NREL Transforming ENERGY

Fall 2023 Solar Industry Update

David Feldman
Krysta Dummit, BGS Contractor for SETO
Jarett Zuboy
Brittany Smith
Dana Stright
Matthew Heine
Robert Margolis

October 26, 2023

Agenda

Executive Summary

Global Solar Deployment

- H1 2023 PV installations increased significantly (y/y) in China (153%) and Germany (102%), and to a lesser extent the United States (34%). Australian and Indian first PV installations in H1 2023 shrank modestly, y/y.

U.S. PV Deployment

- EIA projects the percentage of U.S. electric capacity additions from solar will grow from 45% in 2022 (17 GW_{ac}) to 56% in 2023 (31 GW_{ac}) and 62% (41 GW_{ac}) in 2024.
- The United States installed 11.2 GW_{ac} (11.8 GW_{dc}) of PV in H1 2023—its largest H1 ever—up 44% y/y.
- The United States installed approximately 7.7 GWh (2.5 GW_{ac}) of energy storage onto the electric grid in H1 2023, +32% (+8%) y/y, as a result of growth in all sectors.

PV System and Component Pricing

- U.S. PV system and PPA prices have been flat or increased over the past 2 years.
- Global polysilicon spot prices rose 35% from late June ($7.84/kg, below the weighted average production cost of $8.2/kg) to early October ($10.55/kg).
- Global module prices reached yet another record low, falling 21% between late June and early October to $0.14/$W_{dc}$.
- In Q3 2023 (first 2 months), the average U.S. module price ($0.33/$W_{dc}$) was down 11% q/q and down 23% y/y, but at a 98% premium over the global spot price for monofacial monocrystalline silicon modules.

Global Manufacturing

- According to Infolink (formerly PV Infolink), the top 10 module manufacturers were responsible for 160 GW (+57% y/y) in H1 2023 and the top 5 cell manufacturers together shipped 84 GW of cells (+49% y/y).
- Since the passage of the IRA, more than 240 GW of manufacturing capacity has been announced across the solar supply chain, representing more than 22,000 potential jobs and more than $12 billion in announced investments across 72 new facilities or expansions.
- In H1 2023, the U.S. shipped 3.1 GW of PV modules – an increase of 0.8 GW from H1 2022.

U.S. PV Imports

- The United States imported 25.1 GW_{dc} of PV modules in H1 2023, well over double imports from H1 2022.
- Most panels imported were exempt from Section 201 duties and were therefore likely bifacial. A significant number of thin-film modules were also imported.
- 1.5 GW_{dc} of cells were imported in H1 2023, up 28% y/y.
- The U.S. is not on pace to reach the 5-GW quota exemption limit for Section 201 tariffs.

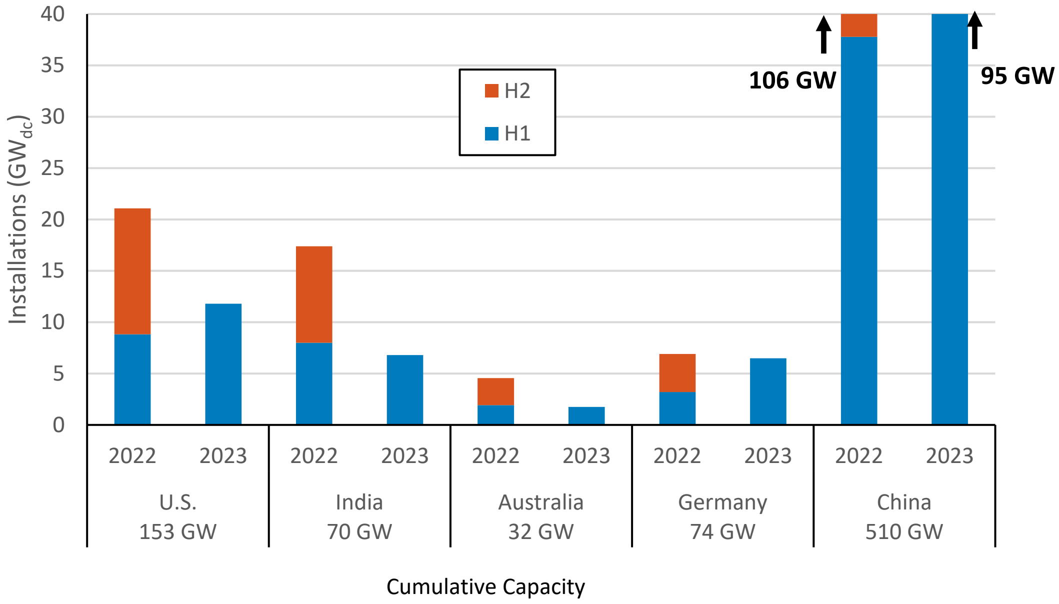
A list of acronyms and abbreviations is available at the end of the presentation.

Agenda

1. **Global Solar Deployment**
2. U.S. PV Deployment
3. PV System Pricing
4. Global Manufacturing
5. Component Pricing
6. U.S. PV Imports
7. PV Domestic Content

- **H1 2023 PV installations increased significantly (y/y) in China (153%) and Germany (102%), and to a lesser extent the United States (34%). Australian and Indian first PV installations in H1 2023 shrank modestly, y/y.**
- **BloombergNEF estimates 2023 installations in China to be around 200 GW, far exceeding last year's record of 106 GW.**

International H1 2023 Installations



- H1 2023 PV installations increased significantly (y/y) in China (153%) and Germany (102%), and to a lesser extent the United States (34%). Australian and Indian PV installations shrank modestly in H1 2023, y/y.
  – BloombergNEF estimates Chinese 2023 PV installations to be around 200 GW, far exceeding last year's record of 106 GW.*
  – JMK Research expects India to install 14–15 GW in 2023 (compared to 17–18 GW in 2022), and estimates the country had a solar pipeline of 47 GW at the end of June.
- At the end of June, these countries had cumulatively installed 839 GW_{dc} of PV.

*China reported 87 GW of PV installations in 2022 and 78 GW in the first half of 2023; however, these numbers reflect a combination of utility-scale projects reported in W_{ac} and distributed PV reported in W_{dc}. IEA estimated Chinese 2022 installations to be 106 GW. Chinese values here reflect the same 2022 ILR.

Sources: Australian Photovoltaic Institute. Mercom (07/31/23, 08/28/23). PV Magazine (06/13/23; 08/28/23); Wood Mackenzie/SEIA: U.S. Solar Market Insight: Q2 2023.

Concentrating Solar Power Update

- Chinese CSP company Cosin Solar currently has 100 MW of projects operational and another 900 MW under construction, making it the first company to supply 1 GW of tower projects.
- HeliosCSP interviewed an engineer who has been working on the 110-MW U.S. Crescent Dunes project—the first large-scale, high-storage CSP plant, which began operation in 2015.
  - Crescent Dunes is essentially recommissioning itself now, slowly bring the plant back online from several repairs. ACS, a multinational EPC firm, indirectly purchased the plant from the original owner, SolarReserve.
  - It is currently selling power to NV Energy, which was originally under a PPA with the contract until the project defaulted in 2019. They are selling electricity exclusively at night or when their storage tanks are full.
  - Reason for operational challenges: (1) The hot tanks were poorly designed the first time (for cost-cutting reasons) and poorly welded when they were replaced. (The welders were not used to working with those type of alloys, causing the tank to crack.) They've been installed now a third time. (2) One of the two superheaters sat with water in it and rusted; it has yet to come online.
  - These expenses are much less than the estimated $250M it would take to satisfy BLM requirements for removing the plant (SolarReserve initially estimated it would cost $7M).

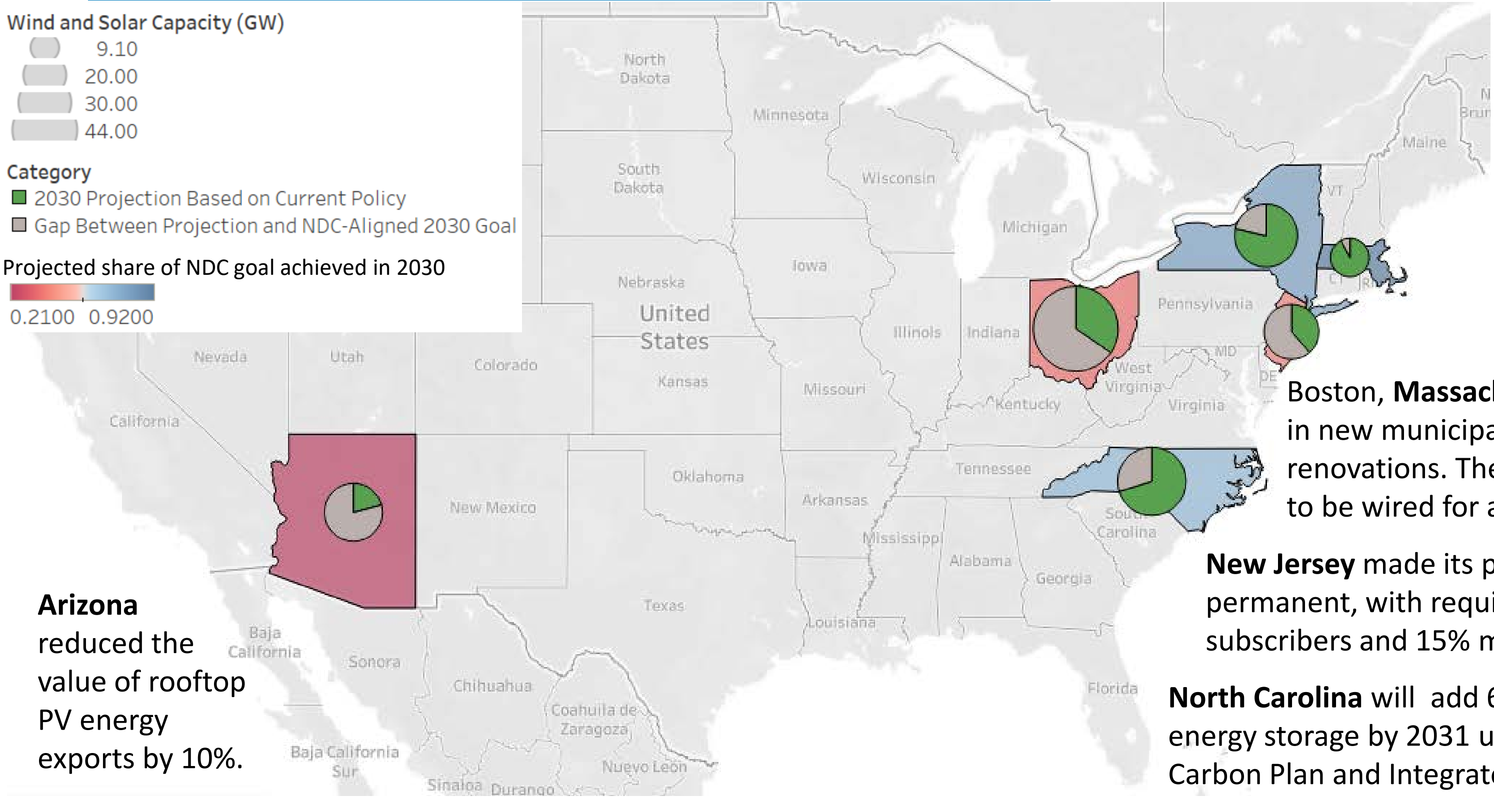
Agenda

1. Global Solar Deployment
2. **U.S. PV Deployment**
3. PV System Pricing
4. Global Manufacturing
5. Component Pricing
6. U.S. PV Imports
7. PV Domestic Content

- **EIA projects the percentage of U.S. electric capacity additions from solar will grow from 45% in 2022 (17 GW_{ac}) to 56% in 2023 (31 GW_{ac}) and 62% (41 GW_{ac}) in 2024.**
- **According to EIA data, the United States installed 11.2 GW_{ac} of PV in H1 2023—its largest H1 ever—up 44% y/y (SEIA reported 11.8 GW_{dc}).**
- **The United States installed approximately 7.7 GWh (2.5 GW_{ac}) of energy storage onto the electric grid in H1 2023, +32% (+8%) y/y, as a result of growth in all sectors.**

States: Q2 2023 Updates

Map shows progress toward installed wind + PV capacity by 2030 compatible with the U.S. Nationally Determined Contribution (NDC) under the Paris Agreement, as modeled by RMI. For example, if current policies are successful, MA will achieve 92% of an NDC-compatible 9-GW wind + PV target by 2030, while AZ will achieve only 21% of a 21-GW target. The gaps are mostly PV in AZ and NJ and a mix of PV and wind in NY, MA, NC, OH.



Ohio required PV installations >50 MW to meet rules related to noise, setbacks, and drilling safety.

New York increased low- and moderate-income (LMI) access to community solar via pre-development grants and technical assistance.

Boston, **Massachusetts** banned fossil fuel use in new municipal building construction and renovations. The city will require all buildings to be wired for all-electric use starting 2024.

New Jersey made its pilot community solar program permanent, with requirements including 51% LMI subscribers and 15% minimum bill savings.

North Carolina will add 6 GW of PV and 2.7 GW of energy storage by 2031 under Duke Energy's updated Carbon Plan and Integrated Resource Plan.

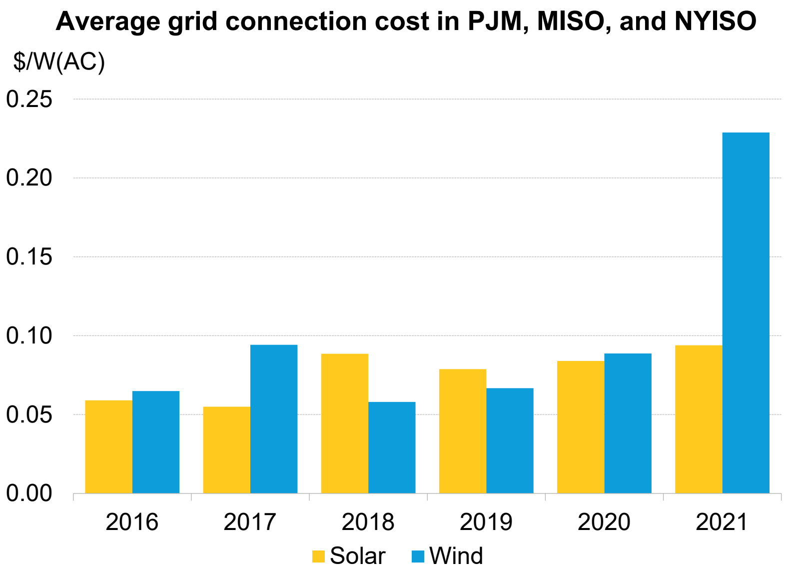
Arizona reduced the value of rooftop PV energy exports by 10%.

Sources: NJBPU (8/16/23); PV Magazine (8/7/23, 8/24/23, 8/28/23); PV Tech (8/18/23); RMI, State Climate Scorecards (2023); Utility Dive (8/8/23)

FERC Issues Order 2023

Background

- Bottlenecks in interconnection queues are holding up 1,700 GW of clean power in the United States (mostly solar and batteries).
- Interconnection approval times can take 3 years or more, on average.
- The cost of interconnection upgrades is increasing.
  - In 2017, more than one-third of systems in the Midwest incurred no upgrade costs, and by 2021 it had dropped to 11%.
- Solar projects in the U.S. pay on average $0.09/W, according to BloombergNEF analysis, or about 8%–10% of their total costs.



Source: BloombergNEF, "US Takes a Step to Clear Grid Backlog But a Leap Is Needed."

FERC Issues Order 2023

The new order includes several changes:

- Implements a first-ready, first-served cluster study process, in which project requests enter a “cluster window” and all receive the same priority, allowing for a group interconnection study rather than sequentially.
  - Cluster study costs imposed on a pro rata and per capita basis, and upgrade costs allocated to cluster on a “proportional impact method.”
  - BNEF stated that most grid operators already (or will soon) conduct joint grid connection studies, and it will not necessarily reduce the combined cost of grid interconnection.
- Implements enhanced financial commitments and withdrawal penalties to discourage withdrawals and requires demonstration of site control at the time of submission (or a deposit of $500k–$2M).
- Aims to increase the speed of the interconnection queue by removing the “reasonable efforts” standard governing transmission provider’s duty for timely completion of studies and places firm study deadlines and penalties for missing study deadlines ($1k per business day of delays to cluster studies / $2.5k for facilities studies).
- Allows interconnection process to have one interconnection point (and study) for co-located facilities.

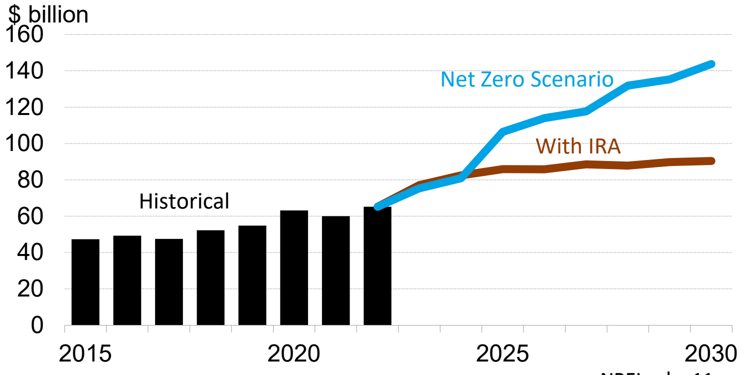
Source: JDSupra (08/11/23); The National Law Review (08/18/23)

FERC Issues Order 2023

Impact

- Once implemented, FERC rules will improve and harmonize existing grid interconnection best practices but do not represent disruptive, structural changes that may be necessary to install the levels of solar and wind necessary to decarbonize the grid by 2035. Such measures may include:
  - Reforms to the cost allocation of grid upgrades (e.g., in Texas, upgrades are borne by the consumer, not the project).
  - Allowing interconnections ahead of all grid upgrades.
  - A more proactive approach for grid planning that identifies areas with high wind and solar potential and preemptively builds out system capacity in those regions.
    - Many of the upgrades occur now as developers seek interconnection.
  - Permitting reform to significantly build out transmission assets. BNEF states that current process has deterred lots of projects that would help.
- After the order was issued, BNEF did not change its outlook on U.S. solar and wind deployment, as it already assumed some level of interconnection process improvements.

