that this level would be sufficient to supply domestic producers of panels for the next two years and would provide an opportunity for domestic cell manufacturers to begin to benefit from the Section 201 measure. Since the tariffs took effect in February 2018, there has been only a single 39-day period in which cell imports exceeded the annual exemption of 2.5 GW and duties were applied (**Figure 5**).[84]

CS PV Panels

Since 2018, the start of the Section 201 tariffs, the volume of CS PV panel imports increased from about 5 GW in 2018 to 19 GW in 2020, led by imports from Malaysia, Vietnam, and Thailand (**Figure 6**). In 2020, domestic production accounted for about 10% of apparent U.S. consumption of CS PV panels, highlighting the inability of domestic production to satisfy U.S. demand.[85] CS PV panel imports from China declined after antidumping and countervailing duties were imposed in 2012. However, as many suppliers of inputs needed for panel assembly are located in China, BloombergNEF contends about two-thirds of a U.S.-installed CS PV panel's value in 2021, whether it is assembled in the United States or Southeast Asia, typically came from China.[86] All CS PV panels assembled in the United States use imported cells.

Figure 6. PV Panel Import Value

2011-2021, by Country



Source: Figure created by CRS using data from the U.S. Census Bureau.

Note: Panel data uses HTS codes 8541406015 and 8541406020 and 8541406035.

Seven CS PV panel plants closed between 2018 and 2021,[87] leaving thirteen U.S. factories operating as of February 2022 according to NREL.[88] The USITC asserted in December 2021 that

February 4, 2022.

[84] USITC December 2021 report, p. 53.

[85] In 2020, the United States imported 18.9 GW of CS PV panels and produced 2.1 GW domestically. USITC December 2021 report, pp. 22 and V-8.

[86] BloombergNEF, *Solar PV Trade and Manufacturing*, February 2021, p.23.

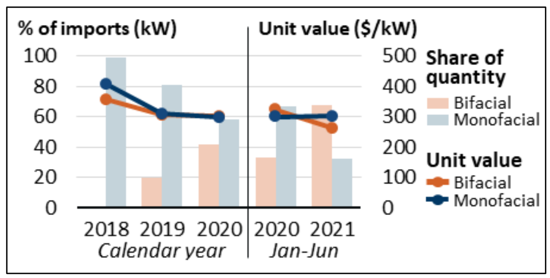
[87] USITC December 2021 report, pp. I-26-I-27.

[88] Communication to CRS from NREL, February 10, 2022.

the domestic CS PV manufacturing industry has made a positive adjustment to import competition during the Section 201 tariff period. According to the USITC, capacity tripled to 3.8 GW largely due to the opening of new panel manufacturing plants in early 2019 by Hanwha in Georgia, LG Electronics in Alabama, and Jinko Solar Industries in Florida.[89] LG Electronics announced in February 2022 that it would exit the solar panel business by June 2022, citing supply chain constraints.[90] Other manufacturers with CS PV panel assembly capacities over 100 MW as of February 2022 include Silfab (Washington), Mission Solar (Texas), Sunspark (California), Auxin Solar (California), and Heliene (Minnesota and Florida). As of February 2022, NREL estimated U.S. panel manufacturing capacity to exceed 4.5 GW of CS PV panels. NREL estimates an additional 2.5 GW of thin-film panel production capacity from U.S.-headquartered First Solar, which operates a plant in Ohio.

Domestic panel producers cite multiple factors for the relatively limited CS PV manufacturing growth since 2018, as compared to increased domestic demand over the same period. These cited factors include the exclusion of bifacial modules from duties at different times within the tariff period, stockpiling of imports, and circumvention by China.[91] During the last two years of the Section 201 tariff period, from 2020 to 2021, tariffs were applied to less than half of all CS PV panel imports due to various exemptions. Additionally, panels subjected to duties were typically less expensive than those produced domestically.[92]

Figure 7. Panel Imports by Type



Source: CRS using data from USITC industry survey in December 2021.

In June 2019, the U.S. Trade Representative exempted bifacial panels from the Section 201 tariffs.[93] Within four months, it sought to withdraw the exemption, stating that rapidly increasing imports of bifacial panels were undermining the objectives of the Section 201 measure.[94] The U.S. Court of International Trade blocked the withdrawal on procedural

[89] USITC December 2021 report, p. 20.

[90] LG, "LG to Exit Global Solar Panel Business," press release, February 23, 2022, at https://www.lg.com/us/press-release/lg-to-exit-global-solar-panel-business.

[91] World Trade Organization member developing countries with less than a 3% share of solar cell and panel imports to the United States are exempt from the Section 201 tariffs. Suniva and Auxin Solar claim imports from Cambodia, excluded from tariffs, have rapidly risen since 2019 due to Chinese companies using the country as an export platform. USITC December 2021 report, p. 27.

[92] According to U.S. Census Data for CS PV panel imports in 2021 (HTS codes 8541406015 and 8541406020), duties were paid on 47% of imports, 15% of imports were free (reported under "Free under HS Chapters 1-98," "Entered into the U.S. Virgin Islands," and "Free special duty program"), and 38% were "Dutiable- HS chapter 99, no duty reported" for reasons that are unclear (rate provision code 79). A comparison of the prices of imports and domestically produced products appears in USITC December 2021 report, pp. 38-39.