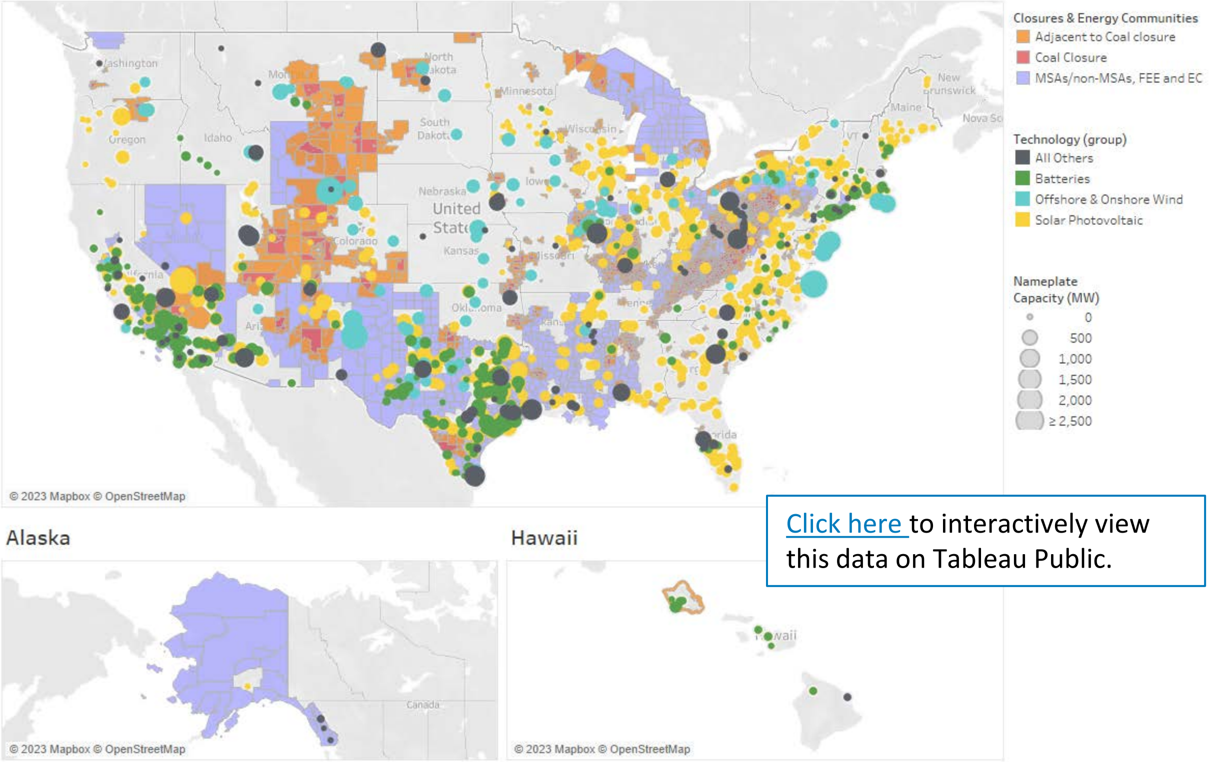
Comparison of U.S. annual grid investment scenarios



Source: BloombergNEF, “US Takes a Step to Clear Grid Backlog But a Leap Is Needed.”

Planned U.S. Electric Generation Plants in Relation to Energy Communities

Planned U.S. Generation Capacity in Relation to Energy Communities, September 2023



Click here to interactively view this data on Tableau Public.

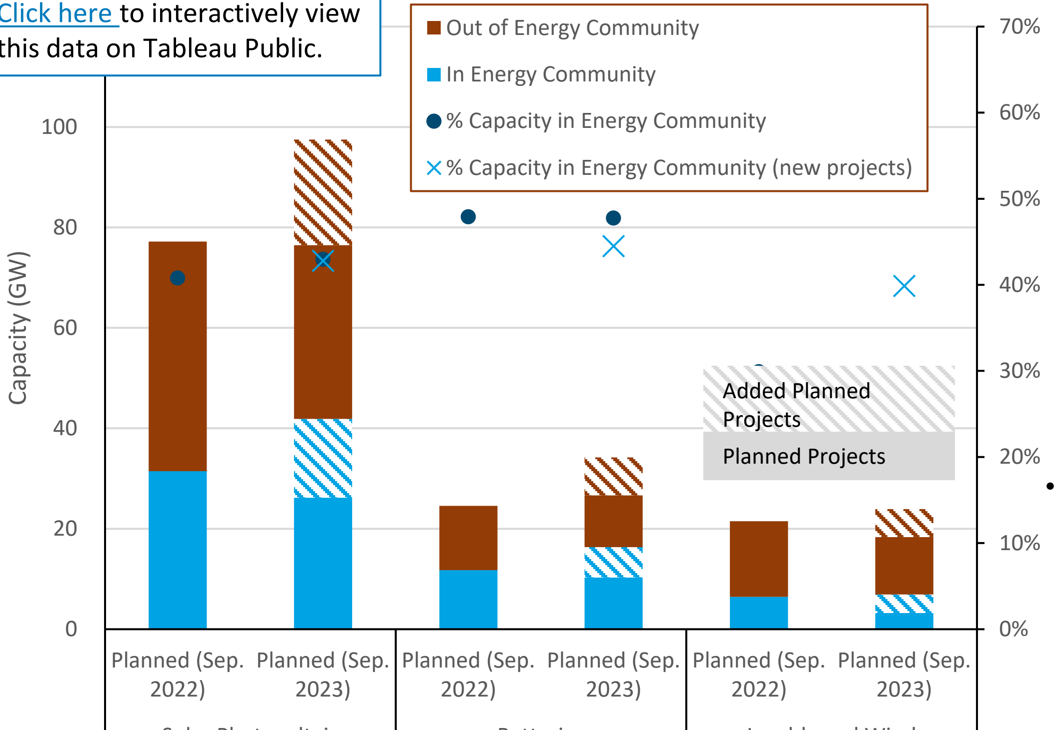
Note: Brownfields, which are also eligible for the energy community bonus credit, do not have the same census tract delineations and so are not included in this analysis.

Sources: U.S. Energy Information Administration (EIA), EIA Form 860 (November 2022, November 2023).

- Since the passage of the Inflation Reduction Act, which provides an additional 10% tax credit for renewable energy projects located in an "Energy Community", a significant amount of new planned renewable energy projects have been announced.
- In September 2022, one month after the passage of the Inflation Reduction Act, the EIA tracked approximately 123 GW of planned utility-scale PV, land-based wind, and battery projects (of which 78 GW had not yet started construction).
  - Since then, 60 GW of new projects have been added to the dataset, 38 GW of which has not yet started construction.

Percent of Planned Solar, Wind, and Battery Markets Located in Energy Communities

Click here to interactively view this data on Tableau Public.

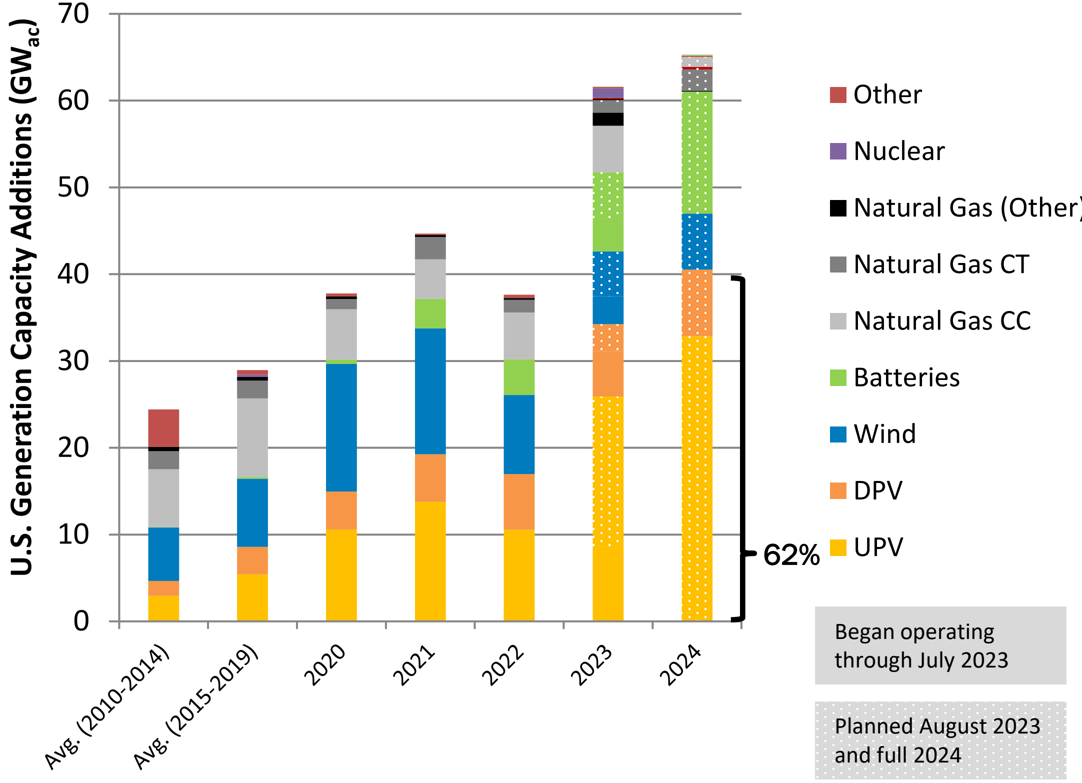


Note: based on EIA data, there were no new planned offshore wind projects announced between September 2022 and September 2023. Additionally, the latitude and longitude of these projects reported in EIA Form 860 likely does not reflect the location in which these projects will determine their eligibility (i.e., the point of interconnection).

Sources: U.S. Energy Information Administration (EIA), EIA Form 860 (November 2022, November 2023).

- NREL analysis found that new projects added to the planned project dataset do not have a significantly higher percentage of capacity located in energy communities as projects which were in the dataset as of September 2022.
  - This analysis also includes projects in construction, however the results are very similar when only looking at new projects which have not begun construction yet.
  - The percentage of planned land-based wind capacity located in energy communities increased the most (from 30% to 40%), however the number of projects located in energy communities increased less dramatically (from 26% to 30%) and was impacted by a few large projects.
  - The percent of planned solar PV capacity in energy communities is relatively consistent (if not lower) than the percent of installed capacity in those areas from 2021 through July 2023 (see LBNL data on slide 20).
- It typically takes years to develop large electric generating assets in the United States, therefore data may not show a significant change in deployment in these communities for some time.
  - Additionally, a relatively large percentage of projects were already being developed in these areas.
  - EIA data is also not necessarily added uniformly in terms of project development and therefore is a better indicator of long-term trends.

U.S. Generation Capacity Additions by Source: 2010–2022 and *Planned* 2023–2024

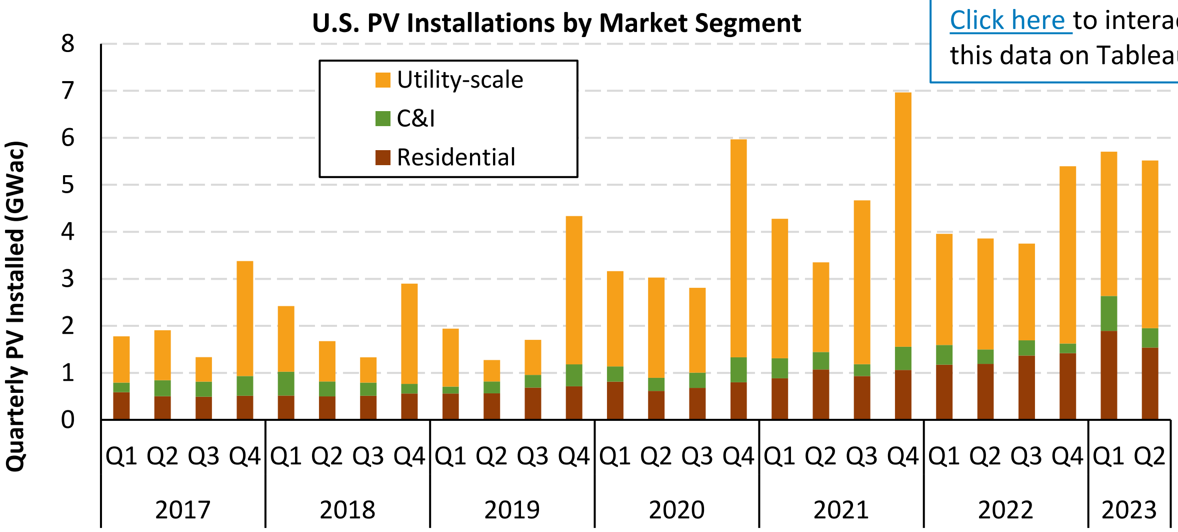


- EIA projects the percentage of U.S. electric capacity additions from solar will grow from 45% in 2022 (17 GW_{ac}) to 56% in 2023 (31 GW_{ac}), and 62% (41 GW_{ac}) in 2024.
  - Wind accounts for 14%, batteries 15%, and nuclear 2% of projected capacity in 2023; in 2024 those percentages are 9%, 19%, and 2%, respectively.
  - Natural gas accounts for the remaining 14% in 2023.
- Over the next 2 years, EIA projects there will be nearly 90 GW_{ac} of capacity additions from wind and solar alone.
- Wood Mackenzie/SEIA projects 32 GW_{dc} of solar installations in 2023 and 35 GW_{dc} in 2024, depending both on favorable supply chain conditions (domestic and international) and on the ability to optimize the Inflation Reduction Act bonus credits.
  - Over the next 5 years, Wood Mackenzie/SEIA projects about 20 GW_{dc} upside or downside relative to their base case as a result of these factors.

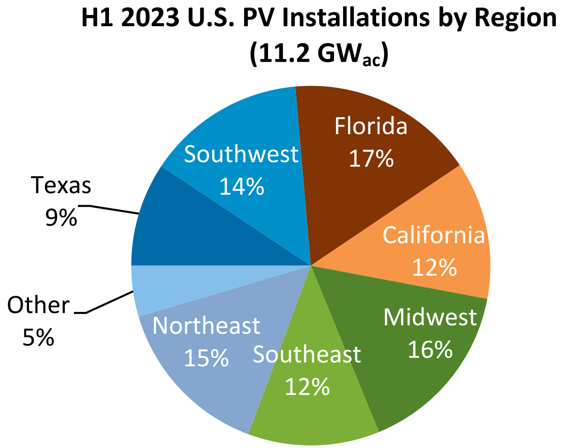
Sources: EIA Form 860M/Preliminary Monthly Electric Generator Inventory ("Planned" and "Operating") and EIA Short-Term Energy Outlook Table 7e, downloaded October 6, 2023; Wood Mackenzie and SEIA US Solar Market Insight Full Report 2Q 2023, Sep 2023.

U.S. Installation Breakdown Quarterly: EIA (GW_{ac})

- According to EIA data, the United States installed 11.2 GW_{ac} of PV in H1 2023—its largest H1 ever—up 44% y/y (SEIA reported 11.8 GW_{dc}).
  - Residential (3.4 GW_{ac}) remained up significantly in H1 2023, 45% y/y, as was nonresidential (1.2 Gw_{ac}—up 60%) and utility-scale (6.6 GW_{ac}—up 40%).
- 39% of U.S. PV capacity installed in H1 2023 was in Texas, Florida, and California.
  - 23 states installed more than 100 MW_{ac} in H1 2023.



Click here to interactively view this data on Tableau Public.



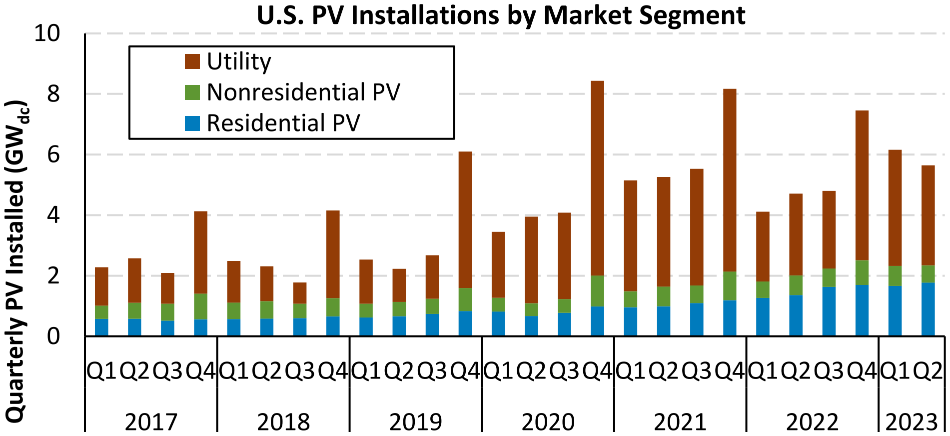
Note: EIA reports values in W_{ac}, which is standard for utilities. The solar industry has traditionally reported in W_{dc}. See the next slide for values reported in W_{dc}.
Sources: EIA, "Electric Power Monthly," forms EIA-023, EIA-826, and EIA-861 (July 2023, February 2022, February 2019).

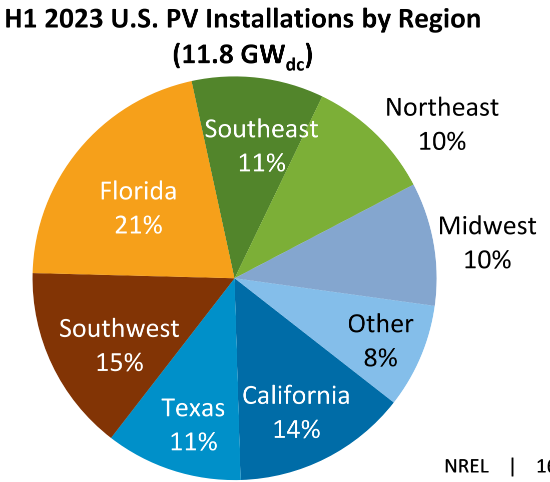
U.S. Installation Breakdown Quarterly: SEIA (GW_{dc})

Unlike the previous slide, these values are in GW_{dc}—not GW_{ac}.