[93] Office of the United States Trade Representative, "Exclusion of Particular Products From the Solar Products Safeguard Measure," 84 *Federal Register* 27684-27685, June 13, 2019.

[94] Office of the U.S. Trade Representative, "Withdrawal of Bifacial Solar Panels Exclusion to the Solar Products Safeguard Measure," 84 *Federal Register* 54244, October 9, 2019; Office of the U.S. Trade Representative, "Withdrawal of Bifacial Solar Panels Exclusion to the Solar Products Safeguard Measure," 85 *Federal Register* 21497-21499, April 17, 2020. President Trump withdrew the exclusion by proclamation effective October 25, 2020; see 85 *Federal Register* 65639, October 9, 2019.

grounds.[95] With the exemption in place, the average selling price for imports of bifacial panels has been lower than those of monofacial panels.[96]

Imports of bifacial panels grew to account for over two thirds of total CS PV panel imports in the first half of 2021 (**Figure 7**).[97] Globally, production of bifacial panels has followed a similar trend, increasing to nearly two-thirds of all panel production in the first half of 2021, as bifacial designs offer greater output at competitive costs of production.[98] In December 2021, the USITC found this exclusion put "significant price pressures on U.S. module producers" and was an impediment to the domestic manufacturing industry's ability to compete.[99] President Biden's February 2022 proclamation extending the Section 201 tariffs on CS PV panel imports explicitly exempted bifacial panels.

In 2020, China accounted for about 70% of global PV panel production and contained the top five PV panel manufacturers globally.[100] In August 2021, an anonymous group purporting to include U.S. solar manufacturers requested that the U.S. Department of Commerce investigate whether a group of companies, mostly headquartered in China, were circumventing duties by sending nearly finished products from China to Thailand, Vietnam, and Malaysia for minor processing before shipping them to the United States. The department rejected the group's petition in November 2021, due largely to the petitioners' choice to remain anonymous and pursue companies rather than countries.[101] In February 2022, U.S.-based Auxin Solar filed a similar petition alleging Chinese circumvention through these three countries and Cambodia.[102] In response, the Department of Commerce initiated an inquiry on March 28, 2022, into whether CS PV cells and panels imported from Cambodia, Thailand, Malaysia, and Vietnam that use parts and components originating in China are circumventing duties on Chinese-made solar products.[103] In anticipation of the decision to initiate the inquiry, CS PV cell imports into the United States surged, with 1.6 GW of cells imported in a one-week period, as any eventual tariffs would be retroactively applied to the day the investigation commenced.[104] Uncertainty of future costs has led to the delay or cancellation of many domestic solar deployment projects according to a survey conducted by the Solar Energy Industries Association.[105] The department is to issue a final decision no later than 300 days, extendable by 65 days, after the inquiry was initiated.

[95] Invenergy Renewables LLC v. United States, U.S. Court of International Trade, Slip Op. 21-155.

[96] David Feldman and Robert Margolis, *Fall 2021 Solar Industry Update*, NREL, October 20, 2021, p. 51.

[97] USITC December 2021 report, p. V-12.

[98] Ibid., p. VI-113.

[99] Ibid., p. 29.

[100] The top five PV panel producers in 2020 were LONGi Green Energy Technology (27 GW), Jinko Solar (18 GW), Trina Solar (16 GW), JA Solar Technology (14 GW), and Canadian Solar (11 GW). Masson and Kaizuka, *Trends in Photovoltaic*, pp. 46-48.

[101] Letter from Abdelali Elouaradia, Director, Office IV, AD/CVD Operations, to American Solar Manufacturers Against Chinese Circumvention, c/o Wiley Rein LLP, November 10, 2021, at https://www.foley.com/-/media/files/insights/publications/2021/11/rejection-of-circ-case.pdf?la=en.

[102] Letter from Thomas M. Beline et al., Counsel to Auxin Solar, to The Honorable Gina M. Raimondo, Secretary of Commerce, February 8, 2022, at https://www.seia.org/sites/default/files/2022-02/Circumvention%20Petition%20Filed%202.8.22.pdf.

[103] International Trade Administration, "Crystalline Silicon Photovoltaic Cells, Whether or Not Assembled Into Modules, From the People's Republic of China: Initiation of Circumvention Inquiry on the Antidumping Duty and Countervailing Duty Orders," 87 *Federal Register* 19081, April 1, 2022.

[104] According to the commodity status report from U.S. Customs and Border Protection, the fill rate for the annual 5 GW tariff rate quota increased from 3.5% to 36% during the first week of March.