- Wood Mackenzie/SEIA reports a record first half of PV installations, with 11.8 GW_{dc} installed in H1 2023—an increase of 34% y/y.
  - Big growth occurred year over year in the residential and utility-scale space, with Q2 residential installations hitting another record level of deployment. SEIA reports that the growth comes despite uncertainties that remain in receiving IRA benefits, higher interest rates, and challenges with UFLPA compliance.
  - Nonresidential installations were mostly flat, with SEIA citing continued impacts of interconnection delays, supply chain constraints, and uncertainty over IRA implementation.

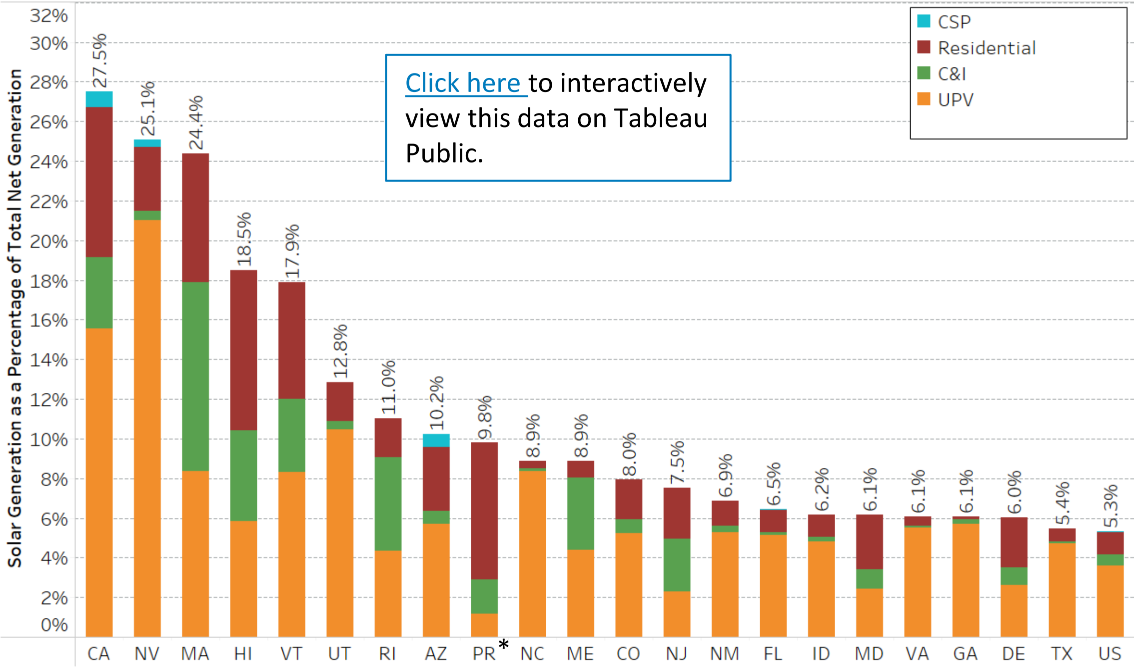
- Installations typically fall after Q4 and this Q1 was particularly large due to delays in projects originally intended for a Q4 installation.
- Florida, California, and Texas continue to lead installations, accounting for 46% of H1 2023 installations.
  - However, 27 states installed more than 100 MW in the first half of the year.





Sources: Wood Mackenzie/SEIA: U.S. Solar Market Insight: Q3 2023.

Solar Generation as a Percentage of Total Generation, Q4 2022–Q3 2023



Note: EIA monthly data for 2023 are not final. Additionally, smaller utilities report information to EIA on a yearly basis, and therefore a certain amount of solar data has not yet been reported. "Net Generation" includes distributed PV generation. Net generation does not take into account imports and exports to and from each state, and therefore the percentage of solar consumed in each state may vary from its percentage of net generation.

*EIA does not estimate distributed PV production in Puerto Rico; utility-scale values derived from EIA Form 923 and distributed PV values represent estimates based on capacity installations from EIA Form 861 and system production from PVWatts.

Source: U.S. Energy Information Administration (EIA), "Electricity Data Browser." Accessed October 2023.

During the 1-year time span from Q4 2022 to Q3 2023, 20 states generated more than 5% of their electricity from solar, with California leading the way at 27.5%.

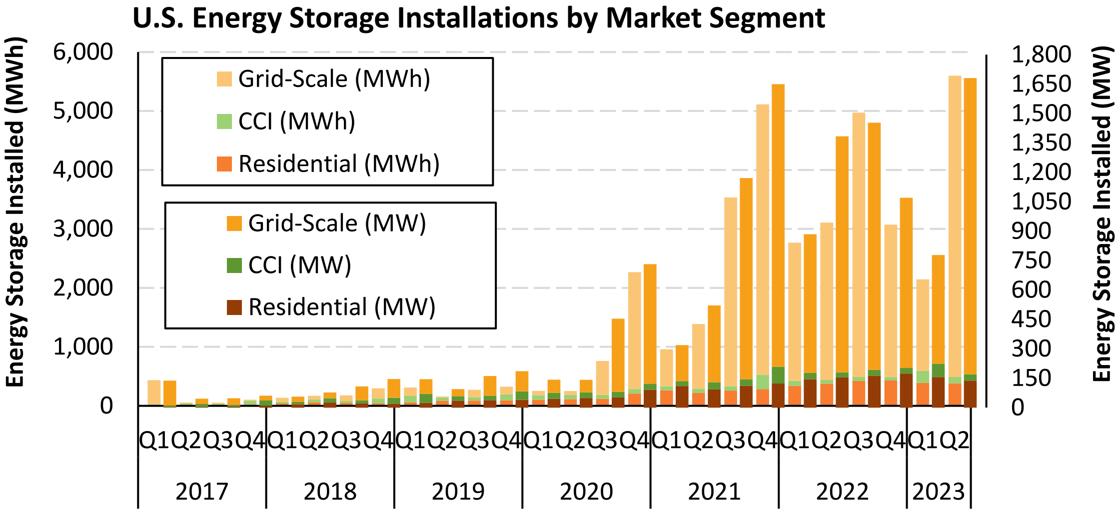
- Five states (California, Nevada, Massachusetts, Hawaii, and Vermont) generated more than 15% of their electricity using solar.
- Three other states generated more than 10% of their electricity using solar: Utah, Rhode Island, Arizona.
- In calendar year 2022, solar generation was 4.1% in Delaware, 4.3% Idaho, and 4.8% in Texas—all these states broke the 5% barrier recently.

Nationally, 5.3% of electricity was generated from solar—up from 4.8% during 2022.

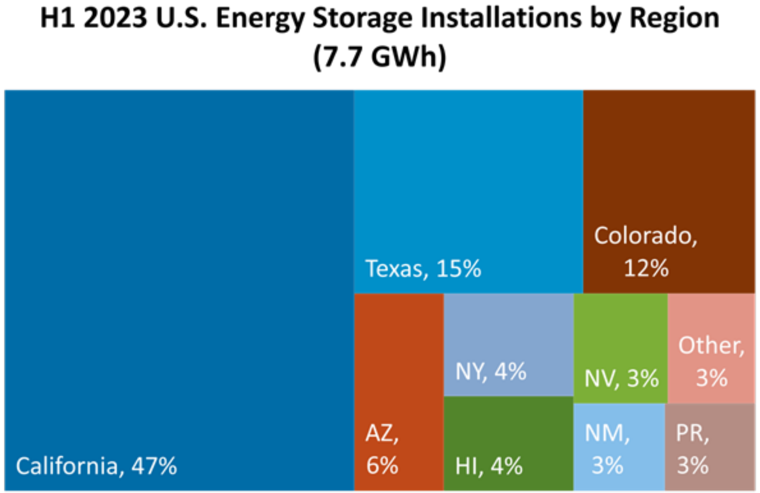
The roles of utility and distributed solar vary by state. Southern and Western states rely more on utility-scale solar, while northern states and Hawaii rely more on distributed solar.

U.S. Energy Storage Installations by Market Segment

- The United States installed approximately 7.7 GWh (2.5 GW_{ac}) of energy storage onto the electric grid in H1 2023, +32% (+8%) y/y, as a result of growth in all sectors.
  - Q2 2023 installations were the highest on record, despite contractions in the residential and CCI markets.
  - In Q2 2023, California had its lowest residential storage installs since 2020.



- Wood Mackenzie reports that battery costs are declining from their late 2022 peak; however, labor and balance of plant costs are increasing.
  - Lithium spot prices decreased, but transformer and inverter costs continue to rise.
- California continues to lead in the residential and utility-scale space, but other markets are developing as well, with 8 other states/territories installing more than 100 MWh in H1 2023. Colorado was the third-leading state thanks to two utility-scale projects installed in H1 2023.

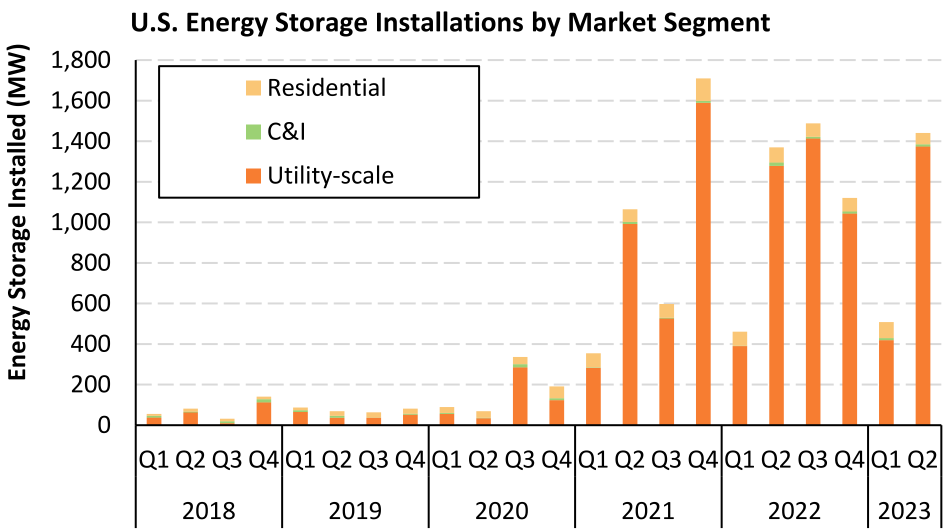


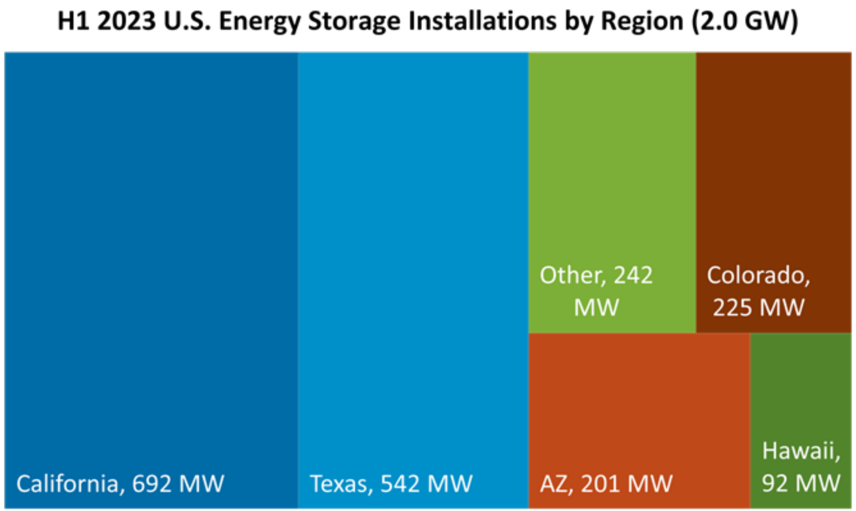
Note: "Grid-scale" refers to all projects deployed on the utility side of the meter, regardless of size or ownership; "CCI" refers to "community-scale, commercial, and industrial."

Source: Wood Mackenzie Power & Renewables and Energy Storage Association, U.S. Energy Storage Monitor: Q2 2023.

U.S. Energy Storage Installations by Market Segment (EIA)

- EIA reports that the United States installed approximately 2.0 GW_{ac} of energy storage onto the electric grid in the first half of 2023—up 5% y/y as a result of high levels of utility-scale and residential deployment.
- California represented approximately 35% of battery storage capacity installed in H1 2023, followed by Texas (27%).
  - The top five markets represented 88% of installed energy storage capacity.

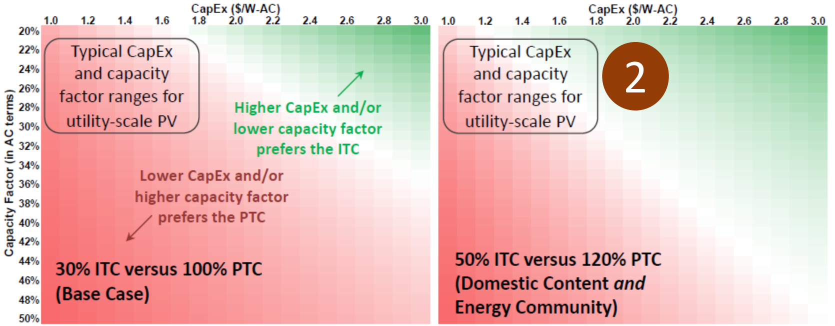


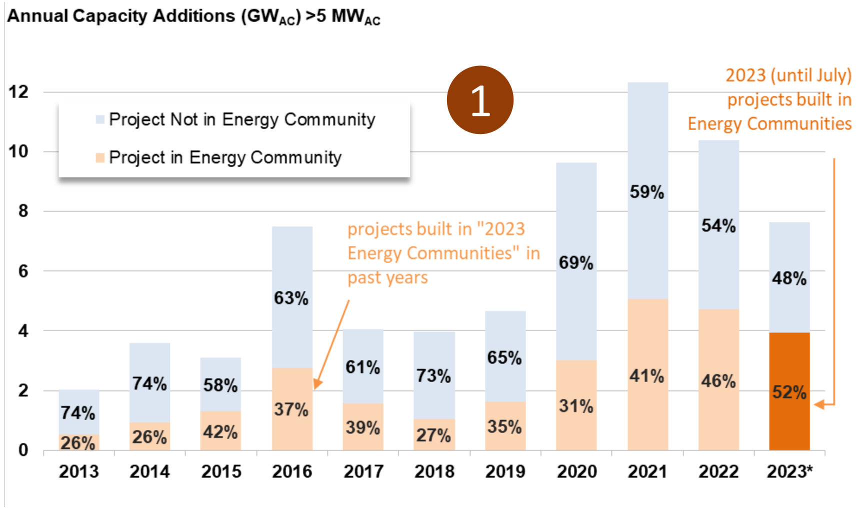


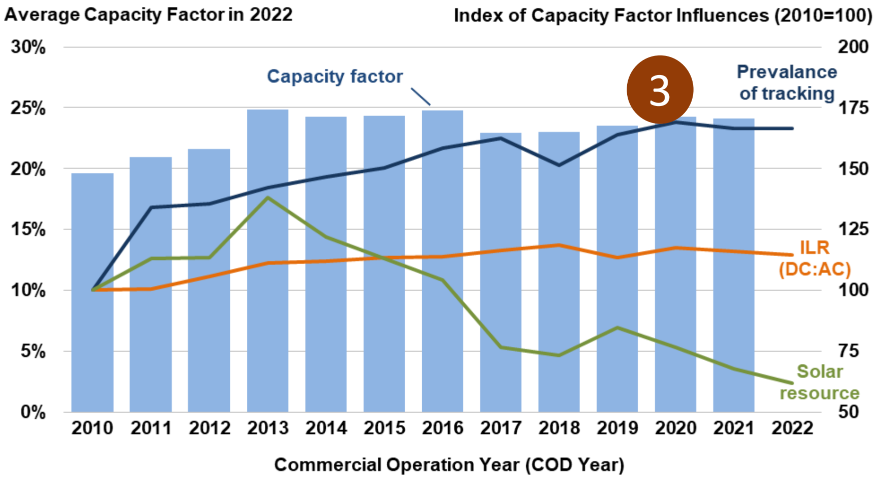
Sources: EIA Form 860M, EIA Form 861M.

Five Things To Know From LBNL's *Utility-Scale Solar, 2023 Edition*

1. Half of utility-scale PV capacity built during January–July 2023 is in Energy Communities and should qualify for the IRA Energy Community tax credit adder.
2. Under IRA, the production tax credit (PTC) is more valuable than the investment tax credit (ITC) for many utility-scale PV systems, especially without bonus credits.
3. Average capacity factors by plant vintage have been flat since 2014 as installation in areas with lower solar resource has offset increases in ILR and use of tracking.
4. 94% of utility-scale capacity installed in 2022 used tracking, the highest ever.
5. Because of high electricity prices, the total (energy plus capacity) value of PV electricity increased 40% between 2021 and 2022, reaching a record $71/MWh.



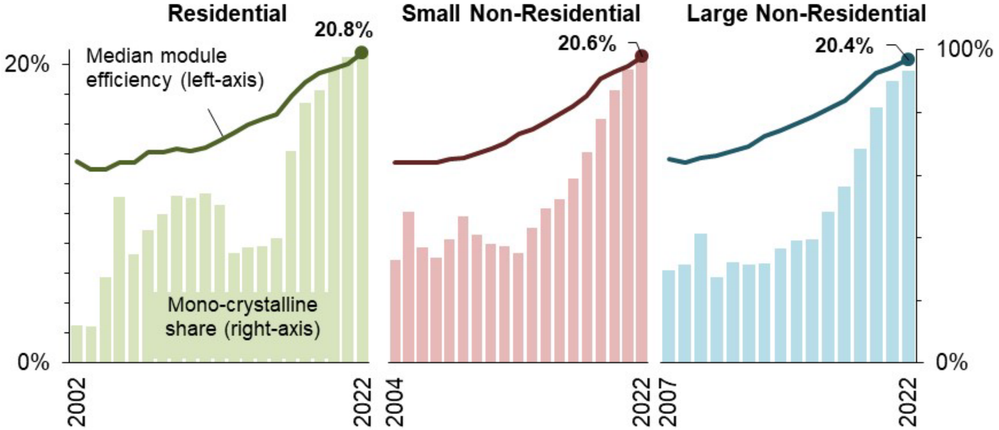




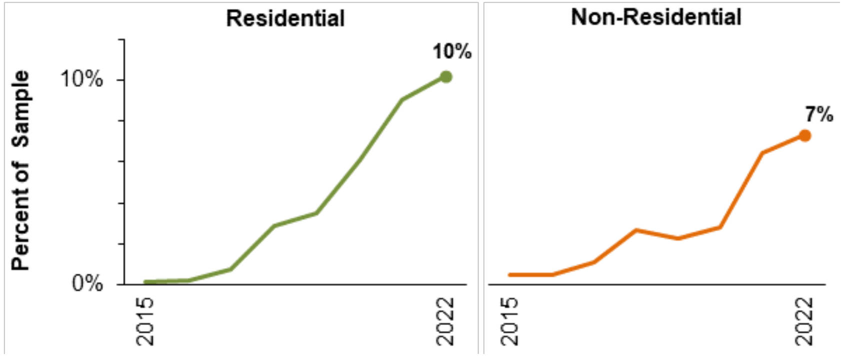
Source: Bolinger et al. 2023. *Utility-Scale Solar, 2023 Edition*. Lawrence Berkeley National Laboratory.