[105] Solar Energy Industries Association, *Impact of the Auxin Solar Tariff Petition*, April 26, 2022, at

Declines in the average price of PV panels have negatively affected the profit structure of companies that only assemble panels.[106] Domestic solar manufacturers have either specialized in differentiated products or integrated different stages of the PV value chain that would be relatively difficult to move offshore and increased their resilience to supply constraints. In the last decade, PV manufacturing equipment costs have declined by around 85%, which may enable domestic producers to better compete with the cost of imported products, particularly if shipping costs become a more important consideration.[107]

Shipping costs also are important considerations for PV panel glass production. China accounted for 86% of PV glass produced globally in 2019.[108] Since then, NSG Group opened a plant in Ohio to produce flat glass for thin-film producer First Solar, and Canadian Premium Sand announced it would pivot from architectural glass to patterned glass for PV modules, a product not currently manufactured in North America.[109]

Inverters and Balance of System

China accounted for about 67% of global PV inverter production in 2020,[110] and Chinese producers' rapid cost declines have led to many company exits and acquisitions globally.[111] According to NREL, the United States had nine PV inverter manufacturers as of February 2022.[112] Solar inverters made in China have faced U.S. tariffs since September 2018 under Section 301 of the Trade Act of 1974, which provides for U.S. sanctions on countries that violate trade agreements or engage in "unjustifiable" or "unreasonable" acts that burden U.S. commerce.[113] The current tariff rate is 25%. These tariffs are set to expire automatically after four years.

So-called "smart" inverters that use a communications network to respond to varying conditions are required by California and Hawaii for distributed solar systems connected to the electric grid. This requirement—under consideration in 12 other states—is intended to improve grid stability but may increase vulnerability to cyberattacks. NREL recently recommended implementation of certification standards for PV inverters to mitigate this risk.[114] New standards and concerns about the cybersecurity of imported inverters may favor domestic production.[115]

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https://www.seia.org/sites/default/files/2022-04/FINAL%20Auxin%20Impact%20Analysis%202022-04-26_0.pdf.

[106] G. Masson and I. Kaizuka, *Trends in Photovoltaic Applications 2020*, International Energy Agency, p. 44, at https://iea-pvps.org/wp-content/uploads/2020/11/IEA_PVPS_Trends_Report_2020-1.pdf.

[107] Smith and Margolis, *Expanding the Photovoltaic*, pp. 14-15.

[108] Anu Bhambhani, "471 New PV Glass Companies Registered In China In 2020," *Taiyang News*, May 21, 2021.

[109] National Glass Association, *The 2022 Forecast*, January 2022, p. 59, at https://www.glassmagazine.com/sites/gm/files/2022-01/DE_GM_JanFeb%202022.pdf.

[110] Masson and Kaizuka, *Trends in Photovoltaic*, p. 51.

[111] Kelsey Misbrener, "How one U.S.-based solar inverter manufacturer stays strong in a tough market," *Solar Power World*, October 9, 2019.

[112] Alencon (Pennsylvania), Chilicon (California), Cyboenergy (California), Morningstar (Pennsylvania), Outback Power (Washington), Sol-Ark (Texas), Ingetean (Wisconsin), TMEIC (Texas), and TMEIC (Illinois).

[113] Concerning Section 301, see CRS In Focus IF11346, *Section 301 of the Trade Act of 1974*, by Andres B. Schwarzenberg.

[114] William Hupp et al., *Cybersecurity Certification Recommendations for Interconnected Grid Edge Devices and Inverter Based Resources*, NREL, November 2021, p. 6, at https://www.nrel.gov/docs/fy22osti/80581.pdf.

[115] Smith and Margolis, *Expanding the Photovoltaic*, p. vii.

BoS components, including racking and mounting hardware for PV systems, are made primarily from steel for ground-mounted systems and aluminum for rooftop installations. Aluminum also is used in panel frames. NREL estimated in 2017 that costs of steel racking made up about 25% of utility-scale PV system costs, and that aluminum racking accounted for 13% of residential PV system costs.[116] The 25% duties on steel and 10% duties on aluminum imposed by the Trump Administration in 2018 have contributed to making racking systems more expensive. As of February 2022, eight companies were known to produce racking domestically, along with three producing tracking systems.[117]

Solar Equipment Recycling

Rapid shifts in solar product manufacturing, driven by efforts to reduce cost and improve efficiency, can lead to early system upgrades as existing systems become obsolete or less reliable due to new, undiscovered failure modes. For instance, in 2011, users reported that a low-cost backsheet material used for packaging panels was failing after 5-7 years, much sooner than anticipated.[118] Although typical warranties for PV systems have lengthened from a few years to 25 years or more over the last several decades, approximately 40% of cumulative solar capacity in 2019 was from systems installed for less than two years.[119] The International Renewable Energy Agency estimates that up to one million metric tons of PV panels could reach the end of their useful lives prior to 2030 in the United States alone.[120] While this creates concerns about waste management, it also offers opportunities to create recycling value chains.

BoS components in a PV system, made up of mostly steel, aluminum, and copper, have established scrap metal markets, while panels and inverters are classified as electronic waste with less robust recycling pathways. The material breakdown of a CS PV panel includes glass sheets, aluminum frames, polymer encapsulants, silicon from solar cells, copper wiring, and silver from electrical contacts. Materials recovered from PV panels might be usable in other industries, including potential applications in lithium-ion batteries, fiberglass, and paper production.[121] Revenue from PV recycling typically does not cover recycling costs, and recycling fees can vary widely.[122] PV repair and maintenance may support an alternative market for reuse. Wood Mackenzie estimates that operation and maintenance of nonresidential solar systems will generate $9 billion annually around the world by 2025, with a large share of that total going toward inverter repair or replacement, which have lifetimes around 10 years.[123]

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[116] Assuming CS PV module cost of $0.35/W as reported in 2017 and not including installation labor or other soft costs, such as permitting. Smith and Margolis, *Expanding the Photovoltaic*, p. 20.