Five New Things To Know From *Tracking the Sun … 2023 Edition*

Module Efficiency and Monocrystalline Market Share



Storage Attachment Rates by Sector (2022)



1. In 2022, the median module efficiency of U.S. residential PV systems was 20.8%, up 0.7 percentage points y/y. 20th/80th percentile range module efficiencies was 20% to 21.5%.
2. Third-party ownership has declined over time from its historical high of 59% of residential installations in 2012 to 25% in 2022. Market share varies a lot by state.
3. For the second year in a row, microinverters represented over half the residential market, beating out DC optimizer systems 53% to 41%. However, for large nonresidential systems, DC optimizer market share continues to grow, up to 39% in 2022, compared to 1% for microinverters.
4. Residential attachment rates have steadily risen over time, reaching 10% of the sample in 2022—approximately eight states have an attachment rate greater than 10%. 65% of paired storage had a capacity of 5 kW; however, market share for larger storage sizes has grown over time, driven by backup power demand.
5. LBNL performed a regression analysis and found prices are generally lower in markets with more cumulative PV installations and areas with higher income. Their modeling also suggests that prices are $0.6/W lower for systems installed during new construction.

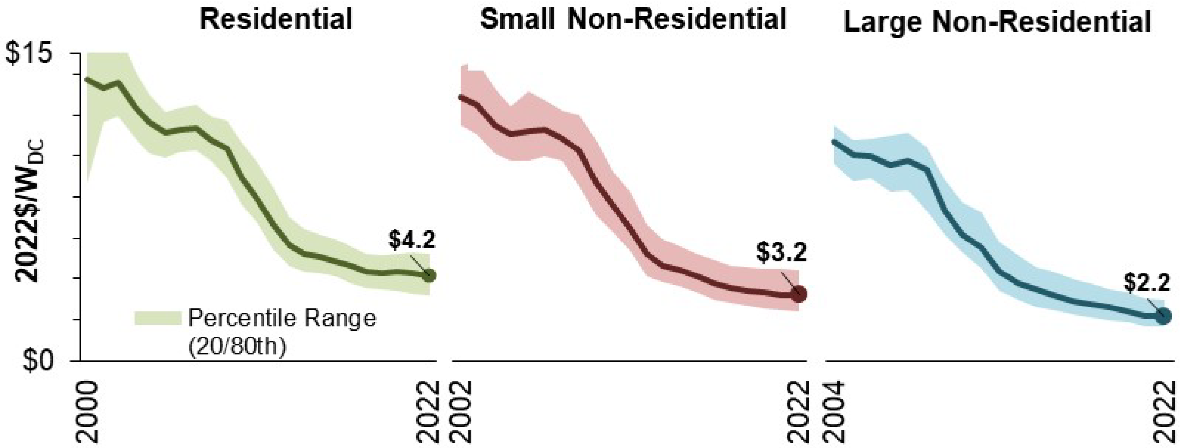
Source: Barbose, G., N. Darghouth, E. O’Shaughnessy, and S. Forrester. 2023. *Tracking the Sun: Pricing and Design Trends for Distributed Photovoltaic Systems in the United States 2023 Edition*. Berkeley, CA: Lawrence Berkeley National Laboratory. September 2023.

Agenda

- **Most data suggest mixed PV system pricing across market segments, with price increases in nominal terms.**
- **U.S. PV system pricing, or costs, is estimated and quoted in a variety of ways, including:**
  - **Reported price (backward-looking)**
  - **Reported costs (backward-looking and may not include profit, unless incorporating “value”)**
  - **Developer quotes (forward-looking)**
  - **Bottom-up cost benchmarking (forward-looking).**
- **In 2022, the ranges in average U.S. PV system pricing across methods were reported to be:**
  - **$3.1/W–$4.2/W for residential solar**
  - **$1.6/W–$3.2/W for nonresidential solar**
  - **$0.9/W–$1.1/W for utility-scale solar.**
- **In the first half of 2023, the ranges in average U.S. PV system pricing across a *smaller set of* methods were reported to be:**
  - **$2.7/W–$4.3/W for residential solar**
  - **$1.8/W–$2.4/W for nonresidential solar**
  - **$1.2/W for utility-scale solar.**

Tracking the Sun: National Price, 2000–2022

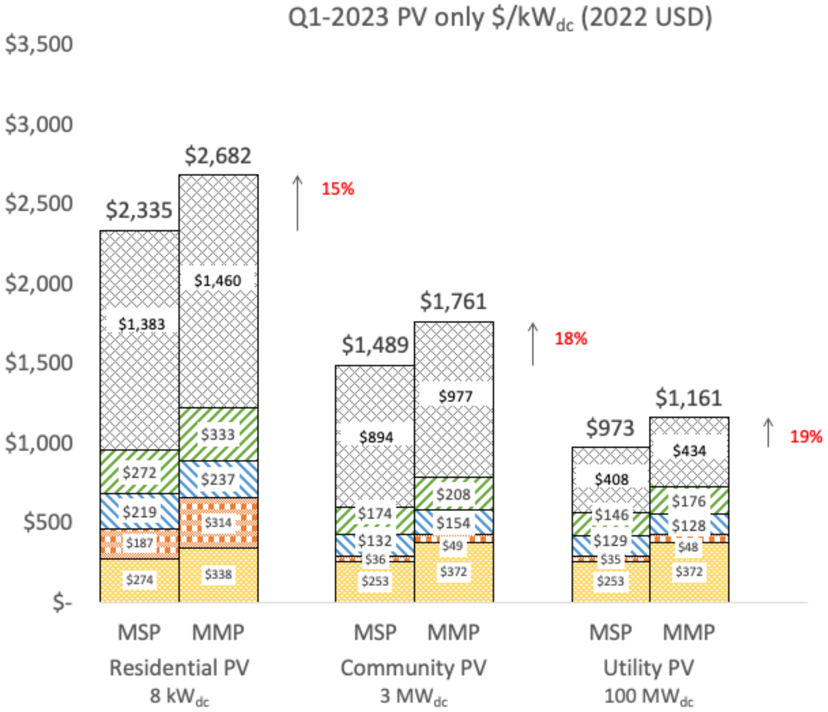
- Over the long term, median installed prices have fallen by roughly $0.4/W per year, on average, but price declines have tapered off since 2013, after which price declines averaged $0.1–$0.2/W across segments, following the trajectory of module costs.
- PV system prices rose in nominal dollars over the past 2 years but continued to fall in real dollars.

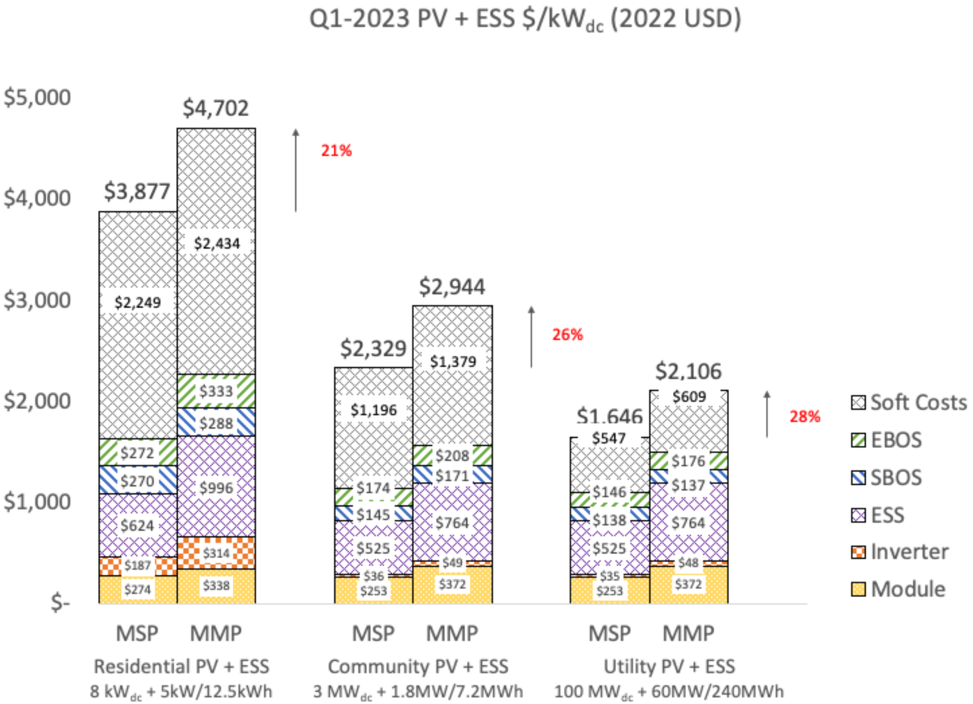


Source: Barbose, G., N. Darghouth, E. O'Shaughnessy, and S. Forrester. 2023. *Tracking the Sun: Pricing and Design Trends for Distributed Photovoltaic Systems in the United States 2023 Edition*. Berkeley, CA: Lawrence Berkeley National Laboratory. September 2023.

NREL Bottom-Up Cost Modeling: Q1 2023 Installed Cost Benchmarks

Modeled market price (MMP) benchmarks are significantly higher than minimum sustainable price (MSP) benchmarks for PV-only and PV-plus-storage systems, indicating significant inflationary market and policy distortion in Q1 2023.



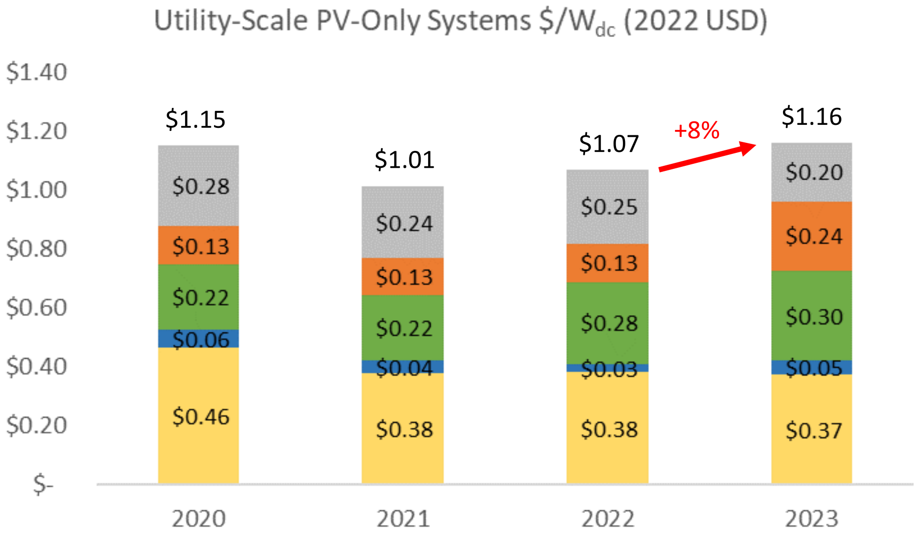


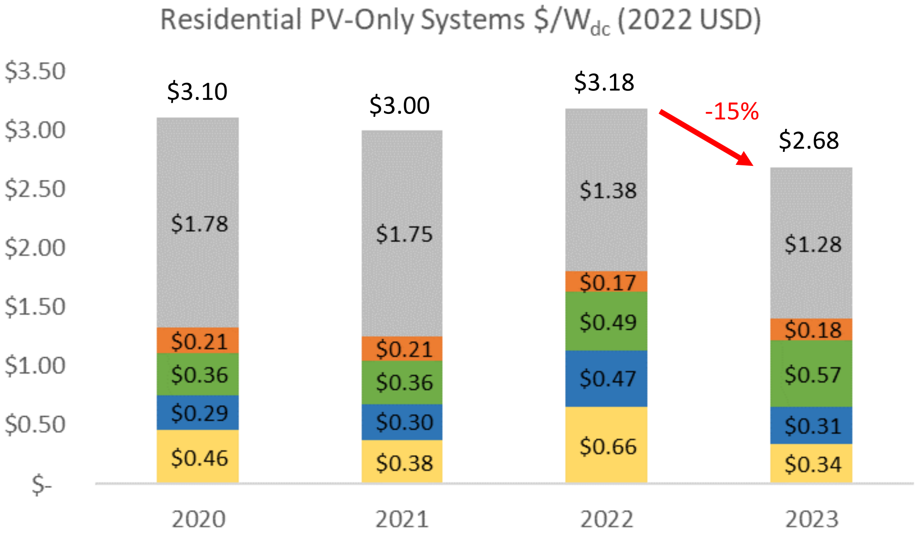
Source: Ramasamy et al. 2023. U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks, With Minimum Sustainable Price Analysis: Q1 2023

NREL Utility-Scale & Residential PV-Only MMP Benchmarks, 2020–2023

- Utility-scale PV-only MMPs were 8% higher in Q1 2023 than in Q1 2022.
- Higher inverter, labor, and electrical BOS (including network upgrade) costs more than offset lower module, structural BOS, and other soft costs.

- Residential PV-only MMPs were 15% lower in Q1 2023 than in Q1 2022.
- Higher BOS costs were more than offset by lower module, inverter, logistics, and customer acquisition costs.



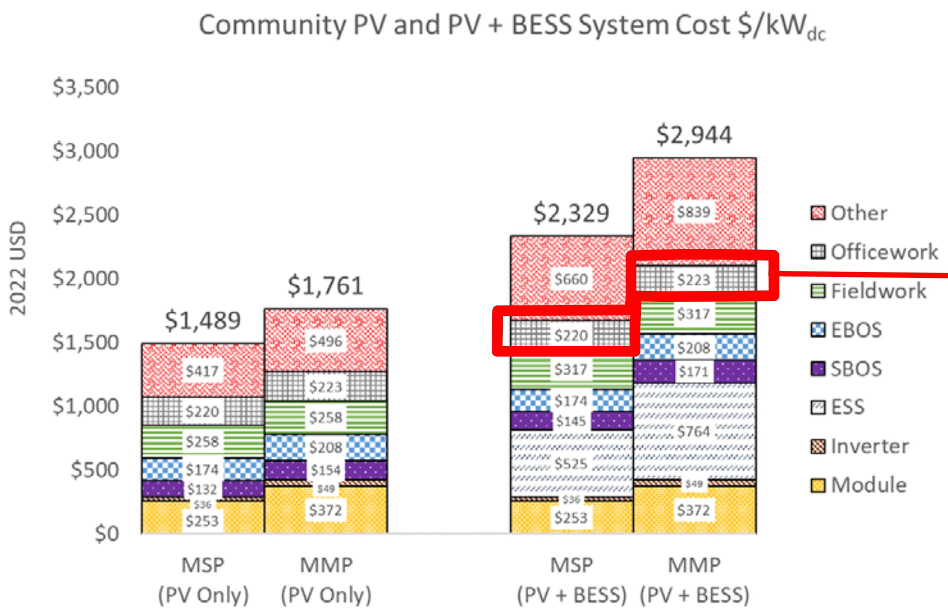


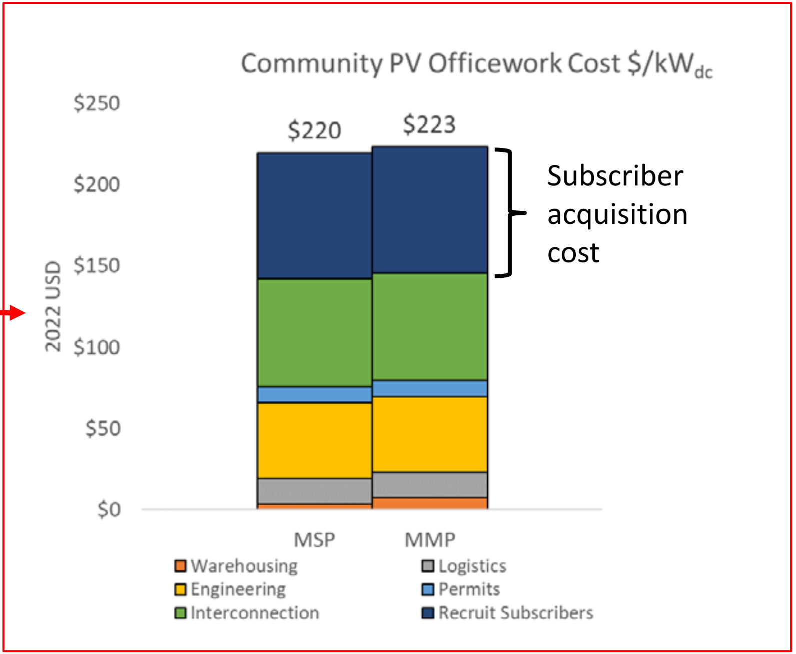
Module | Inverter | Balance of System | Installation Labor | Other Soft Costs

Source: Ramasamy et al. 2023. U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks, With Minimum Sustainable Price Analysis: Q1 2023

NREL Community Solar Benchmarks, Q1 2023

The cost of community solar systems was benchmarked for the first time, including unique expenses for subscriber acquisition and management.