[117] Communication to CRS from NREL, February 10, 2022.

[118] Woodhouse et al., p. 34.

[119] Stephanie Weckend, Andreas Wade, and Garvin Heath, *End-of-Life Management: Solar Photovoltaic Panels*, International Renewable Energy Agency and International Energy Agency Photovoltaic Power Systems, 2016, p. 34, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_IEAPVPS_End-of-Life_Solar_PV_Panels_2016.pdf.

[120] Taylor L. Curtis et al., *Solar Photovoltaic Module Recycling: A Survey of U.S. Policies and Initiatives*, NREL, March 2021, p. 1 (Hereinafter Curtis et al., *Solar Photovoltaic Module Recycling*.)

[121] DOE, *Solar Futures Study*, p. 187.

[122] Curtis et al., *Solar Photovoltaic Module Recycling*, p. 9.

[123] Wood Mackenzie, "Annual solar repairs and maintenance spend to grow to $9 billion by 2025," press release, June 22, 2020, at https://www.woodmac.com/press-releases/annual-solar-repairs-and-maintenance-spend-to-grow-to-$9-billion-by-2025/.

Laws or regulations that directly address PV recycling have been enacted in Washington, New Jersey, North Carolina, and California.[124] The Washington approach requires manufacturers to pay for the reuse or recycling of panels sold within or into the state after July 1, 2022, at no cost to owners, through a Photovoltaic Module Stewardship and Takeback Program.[125]

U.S. Solar Employment

As of 2020, solar manufacturing establishments in the United States reportedly employed approximately 31,500 workers, accounting for about 15% of total domestic solar-related employment.[126] According to the USITC, of these, approximately 2,500 were employed in the production of CS PV panels.[127] States with the largest manufacturing facilities, such as Ohio and Georgia, primarily rely on out-of-state solar demand. Smaller facilities tend to create corporate clusters in locations with relatively higher solar deployment, as in New York and California.[128] **Figure 8** shows locations of domestic PV component manufacturing as of 2021.

[124] Curtis et al., *Solar Photovoltaic Module Recycling*, p. 22.

[125] Wash. Rev. Code §70A.510.010

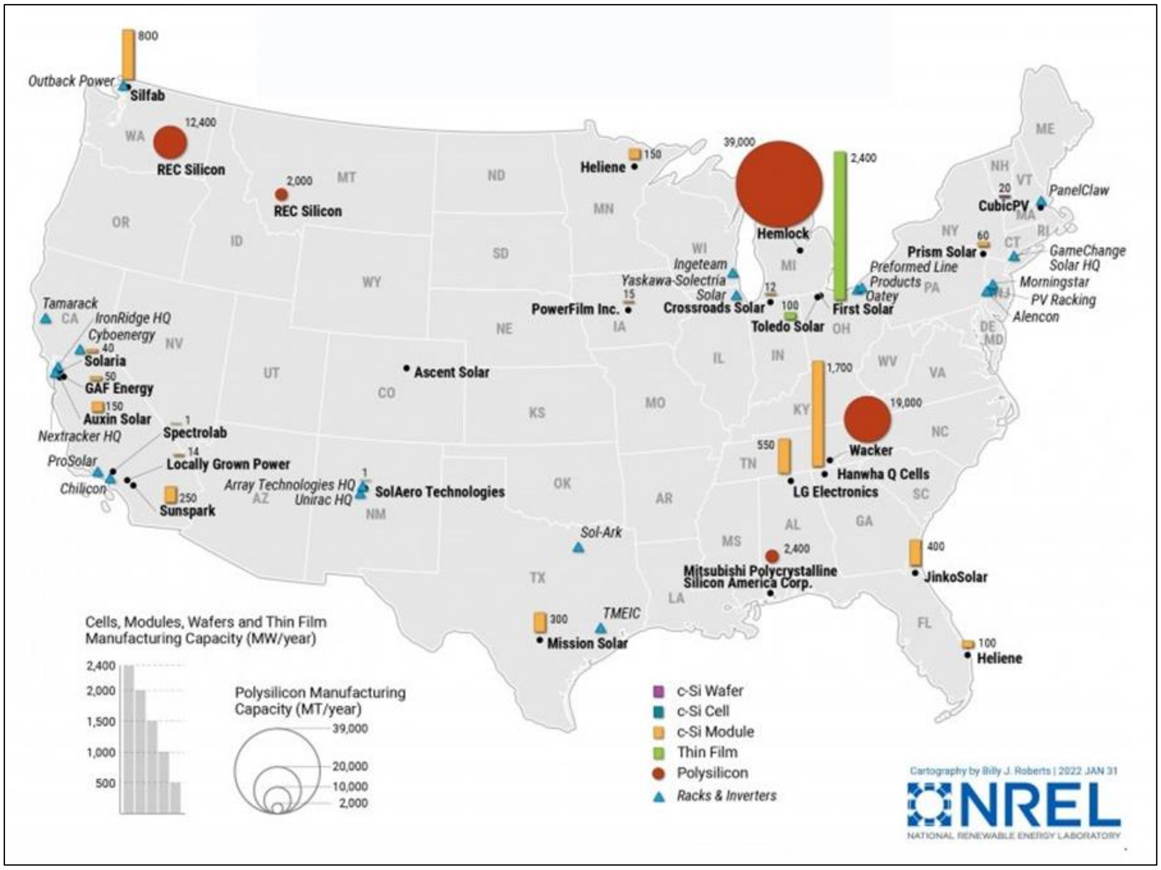
[126] Solar employment figures are taken from SEIA, Solar Foundation, and Interstate Renewable Energy Council, *National Solar Jobs Census 2020*, May 2021. (Hereinafter SEIA et al., *National Solar Jobs Census 2020*.) The Bureau of Labor Statistics does not collect solar employment data.

[127] USITC December 2021 report, p. 21.

[128] SEIA et al., *National Solar Jobs Census 2020*, p. 15.

Figure 8. Domestic PV Manufacturing

(January 2022)



Source: National Renewable Energy Laboratory.

Notes: Map includes all active manufacturing sites and shows nameplate annual capacity or potential annual output. Facilities may not have produced the amounts shown. No manufacturing capacity was located in Alaska and Hawaii as of January 2022.

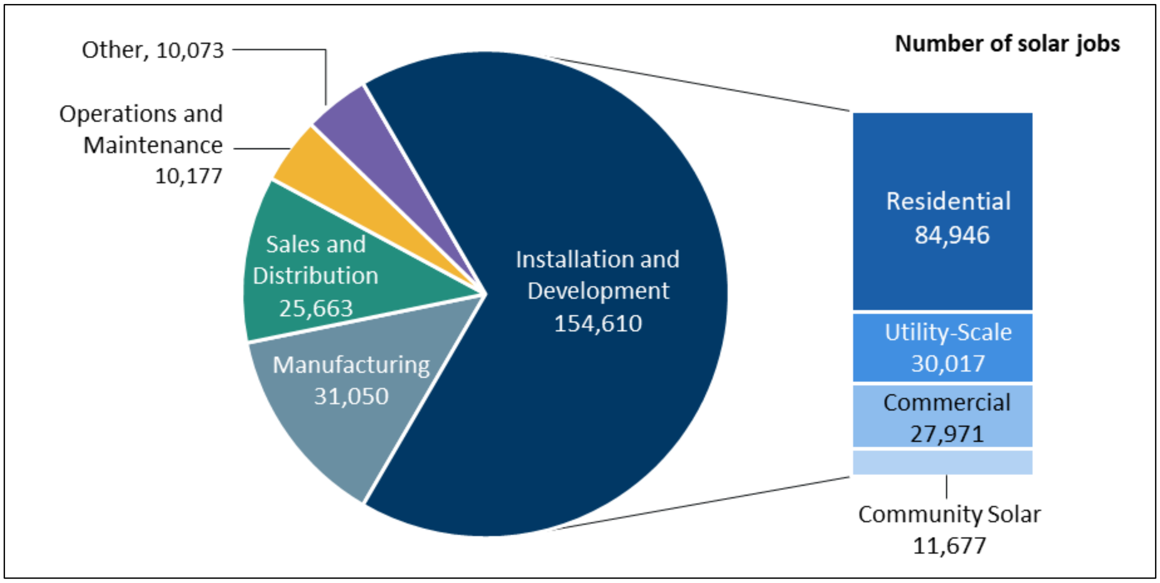
Beyond hardware manufacturing, solar systems require many other services, including site assessment, design, permitting, financing, installation, operations, and maintenance. In 2020, solar PV provided the largest share of jobs in the U.S. electric power generation sector, at 231,474 jobs,[129] despite accounting for about 3% of total generation.[130] Over two-thirds of the solar-related jobs counted in the 2020 survey were in installation and development (**Figure 9**), which has been a consistent pattern since 2015. Residential systems provided about 20% of total solar power generation in 2020. Over half of all installation employment was related to residential-scale projects, which tend to be much more labor intensive than utility-scale and commercial

[129] Solar employment figure of 231,474 pertains to individuals spending 50% or more of their labor hours on solar goods or services. SEIA et al., *National Solar Jobs Census 2020*, p. 8. Jobs for other sources of electric power in the United States from DOE, *2021 United States Energy Employment Report*, DOE/SP-0001, 2021.

[130] Estimation includes both small-scale and utility-scale solar PV systems. U.S. Energy Information Administration, *Electricity generation, capacity, and sales in the United States*, March 18, 2021, at https://www.eia.gov/energyexplained/electricity/electricity-in-the-us-generation-capacity-and-sales.php#:~:text=In%202020%2C%20net%20generation%20of,solar%20photovoltaic%20(PV)%20systems.

projects.[131] These installation and development jobs tend to be located in states that have higher levels of solar deployment. California, Texas, and Florida had the highest cumulative solar capacity installed as of 2021 and rank in the top four states for the greatest number of solar jobs along with New York.[132] Because most jobs are in installation and development, circumstances affecting demand for residential solar deployment can adversely affect total solar industry employment.

Figure 9. Solar Employment Breakdown by Sector 2020



Source: Figure created by CRS using data from Solar Energy Industries Association (SEIA), Solar Foundation, and Interstate Renewable Energy Council, *National Solar Jobs Census 2020*, May 2021.