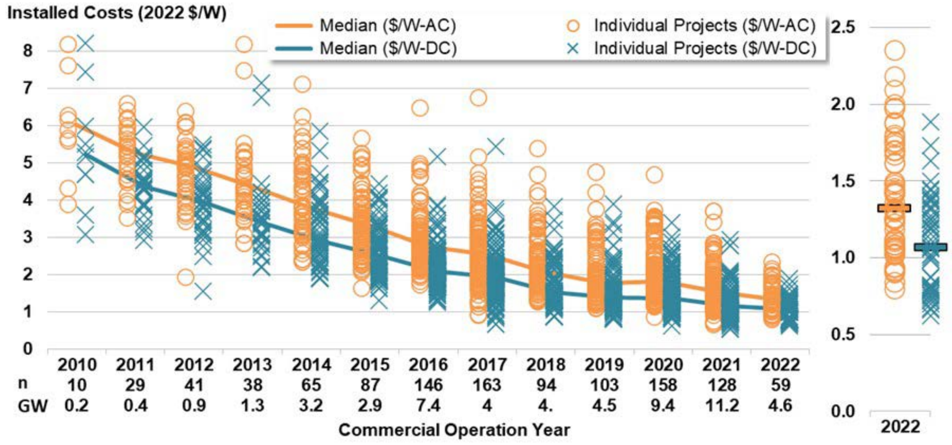


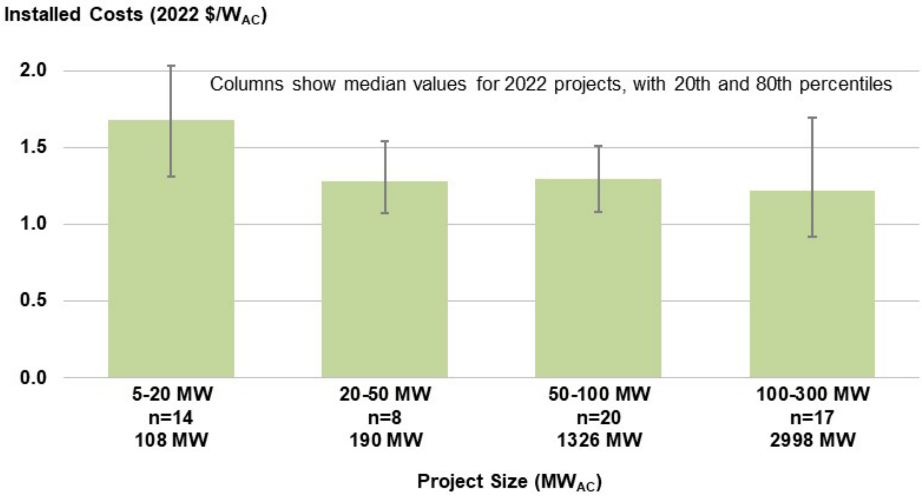


Source: Ramasamy et al. 2023. U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks, With Minimum Sustainable Price Analysis: Q1 2023

Reported Price of U.S. Utility-Scale PV Projects Over Time

- The median installed price of PV has fallen by 78% since 2010 to $1.32/W_{ac}$ ($1.07/W_{dc}$) in 2022.
- The lowest 20th percentile of project prices fell below $1.1/W_{ac}$ ($0.8/W_{dc}$) in 2022.
- Larger utility-scale solar projects (50–100 MW) cost 21% less than smaller projects (5–20 MW) per megawatt of installed capacity in 2022.
- This sample is backward-looking and may not reflect the price of projects built in 2023 and 2024.

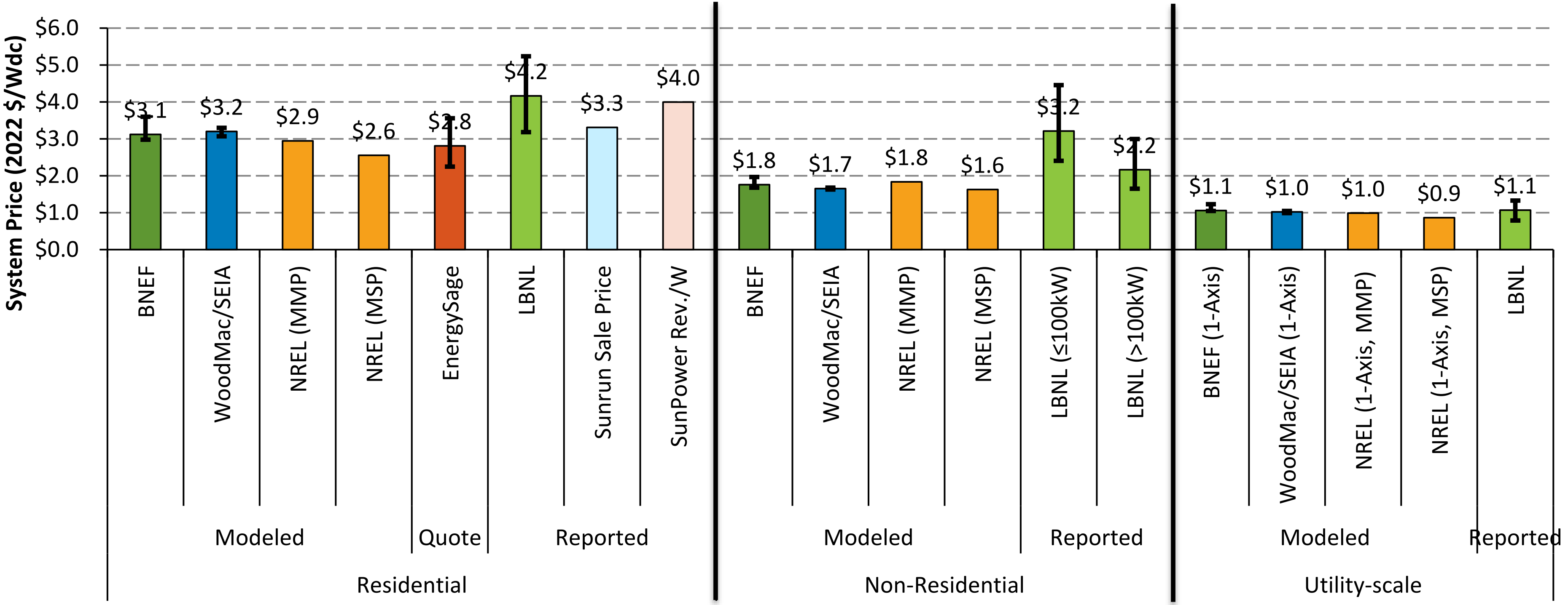




Source: Bolinger, M., J. Seel, C. Warner, and D. Robson. 2023. *Solar Empirical Trends in Project Technology, Cost, Performance, and PPA Pricing in the United States: 2023 Edition*. Berkeley, CA: Lawrence Berkeley National Laboratory.

2022 Modeled, Reported, and Quoted System Price From Various Sources

- NREL and LBNL PV system price ranges generally overlap other sources.
- Across various sources, reported system pricing is generally higher than modeled and quoted system pricing.



Note: Some sources only report a range, which is represented by the error bars.

Sources: Barbose et al. 2022; Bolinger et al. 2022; Ramasamy et al. 2022; BNEF, "H1 2022 U.S. PV Market Outlook," April 2022; : Wood Mackenzie/SEIA: U.S. Solar Market Insight: 2021 Year-in-Review, March 2022; EnergySage, Solar Marketplace Intel Report H1 2021 – H2 2022.

Why is there such price variation?

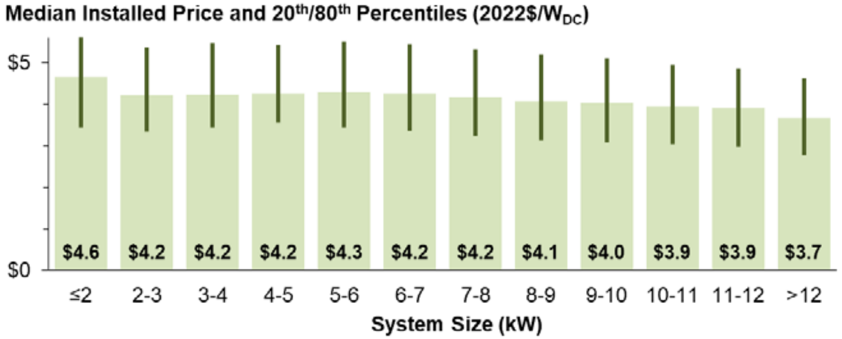
- Utility-scale PV
  - There is some variation in estimates; however, reported and modeled pricing is relatively consistent between sources.
    - Soft costs are more easily spread out over large projects.
    - There are diminishing returns to economies of scale.
    - Utility-scale businesses operate under very competitive operating conditions, where bid-price typically becomes the differentiator.
- Nonresidential PV
  - Nonresidential PV contains a large variation in project type from offtaker (industrial, commercial, nonprofit, government), system size (lots of small projects, but a significant capacity of larger projects), and project design (rooftop, ground-mount, carport).

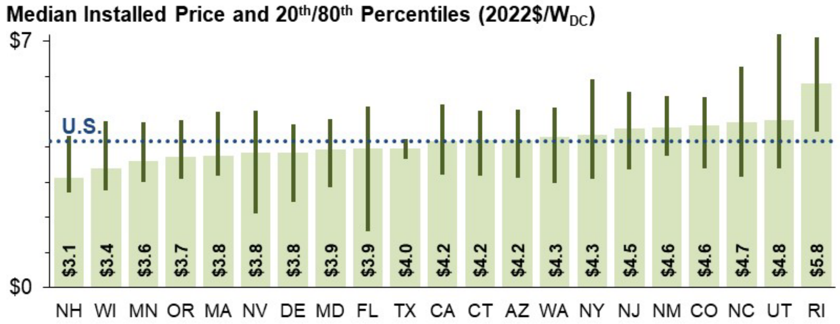
Why is there such price variation?

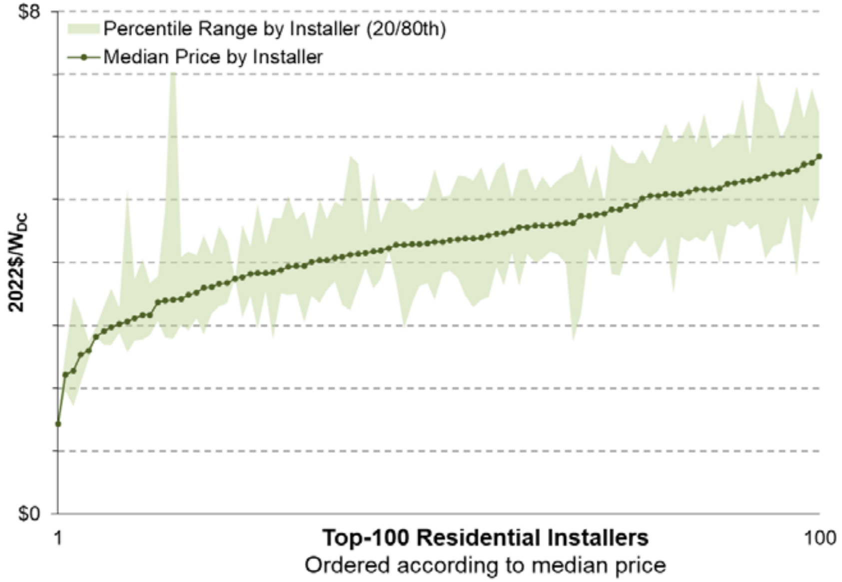
- Residential
  - Some of the variation in residential pricing can be explained by different installers; state environments; temporal differences between when a system or component has a quoted price and when a system is installed; and sizes in datasets.
    - 2022 system size: LBNL (7.2 kW); NREL (7.9 kW); EnergySage (10.2 kW); Sunrun (7.2 kW).
  - However, when accounting for these factors, large discrepancies still exist.

Why is there such price variation?

- Modeled and quoted residential PV system prices between \$2.8/W (EnergySage) and \$3.10 (BNEF) correspond to some of the lowest state and installer reported pricing; this discrepancy cannot be explained by economies of scale (system size).





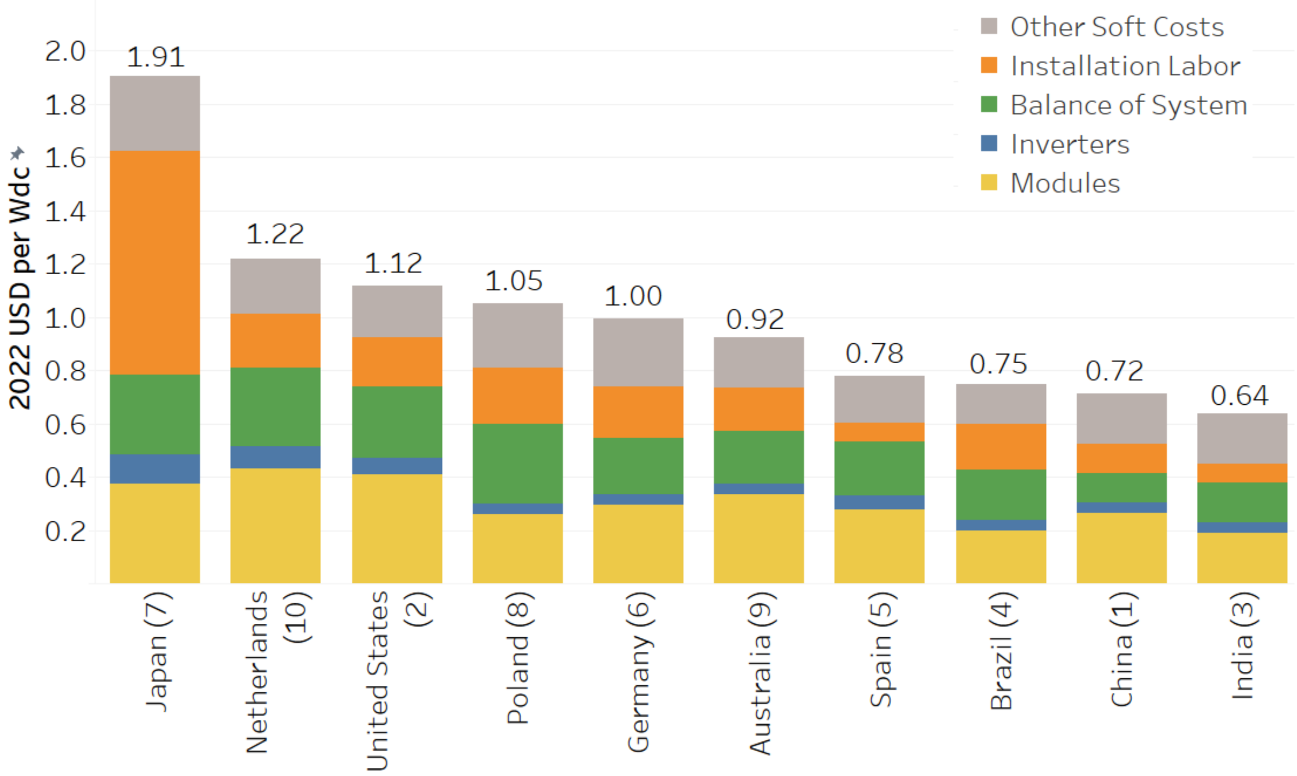


Source: Barbose, G., N. Darghouth, E. O'Shaughnessy, and S. Forrester. 2023. *Tracking the Sun: Pricing and Design Trends for Distributed Photovoltaic Systems in the United States 2023 Edition*. Berkeley, CA: Lawrence Berkeley National Laboratory.

Why is there such price variation?

- Financing and other costs are likely responsible for a larger portion of the additional discrepancies in residential PV reported price.
  - TPO Finance: Sunrun, which finances most of its customers' systems, reported a 2022 value per customer of $5.80/W, which represents the net present value of contracted cash flows, tax credits, and other benefits, including an assumed contract extension. Financing and operating a PV system for 30 years requires additional costs beyond just installation. Its 2022 "creation cost" was $4.17/W compared to its average PV system sales price of $3.30/W.
  - Loan finance: Loans, which represented most residential PV system installations in 2022, incur additional costs to set up. Additionally, many loan providers charge "dealer fees" to lower the interest rate of the loan, which show up in the reported price of a system.
  - Other costs not necessarily quoted (or modeled) in a standard PV system, but which may be reported in a system price, include certain roof repairs, main panel upgrades, and battery storage (which were attached to 10% of residential PV in 2022).

Utility-Scale PV Installed Costs by Country, 2022



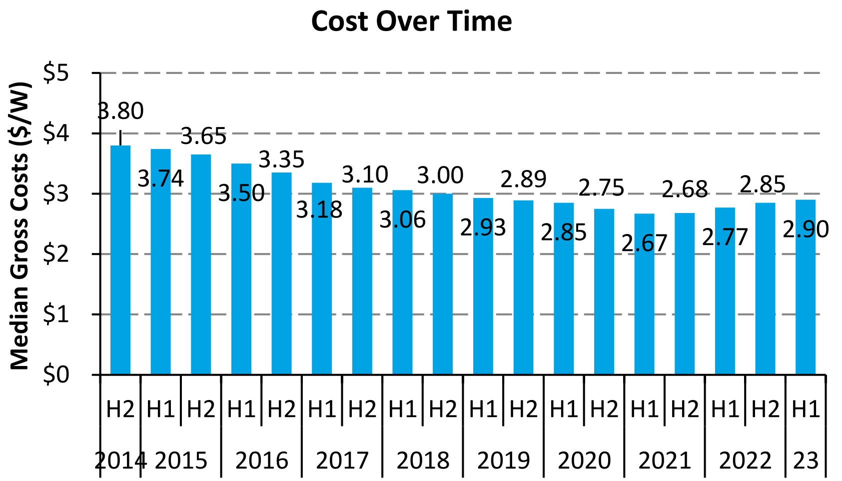
Top 10 Global PV Markets in 2022

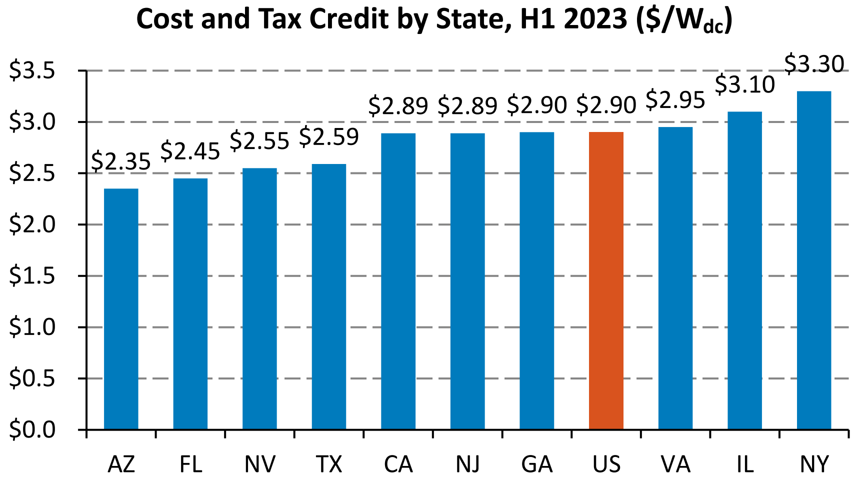
- The global capacity-weighted average total installed cost of utility-scale projects commissioned in 2022 was \$0.88 (USD)/W_{dc}.
- Average component costs as a percentage of total costs:
  - Module and inverter 37%
  - Balance of system hardware 23%
  - Installation labor 19%
  - Other soft costs 21%.
- Costs and cost components varied across countries:
  - India had the lowest cost (\$0.64 (USD)/W_{dc}) and Japan the highest (\$1.91 (USD)/W_{dc}).
  - The ratio of highest-cost to lowest-cost country declined from 3.5 in 2019 to 3.0 in 2022, suggesting that global PV costs are converging.
  - Labor costs varied the most across countries.