Notes: Solar job figures shown here account for employment positions in which more than 50% of working hours are spent on solar-related work.

The Solar Power Market

Solar PV systems most often are connected to transmission and distribution networks that can move power over long distances and deliver it to consumers. Decentralized PV systems are solar panels used in residential or commercial settings that can route excess electricity not required in the building to the network and switch to import electricity when needed. Centralized PV systems are designed for utility applications in which a large array of solar panels generates electricity for transmission and distribution. Smaller electrical networks, often called "microgrids," can also be designed to operate in isolation in the event of power disturbances due to, for example, inclement weather. PV systems not connected to transmission and distribution networks generally produce comparatively small amounts of power for stand-alone uses and are typically paired with battery storage for such purposes as illuminating highway signs, powering compactors attached to trash

[131] DOE, *2021 United States Energy Employment Report*, DOE/SP-0001, 2021, p. 51.

[132] SEIA, "Top 10 Solar States," at https://www.seia.org/research-resources/top-10-solar-states-0; and SEIA et al., *National Solar Jobs Census 2020*, p. 14.

cans in public spaces, and powering electronics in remote areas where electrical network connection is unavailable.[133]

Four distinct segments comprise the market for PV systems:

- **Residential.** The residential sector accounts for 96% of the 3 million PV systems installed in the United States, and made up about 20% of cumulative installed solar PV capacity in 2021, according to SEIA and Wood Mackenzie.[134] The median size of a residential solar system was 6.5 kW in 2020.[135] A system of this size typically requires 15-24 solar panels, depending on panel efficiency and geographic location.[136]
- **Nonresidential.** The nonresidential sector (sometimes called Commercial and Industry, or C&I) includes commercial, industrial, and governmental entities utilizing solar power. Solar systems for this market typically have capacities from a few to hundreds of kW. In 2020, the median size of a nonresidential system was 42 kW. [137]
- **Community Solar.** Community solar systems, also called shared solar or solar gardens, are arrangements where individuals and businesses, typically in the hundreds, can subscribe to one large off-site solar system and receive energy credits on their electric bills. Customers either rent or own different amounts of the array and receive credit for their portion of electricity produced. Domestic community solar capacity is led by Minnesota, Florida, Massachusetts, and New York, although 21 states and Washington, DC, have policies enabling it. States may limit the size of community solar projects, and the median is about 1 megawatt (MW).[138] The market for community solar is potentially large, as over half of U.S. households are identified as not in a position to install rooftop systems.[139]
- **Utility.** Utilities either buy solar energy from independent producers or own and operate PV systems themselves, depending on state regulations.[140] Utility-scale PV installations typically range in size from a few MW to hundreds of MW. In 2020, 969 utility-scale PV installations totaled over 38,000 MW across 43 states,

[133] Christopher Anderson, David Feldman, and Lenny Tinker, *National Survey Report of PV Power Applications in United States of America*, DOE, Solar Energy Technologies Office, 2018.

[134] SEIA and Wood Mackenzie, *Solar Market Insight Report 2021 Q3*, September 14, 2021, at https://www.seia.org/research-resources/solar-market-insight-report-2021-q3; and SEIA, *Solar Industry Research Data*, https://www.seia.org/solar-industry-research-data.

[135] Barbose et al., *Tracking the Sun*, p. 11.

[136] Andrew Sendy, "How much does a 6kW solar power system cost and how much electricity does it produce?," *SolarReviews*, January 14, 2022, at https://www.solarreviews.com/blog/how-much-does-a-6kw-solar-power-system-cost-and-how-much-electricity-does-it-produce.

[137] Barbose et al., *Tracking the Sun*, p. 11.

[138] Jenny Heeter, Kaifeng Xu, and Gabriel Chan, *Sharing the Sun: Community Solar Deployment, Subscription, and Energy Burden Reduction*, July 2021, pp. 7, 15, at https://www.nrel.gov/docs/fy21osti/80246.pdf.

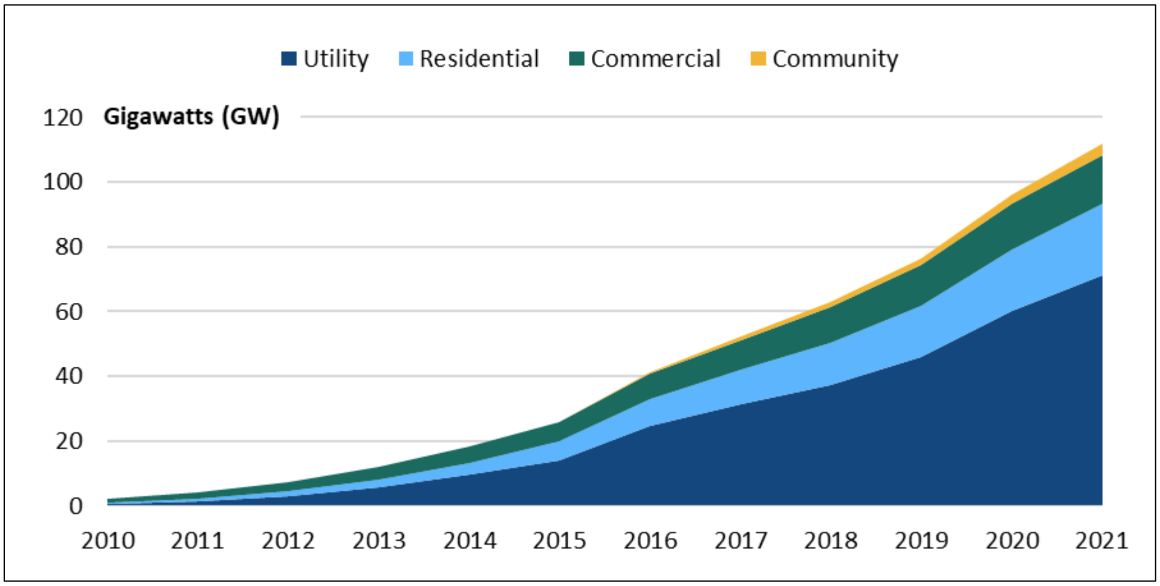
[139] Deloitte, *2022 Renewable Energy Industry Outlook*, at https://www2.deloitte.com/us/en/pages/energy-and-resources/articles/renewable-energy-outlook.html.

[140] Utilities may also be required to buy electricity from small solar projects pursuant to the Public Utility Regulatory Policies Act (PURPA; P.L. 95-617). For a discussion of PURPA and utility regulation, see CRS Report R44783, *The Federal Power Act (FPA) and Electricity Markets*, by Richard J. Campbell.

which accounted for 60% of all domestic PV capacity installed that year.[141] Systems of this size generally produce power at a lower cost per kilowatt hour (kWh) than smaller installations, as they benefit from economies of scale.[142]

Approximately two-thirds of total U.S. solar power capacity in 2021 (111 GW) was from large-scale PV systems in the utility segment (**Figure 10**).

Figure 10. Cumulative U.S. Solar Installations 2007-2021



Source: Figure created by CRS from SEIA and Wood Mackenzie, *US Solar Market Insight Q4 2021*, December 2021.

Solar Financing and Leasing

Where state law permits, solar systems may be owned by third-party financing and leasing firms rather than by the owners of the property on which they are installed. According to the Lawrence Berkeley National Laboratory, third-party ownership in the residential sector declined from about 60% in 2012 to 35% in 2020 as individual ownership increased with lower system costs and residential loan options for solar financing became more widely available. In nonresidential sectors, between 18% and 34% of PV systems are leased.[143]

Under the financing scheme of a power purchase agreement, an entity planning to install a CS PV system signs an agreement with a user of electricity or an electric utility to purchase the power at a predetermined rate. Independent wholesale producers that sell the power to customers under such agreements generate most solar power in the United States. The wholesale producer pays for the equipment, installation, and maintenance, allowing the customer to purchase solar electricity without a large capital investment at predetermined prices for terms that are usually 15-20

[141] Bolinger et al., *Utility-Scale Solar, 2021 Edition*, p. 2.

[142] Gavin Ross, *Solar Power in the US*, IBISWorld, Industry Report 22111E, September 2021, pp. 18-19.

[143] Barbose et al., *Tracking the Sun*, p. 17. As of 2021, 29 states, the District of Columbia, and Puerto Rico authorized third-party ownership of solar panels. North Carolina Clean Energy Technology Center, Database of State Incentives for Renewables & Efficiency (DSIRE), "3rd Party Solar PV Power Purchase Agreement (PPA)," March 2015, at https://ncsolarcen-prod.s3.amazonaws.com/wp-content/uploads/2021/12/DSIRE_3rd-Party-PPA_Aug_2021-2.pdf.

years.[144] As of August 2021, 29 states allow power purchase agreements for distributed solar.[145] Many utilities have turned to power purchase agreements with solar producers to meet state renewable portfolio standards.[146] Solar power purchase agreements cost less per kWh than wind power purchase agreements in most areas of the United States.[147] A similar instrument, a solar lease, enables non-utility customers (e.g., households) to pay a flat monthly fee for solar power.

Net energy metering allows residential and commercial utility customers that generate their own solar electricity on-site to receive financial credits for exporting excess electricity to the grid.[148] Virtual net metering is available for customers invested in a portion of an off-site solar system, as in community solar, to receive credits for their share of any net exports of electricity into the grid. Mandatory net metering policies for power from renewable sources have been established in 41 states, Washington, DC, and 4 U.S. territories. The rate of compensation for solar system owners varies and is under active debate in many states.

U.S. Government Support for Solar Manufacturing

Congress has enacted several measures that, among other activities, support domestic PV manufacturing as well as research and development of solar PV technologies. Among them are

- **American Recovery and Reinvestment Act of 2009 (ARRA).** ARRA included authorization of $2.3 billion in tax credits for qualified advanced energy projects. The Section 48C Advanced Manufacturing Tax Credit provided a 30% investment tax credit to clean energy manufacturing facilities, including solar manufacturers.[149] Many credits were not claimed, as many of the 183 awardees were not able to generate a taxable profit.[150]
- **U.S. Department of Energy Loan Guarantee Programs.** DOE's Loan Programs Office has up to $4.5 billion available for Renewable Energy & Efficient Energy Projects under the Title 17 Innovative Energy Loan Guarantee Program authorized by the Energy Policy Act of 2005.[151] Solar manufacturing equipment may be eligible for loan guarantees under this program.[152]
- **Infrastructure Investment and Jobs Act (IIJA).** The IIJA (P.L. 117-58), enacted in November 2021, appropriated funds for solar activities detailed in the Energy Act of 2020 (42 U.S.C. §16238 (b)(2-4)), including $40 million for solar

[144] SEIA, "Third Party Solar Financing," at https://www.seia.org/initiatives/third-party-solar-financing.