Source: International Renewable Energy Agency. 2023. Renewable Power Generation Costs in 2022

Residential System Price Reported by EnergySage

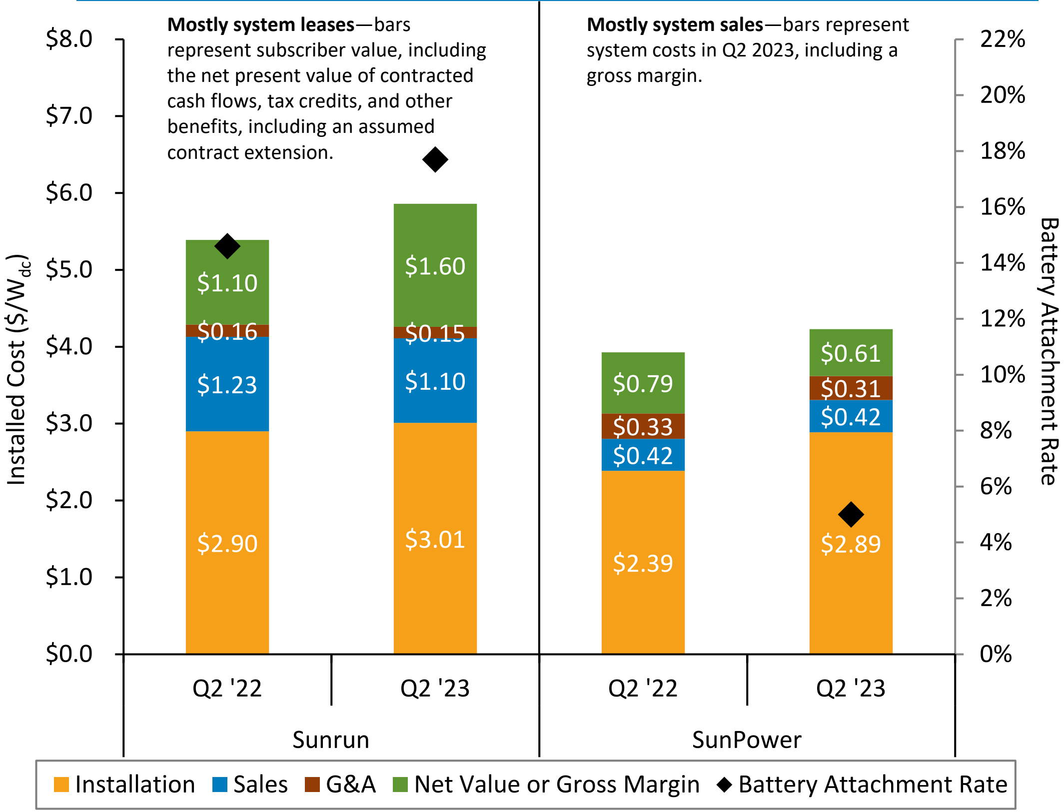
- The median reported price by EnergySage for residential PV systems increased 4.7% y/y, for the fourth straight period, after never having done so before.
  - However, EnergySage reported seeing price declines in July and August.
- Residential system price varied by state. In H1 2023, the median price of a residential system in New York was 40% higher than the median price of a residential system in Arizona.
  - Part of the price disparity between states is due to differences in average system size, though other factors, such as cost of living (e.g., Massachusetts), also play a role.





Note: Price based on winning quoted price.
Source: EnergySage, Solar Marketplace Intel Report H2 2022 – H1 2023.

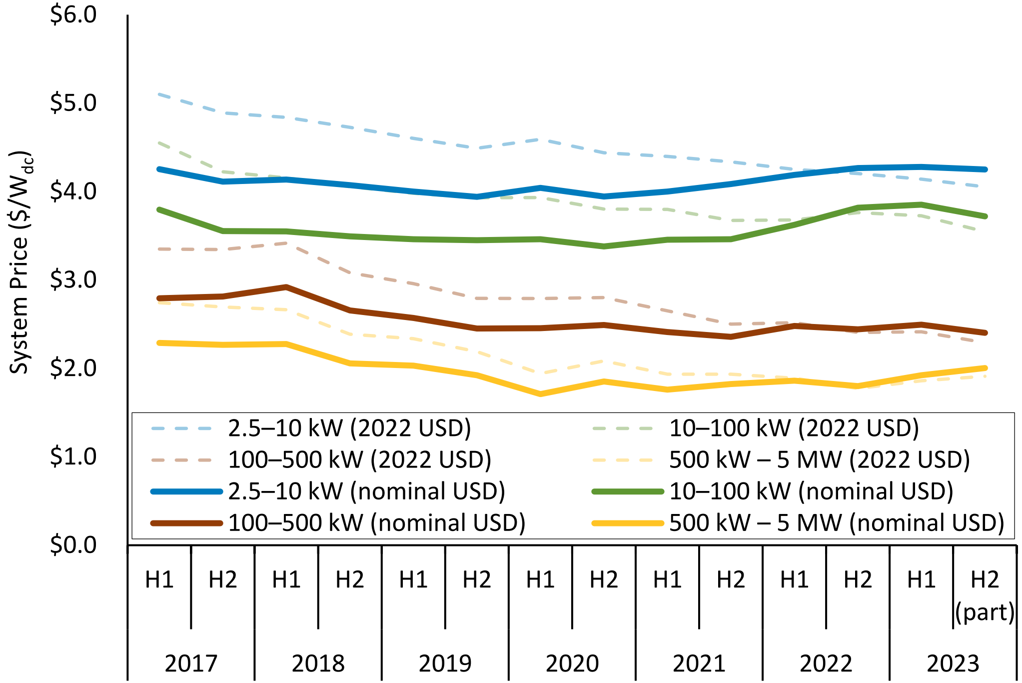
Large Residential Installer Cost and Value, Q2 2023



- Large residential installers Sunrun and SunPower reported system value/cost changes of +8% to +9% y/y but −1% to +3% q/q.
- Factors reported as supporting higher system value and/or costs (for Sunrun, SunPower, and Sunnova):
  - Increasing inflation and interest rates
  - Increasing retail electricity rates
  - Increasing battery attachment rates (batteries add cost but can yield higher margins)
    - Sunrun rate up from 15% to 18% y/y
    - Up to 80%+ rate ca. July–Aug. 2023 in California, under new PV compensation policy
    - Up to 100% rate in Hawaii and Puerto Rico.
- Factors reported as supporting lower PV system costs and/or higher margins:
  - Declining equipment prices
    - Module and battery procurement costs down by >20% compared with recent highs
    - Cost reductions expected to have impact over at least the next several quarters.
- Increasing permitting automation (SolarAPP+).

Sources: Corporate filings; Personal Communication, Mike Weinstein (Vice President of Investor Relations, SunPower), September 2023

Distributed PV System Pricing From Select States



2023 MW data YTD: Arizona (165), California (1,148), Massachusetts (67), New York (518)

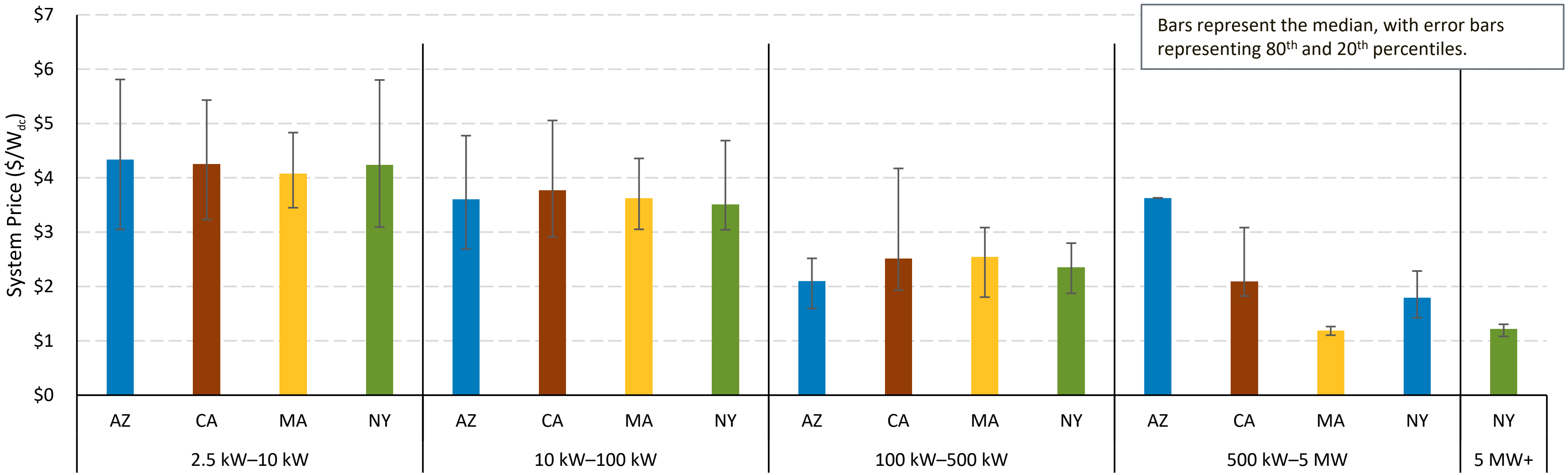
Note: System prices above $10/W and below $0.75/W were removed from the dataset. There were not enough reported prices for systems above 5 MW in the dataset to show a trend over time.

Sources: Arizona Goes Solar (10/13/23); California Distributed Generation (8/31/23); Massachusetts Lists of Qualified Generation Units (10/3/23); Solar Electric Programs Reported by NYSERDA (10/19/23).

- From H2 2022 to H2 2023 (partial), the median reported distributed PV system price—**in nominal USD**—across Arizona, California, Massachusetts, and New York:
  - Decreased 0.4% to $4.25/W$_{dc}$ for systems 2.5 to 10 kW
  - Decreased 3% to $3.72/W$_{dc}$ for systems 10 to 100 kW
  - Decreased 2% to $2.40/W$_{dc}$ for systems 100 to 500 kW
  - Increased 11% to $2.00/W$_{dc}$ for systems 500 kW to 5 MW.
- From H2 2022 to H2 2023 (partial), the median reported distributed PV system price—**in 2022 (inflation-adjusted) dollars**—across these states:
  - Decreased 4% for systems 2.5 to 10 kW
  - Decreased 6% for systems 10 to 100 kW
  - Decreased 5% for systems 100 to 500 kW
  - Increased 8% for systems 500 kW to 5 MW.
- Adjusting for inflation reveals the continuing real distributed PV price reductions over the past several years of economic volatility.

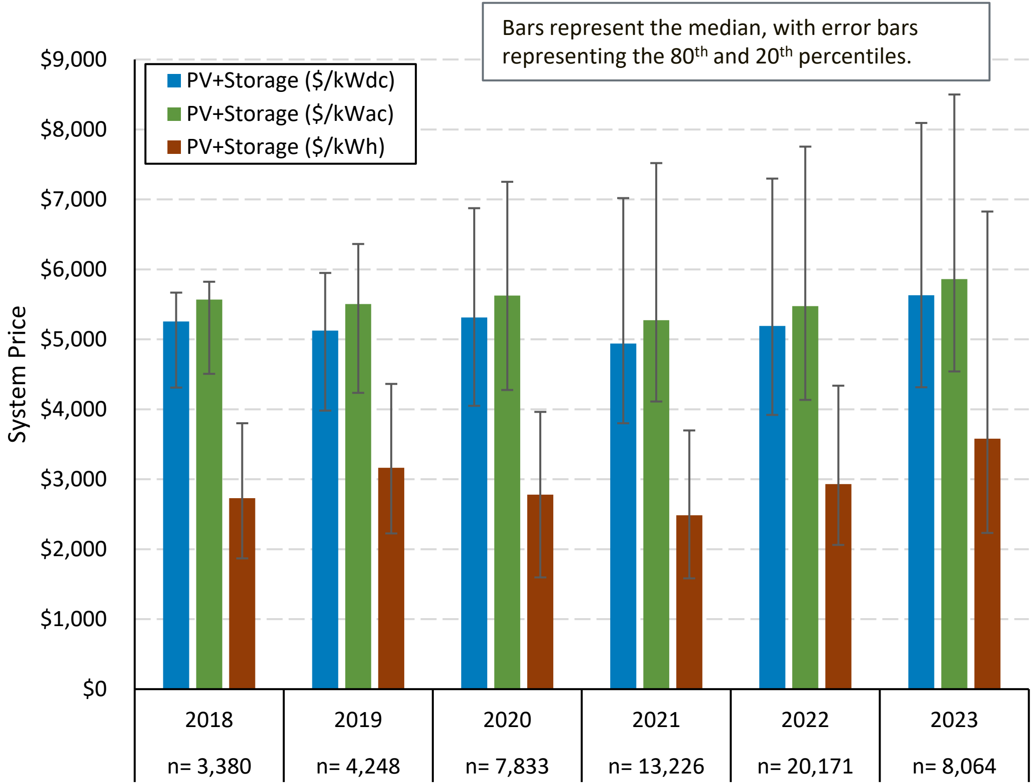
Distributed System Pricing From Select States, H2 2023 (partial)

- In addition to price differences based on system size, there is variation between states and within individual markets.
- Dollar-per-watt prices generally decrease as system size increases.
- For systems of 2.5–10 kW, nominal price changes varied between H2 2022 and H2 2023 (partial):
  - −2% in Arizona, − 0.2% in California, +4% in Massachusetts, −1% in New York.
- Large system prices are based on relatively few systems.
  - For example, Arizona only installed one system of 500 kW–5 MW in H2 2023 (partial).



2023 MW data YTD: Arizona (165), California (1,148), Massachusetts (67), New York (518)
Note: System prices above $10/W and below $0.75/W were removed from the dataset.
Sources: Arizona Goes Solar (10/13/23); California Distributed Generation (8/31/23); Massachusetts Lists of Qualified Generation Units (10/3/23); Solar Electric Programs Reported by NYSERDA (10/19/23).

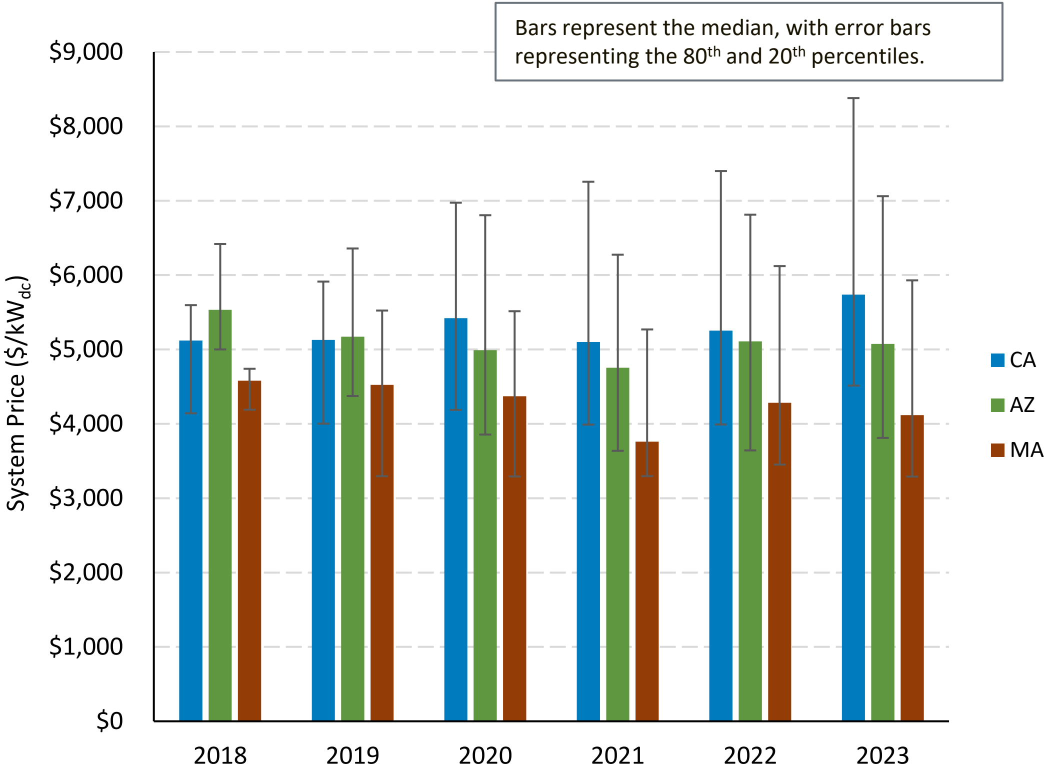
Residential U.S. PV+Storage Pricing



- In 2023 YTD, residential PV+storage systems in Arizona, California, and Massachusetts had a median system price of $3,580/kWh, or $5,862/kW$_{ac}$ ($5,629/kW$_{dc}$)—an increase of 7%–22% compared with full 2022 median values.
  - Most of these systems offer 2–3 hours of storage.
  - Units represent total system price divided by the capacity of the battery (kWh) or the capacity of the PV system (kW).

2023 YTD residential PV+storage sample, after data cleaning (MW$_{dc}$): Arizona (11), California (54), Massachusetts (6)
Sources: Arizona Goes Solar (10/13/23); California Distributed Generation (8/31/23); Massachusetts Lists of Qualified Generation Units (10/3/23).