[145] North Carolina Clean Energy Technology Center, "3rd Party Solar PV Power Purchase Agreement (PPA)," October 2021, at https://ncsolarcen-prod.s3.amazonaws.com/wp-content/uploads/2021/08/DSIRE_3rd-Party-PPA_Aug_2021.pdf.

[146] Gavin Ross, *Solar Power in the US*, IBISWorld, Industry Report 22111E, September 2021, p. 19.

[147] Bolinger et al., *Utility-Scale Solar, 2021 Edition*, p. 7.

[148] For more information on net metering, see CRS Report R46010, *Net Metering: In Brief*, by Ashley J. Lawson.

[149] DOE, *Fact Sheet: 48C Manufacturing Tax Credits*, at https://www.energy.gov/sites/prod/files/FACT%20SHEET%20—%2048C%20MANUFACTURING%20TAX%20CREDITS.pdf.

[150] DOE, *Solar Photovoltaics*, February 24, 2022, p. 76, at https://www.energy.gov/sites/default/files/2022-02/Solar%20Energy%20Supply%20Chain%20Report%20-%20Final.pdf.

[151] DOE, Loan Programs Office, "Renewable Energy & Efficient Energy Projects Loan Guarantees," press release, at https://www.energy.gov/lpo/renewable-energy-efficient-energy-projects-loan-guarantees.

[152] For example, see Ambient Photonics, "Ambient Photonics Invited to Submit Part II Application for Proposed $162 Million From DOE's Title XVII Loan Guarantee Program," press release, December 21, 2021, at https://ambientphotonics.com/ambient-invited-to-phase-2-of-162m-doe-loan-program.

energy research and development, $20 million for an advanced solar manufacturing initiative, and $20 million for solar technology recycling development through 2025.

- **Department of Energy PV Research Funding.** The Solar Energy Technologies Office provides various funding opportunities for photovoltaics, as well as manufacturing and competitiveness. In 2021, DOE announced funding of $63 million for advancing thin-film-based PV performance and manufacturing for both CdTe and perovskite based devices. DOE also announced $7 million in funding for projects that aim to increase CS PV system lifetimes from 30 years to 50 years.[153]

Two bills pending in the 117th Congress seek to promote domestic manufacturing of solar equipment through production incentives. The Solar Energy Manufacturing for America Act, included in the Build Back Better Act (H.R. 5376) and passed in the House on November 19, 2021, would offer refundable manufacturing tax credits for many components in the PV value chain. Such tax credits would be 4 cents per watt for PV cells, $12 per square meter of PV wafers, $3 per kilogram of solar-grade polysilicon, and 7 cents per watt for thin-film and CS PV panels. The America COMPETES Act of 2022 (H.R. 4521), passed in the House on February 4, 2022, would authorize the Secretary of Commerce to establish a program to award grants and direct loans for constructing new solar manufacturing facilities or upgrading existing solar factories. The bill would authorize $600 million each year through 2026 for the program. Manufacturers of solar components, including polysilicon, wafers, cells, panels, inverters, racking, and trackers, would be eligible to apply for the grants and loans. The solar provisions were not included in the version of H.R. 4521 approved by the Senate on March 28, 2022.

Other policies may encourage greater efforts to generate solar power but not typically require or support domestic manufacturing of solar equipment. For example, federal policies that aim to support solar power generation include an investment tax credit for solar system costs, most recently extended in the Consolidated Appropriation Act, 2021 (P.L. 116-260).[154] Additionally, a mandate first established in the Public Utilities Regulatory Policies Act of 1978 (P.L. 95-617) requires that utilities purchase electricity from qualified energy producers, including those using renewable sources, when the cost of the electricity is equal to or lower than what the utilities would have paid to produce the electricity on their own. President Biden signed an executive order on December 8, 2021, directing the federal government to be carbon neutral by 2050 and setting a goal of 100% carbon pollution-free electricity by 2035, half of which is to be locally supplied clean energy.[155] These efforts aim to incentivize further adoption of renewable electricity sources, including solar power.

[153] DOE, "DOE Announces Goal to Cut Solar Costs by More than Half by 2030," press release, March 25, 2021, at https://www.energy.gov/articles/doe-announces-goal-cut-solar-costs-more-half-2030.

[154] For more information about federal tax incentives for solar energy, see CRS In Focus IF10479, *The Energy Credit or Energy Investment Tax Credit (ITC)*, by Molly F. Sherlock.

[155] "Executive Order on Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability," December 8, 2021, at https://www.whitehouse.gov/briefing-room/presidential-actions/2021/12/08/executive-order-on-catalyzing-clean-energy-industries-and-jobs-through-federal-sustainability/.

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