Residential U.S. PV+Storage Pricing



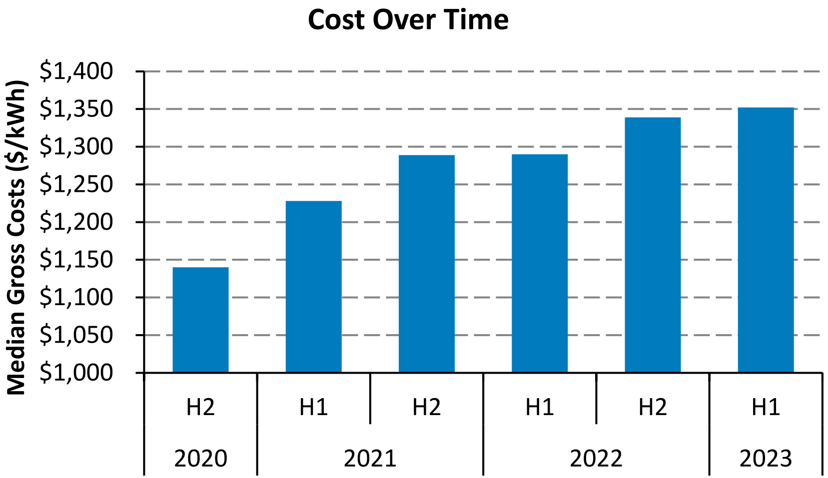
- During 2023 YTD, residential PV+storage system prices in Arizona, California, and Massachusetts varied between states and internally.
  - Prices may vary due to differences in storage power and capacity, permitting and interconnection differences, local competitive factors, and installer experience.
- Compared with full median 2022 values, prices (in dollars per kW_{dc} of PV capacity) increased in 2023 YTD in California (9%) while decreasing in Massachusetts (4%) and Arizona (1%).

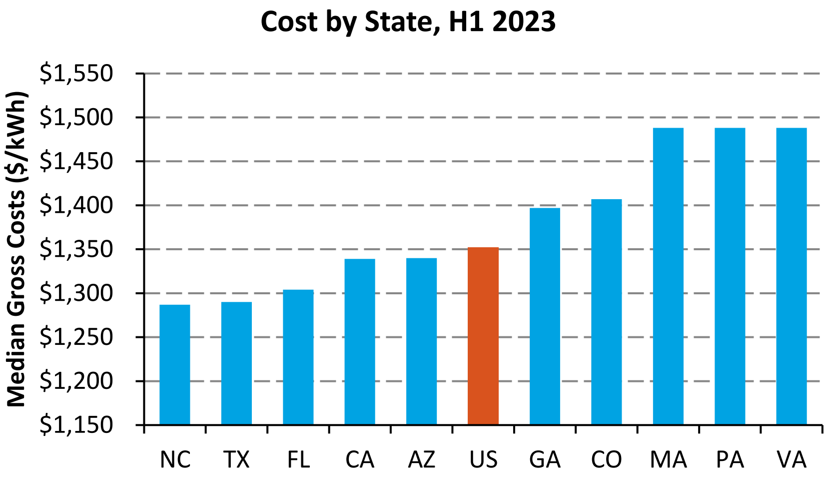
2023 YTD residential PV+storage sample, after data cleaning (MW_{dc}): Arizona (11), California (54), Massachusetts (6)

Sources: Arizona Goes Solar (10/13/23); California Distributed Generation (8/31/23); Massachusetts Lists of Qualified Generation Units (10/3/23).

Residential Storage Price Reported by EnergySage

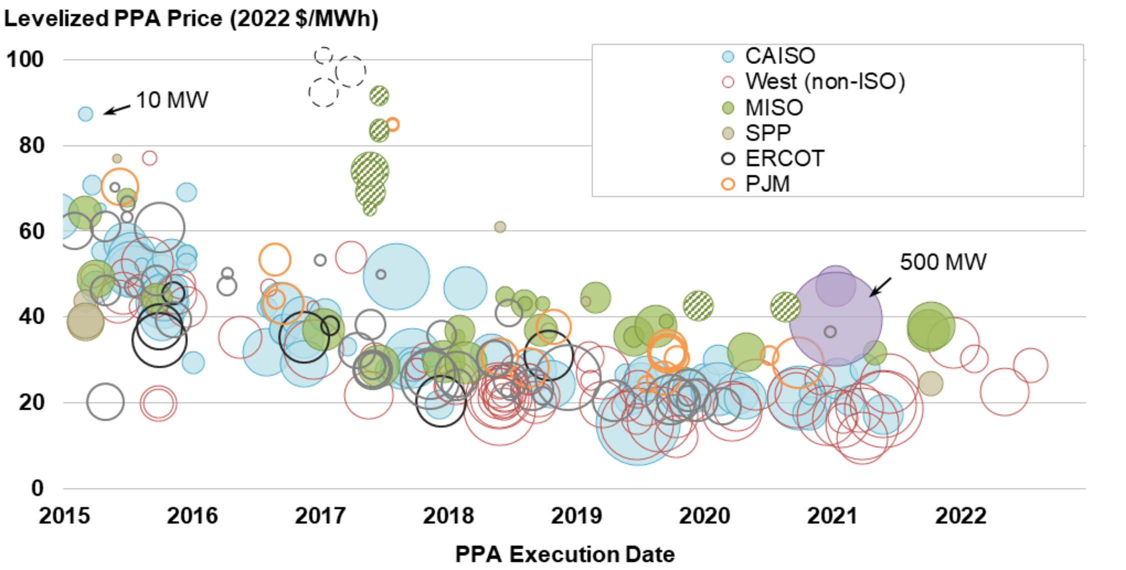
- The median reported price by EnergySage for residential PV systems increased 4.8% y/y.
  - Despite the median national average pricing increasing, prices remained flat or dropped in 6 of the top 10 markets.
- Residential storage system price varied by state. In H1 2023, the median price of a residential storage system in Massachusetts was 16% higher than the median price of a residential storage system in North Carolina.
  - In the EnergySage dataset, the median cost of a battery in the top 10 states ranged from $13,000 to $19,000.





Note: Price based on winning quoted price.
Source: EnergySage, Solar Marketplace Intel Report H2 2022 – H1 2023.

U.S. Utility-Scale PV PPA Pricing



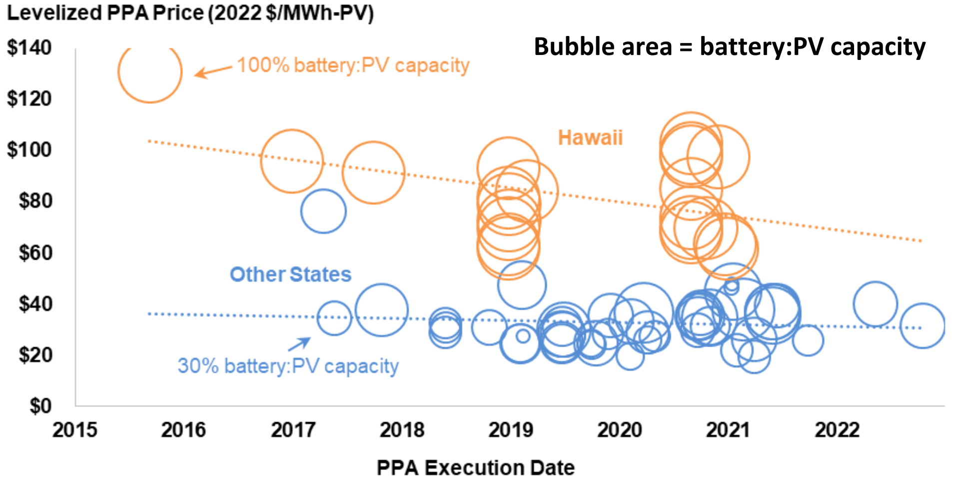
- Average PPA prices in the Lower 48 fell by ~87% (or ~19%/year) from 2009 to 2019, but they have been stagnant (or slightly higher) ever since.
- The most recent PPAs in the LBNL sample are priced around $20–$30/MWh for projects in CAISO and the non-ISO West and at $30–$40/MWh for projects elsewhere in the continental United States.
- Solar PPA prices are now often competitive with wind PPA prices, as well as the cost of burning fuel in *existing* gas-fired generators.

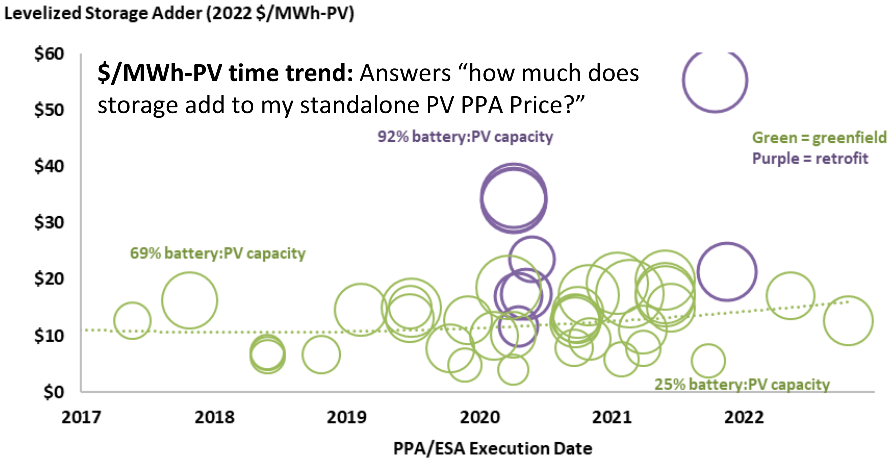
Source: Bolinger, M., J. Seel, C. Warner and D. Robson. 2023. *Solar Empirical Trends in Project Technology, Cost, Performance, and PPA Pricing in the United States: 2023 Edition*. Berkeley, CA: Lawrence Berkeley National Laboratory

U.S. Utility-Scale PV+Battery PPA Pricing From LBNL

- New PV+battery system capacity reached a record high in 2022 with 26 new plants (2.2 GW_{ac} PV), plus 9 retrofitted systems (1.4 GW_{ac} PV).
- Average combined costs for a sample of PV+battery systems decreased from \$4.15/W_{ac} PV in 2021 to \$2.19/W_{ac} PV in 2022, as the proportion of new builds increased and the average storage duration decreased (from 3.2 to 2.7 hours).
- Sampled hybrid PPA prices have declined over time but have leveled off recently outside of Hawaii, where the battery-to-PV capacity ratio is always 100%.

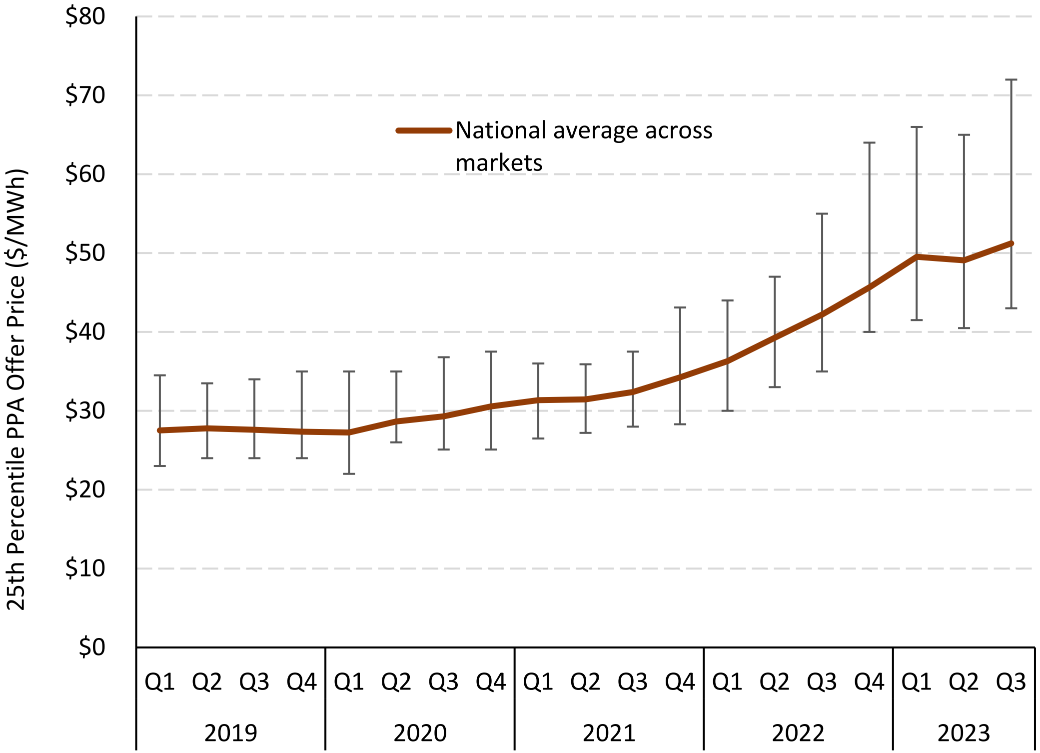
- The upward trend of "levelized storage adders" (premiums for PV+battery PPAs relative to standalone PV PPAs) continued in 2022 despite the year's modest battery system sizes.
- Overall, the storage adder increases linearly with increasing battery-to-PV capacity ratio:
  - ~\$11/MWh PV at 50%
  - ~\$18/MWh PV at 80%.





Source: Bolinger et al. 2023. *Utility-Scale Solar, 2023 Edition*. Lawrence Berkeley National Laboratory.

U.S. Solar PPA Pricing (LevelTen)

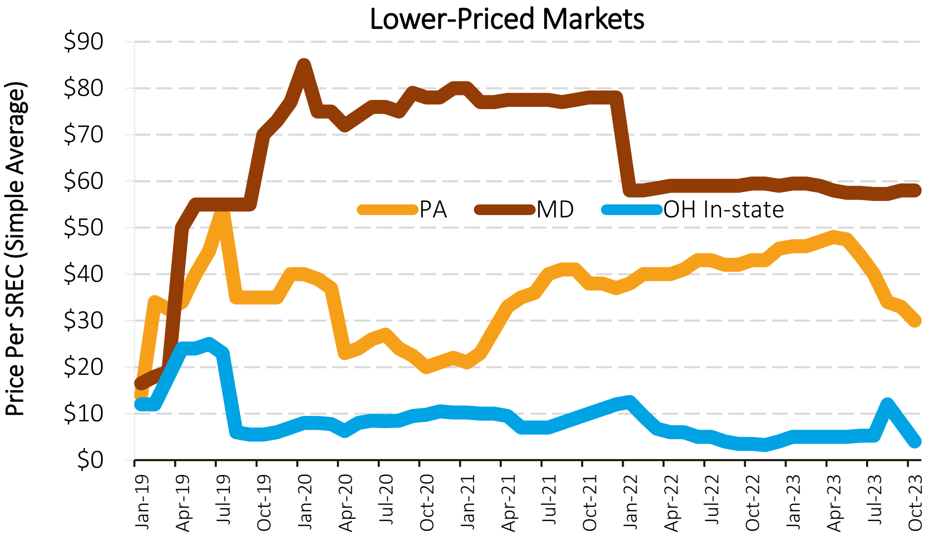


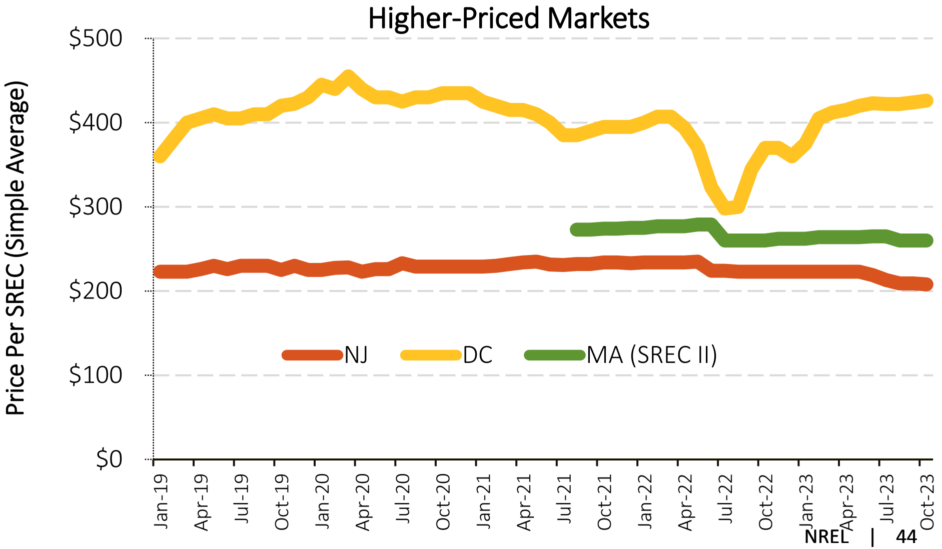
- LevelTen reports that following a modest dip in prices in Q2, U.S. utility-scale PV PPA prices increased 4% in Q3 2023 despite many markets remaining relatively flat or declining in price.
  - LevelTen attributes this change to rising prices in PJM and SPP and the inclusion of high-priced ISO-NE in the index.
  - PJM prices were likely pushed up by an overfilled interconnection queue and permitting challenges.

Source: LevelTen, PPA Price Index.

SREC Pricing

- Solar renewable energy certificate (SREC) pricing has been relatively flat in 2023, particularly for legacy programs like New Jersey and Massachusetts, which are not accepting new projects.
- However, potential programmatic or supply/demand changes can still impact markets, likely the reason for the ~40% price decline of PA SRECs in 2023 or the 140% increase in price for Ohio SRECs in August 2023 before relapsing in September and October.





Source: SRECTrade, https://www.srectrade.com/, accessed 10/20/23.

Agenda

- **According to Infolink (formerly PV Infolink), the top 10 module manufacturers were responsible for 160 GW (+57% y/y) in H1 2023 and the top 5 cell manufacturers together shipped 84 GW of cells (+49% y/y).**
- **Since the passage of the IRA, more than 240 GW of manufacturing capacity has been announced across the solar supply chain, representing more than 22,000 potential jobs and more than $12 billion in announced investments across 72 new facilities or expansions.**
- **In H1 2023, the U.S. shipped 3.1 GW of PV modules—an increase of 0.8 GW from H1 2022.**

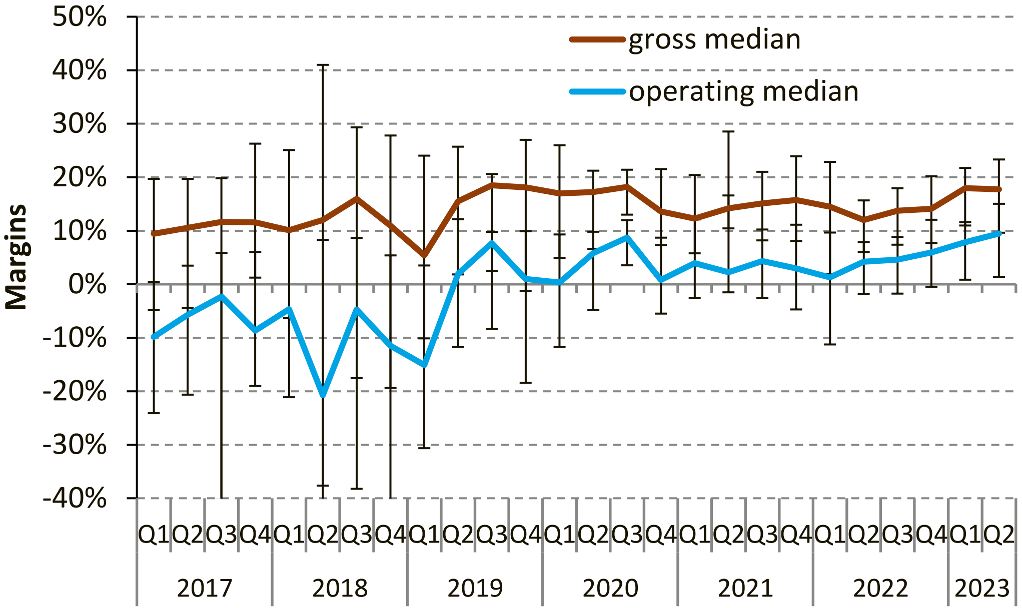
PV Shipment Rankings

Rank	H1 2023 Shipments Cells	Modules
1	Tongwei	Jinko Solar (30.8 GW)
2	Aiko	▲ LONGi (26.6 GW)
3	▲ Solar Space	▼ Trina (27 GW)
4	▼ Runergy	JA Solar (24.0 GW)
5	▲ Jietai	Canadian Solar (14.3 GW)
6		Astronergy/↑Tongwei (8-9 GW)
7		
8		Risen Energy (8-9 GW)
9		↓ DAS Solar
10		↓ First Solar (5.3 GW produced)

- According to Infolink, the top 10 module manufacturers were responsible for 160 GW of shipments (+57% y/y) in H1 2023.
  - The top four manufacturers shipped more than 100 GW in H1 2023, widening the gap from other leading manufacturers.
  - Tongwei expanded into module manufacturing last year, launching into the top 10.
  - M10/182 mm and G12/210 mm modules accounted for 98% of shipments, up from 80% in H1 2022.
  - N-type modules accounted for 18% of sales.
- The top five cell manufacturers together shipped 84.4 GW of cells in the H1 2023 (+49% y/y), accounting for 72% of 2022 annual shipments.
  - 87% of top five cell manufacturer shipments in H1 2023 used PERC technology, and another 12% used TOPCon.
  - M10 and M12 formats represented 75% and 21% of top five cell manufacturer shipments in H1 2023.

Sources: InfoLink: 2023H1 cell shipment rankings, 2023H1 Module shipment ranking, PVTech (09/01/23, 09/05/23).

PV Manufacturers' Margins



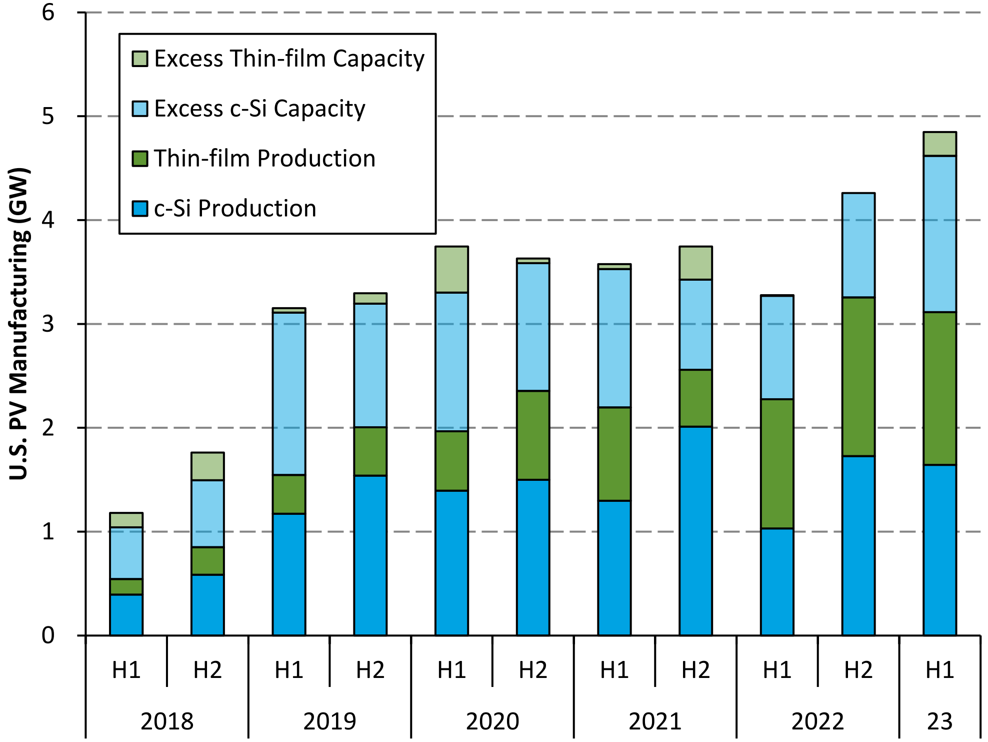
- PV manufacturers, mostly Chinese companies, have generally been profitable since 2019.
- Margins have steadily increased since 2022 due to increased shipments from leading manufacturers.
  - Increased shipments were partially offset by reduction in ASP.
  - The median gross margin of the publicly traded PV companies represented to the left was flat q/q, though up 60% y/y. The median operating margin was up 20% q/q and 125% y/y.
- There continues to be significant variation by individual companies as individual factors come into play, although variation has been substantially less since 2019.

Lines represent the median, with error bars representing 80th and 20th percentiles for the following companies in Q1 2023: Canadian Solar, First Solar, JA Solar, Jinko Solar, LONGi, Maxeon, Motech Industries, REC Silicon, Renesola, Risen, Shanghai Aiko, Shanghai Aerospace, Tongwei, Trina Solar, and United Renewable Energy. Margin data from Hanwha Q Cells, Sunpower, and Yingli are also included from Q1 2010 to Q2 2020 where available.

Note: Gross margin = revenue – cost of goods sold (i.e., the money a company retains after incurring the direct costs associated with producing the goods or services it sells); operating margin = gross margin minus overhead and operating expenses (i.e., the money a company retains before taxes and financing expenses).

Sources: Company figures based on public filings and finance.yahoo.com; PVTech (10/11/22).

U.S. PV Manufacturing



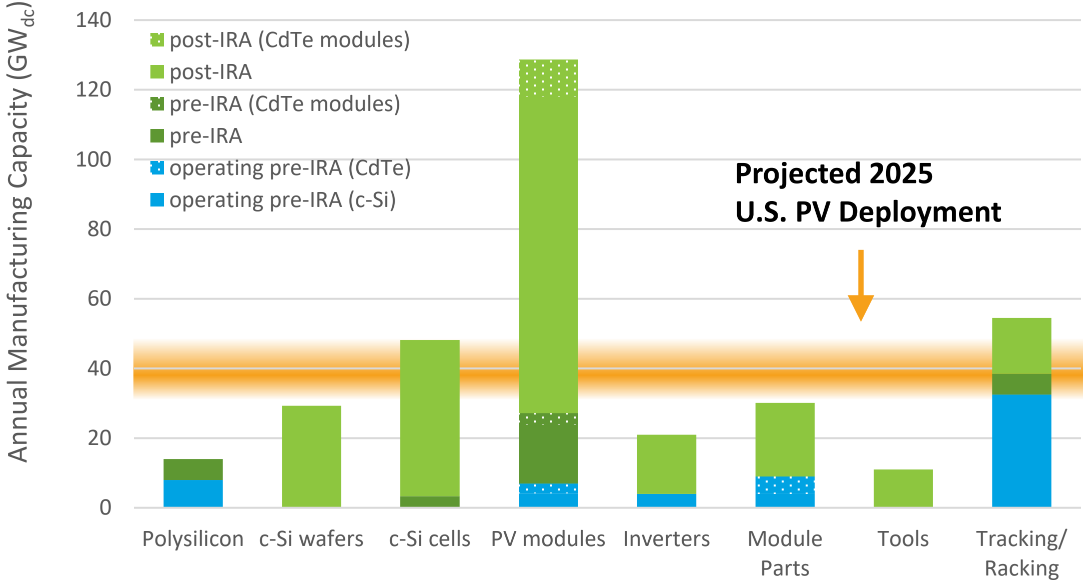
- In H1 2023, the U.S. shipped 3.1 GW of PV modules—an increase of 0.8 GW from H1 2022.
- Since 2018, U.S. module manufacturing has increased by approximately 4X, with the larger growth, both in terms of production and manufacturing capacity, coming from thin-film panels.
- Over the past year, c-Si production and capacity has been the growth leader, with production and capacity growing 59% and 55% from H1 2022 to H1 2023, respectively.
  - At the end of Q2 2023, the U.S. had an annual module manufacturing capacity of approximately 10 GW.
  - However, this growth is relatively small compared to the growth expected to come at the end of 2024 and 2025 based on corporate announcements of domestic manufacturing capacity additions as a result of the passage of IRA.
    - First Solar announced in September that it would have 6 GW of U.S. manufacturing by the end of 2023—significantly higher than what Wood Mackenzie and SEIA report for H1 2023.

Sources: Wood Mackenzie/SEIA: U.S. Solar Market Insight: Q3 2023.

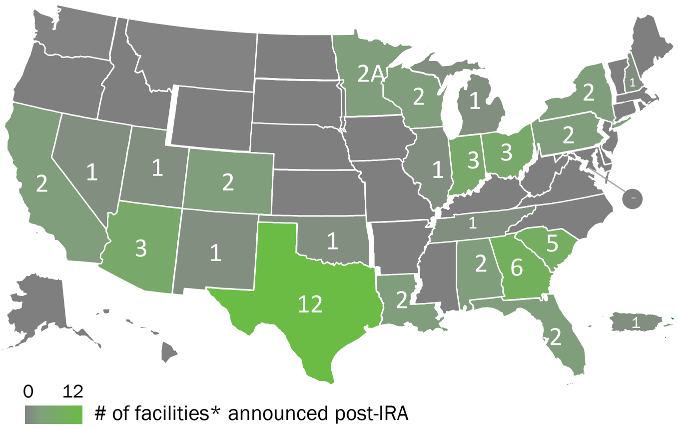
IRA Impacts on U.S. Solar PV Manufacturing Capacity

- Since the passage of the IRA, >240 GW of manufacturing capacity has been announced across the solar supply chain, representing more than 22,000 potential jobs and more than $12 billion in announced investments across 72 new facilities or expansions.*
  - 101 GW of solar module capacity (including 11 GW of CdTe)
  - 45 GW of c-Si cell capacity
  - 29 GW of c-Si wafer capacity
  - 62 GW of BOS (including glass, encapsulant, backsheet, junction boxes, inverters, trackers, tracker components, etc.)*
  - Another 35 GW of solar manufacturing capacity had been announced since the start of the Biden Administration prior to the passage of IRA.

Manufacturing Announcements by Supply Chain Segment



These announcements post-IRA represent potential investment in 23 states and Puerto Rico.

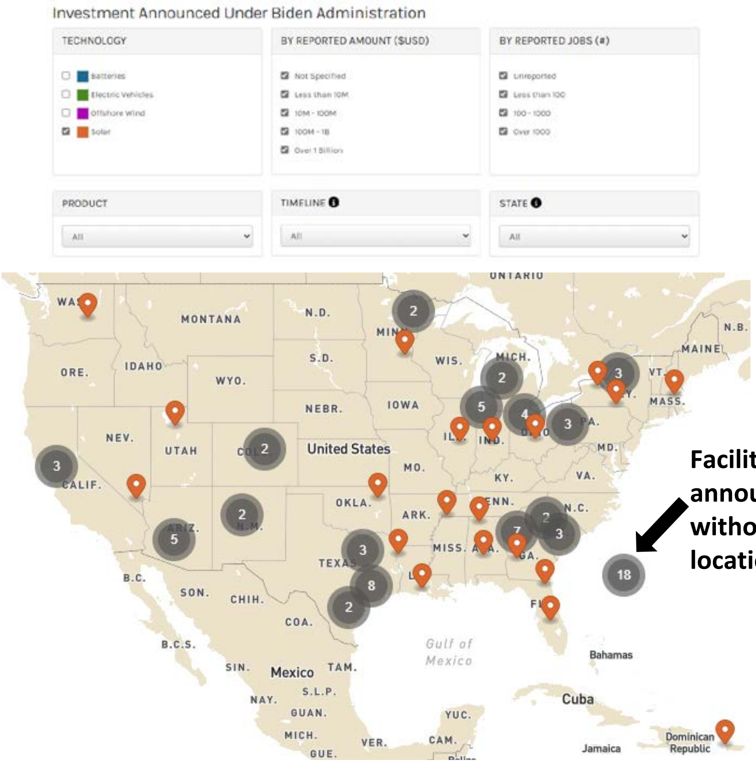


Sources: Internal DOE tracking of public announcements and BNEF Global PV Market Outlooks and Wood Mackenzie and SEIA Solar Market Insights Q2 2022 and Q2 2023.

*Not all announcements include facility locations, job, or investment numbers. See: [Building America's Clean Energy Future | Department of Energy]

Recent Manufacturing News

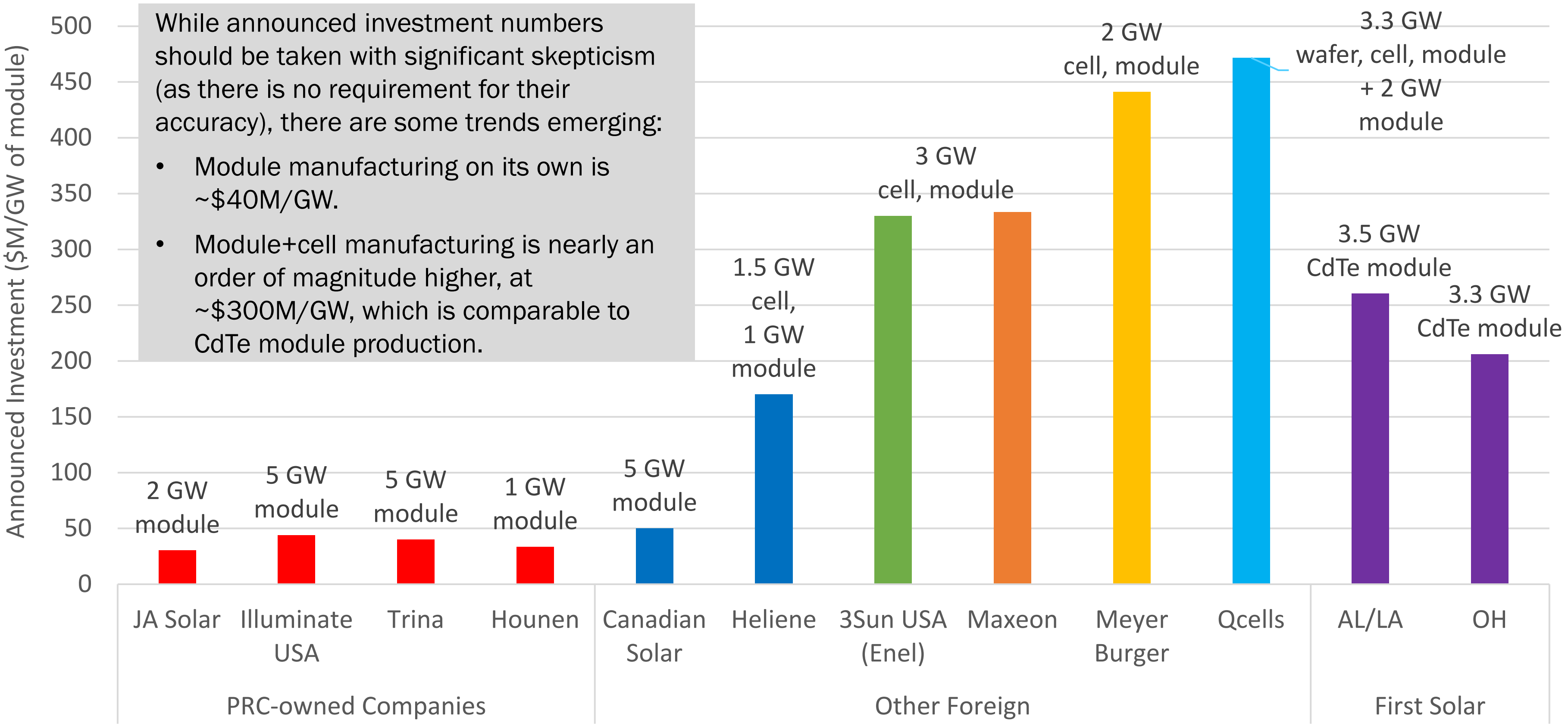
- Notable announcements over the last several months include:
  - Amphenol: ~1.2 million junction boxes/yr in Mesa, Arizona
  - Fronius: 7 GW/yr of inverters in Portage, Indiana
  - Great Lakes Solex: 6 GW/yr of modules in Aguadilla, Puerto Rico
  - JinkoSolar: 0.8 GW/yr expansion of module production in Jacksonville, Florida
  - Navitas USA by Colby: 10 GW/yr of modules
  - New East Solar: 2 GW/yr of modules in Phoenix, Arizona
  - OMCO Solar: racking, tracker components, and frames in Alabama
  - Re:Build Manufacturing: wafer production tools in Pennsylvania
  - Suniva: 2.5 GW/yr of cells in Norcross, Georgia
  - Trina: 5 GW/yr of modules in Wilmer, Texas.
- Qcells also recently announced that their module expansions in Georgia are online, bringing their total domestic nameplate capacity to 5.1 GW. First Solar's new capacity in Lake Township has also been brought online, bringing their total domestic nameplate capacity to 6.3 GW.



Facilities announced without locations

https://www.energy.gov/invest, updated 10-23-23

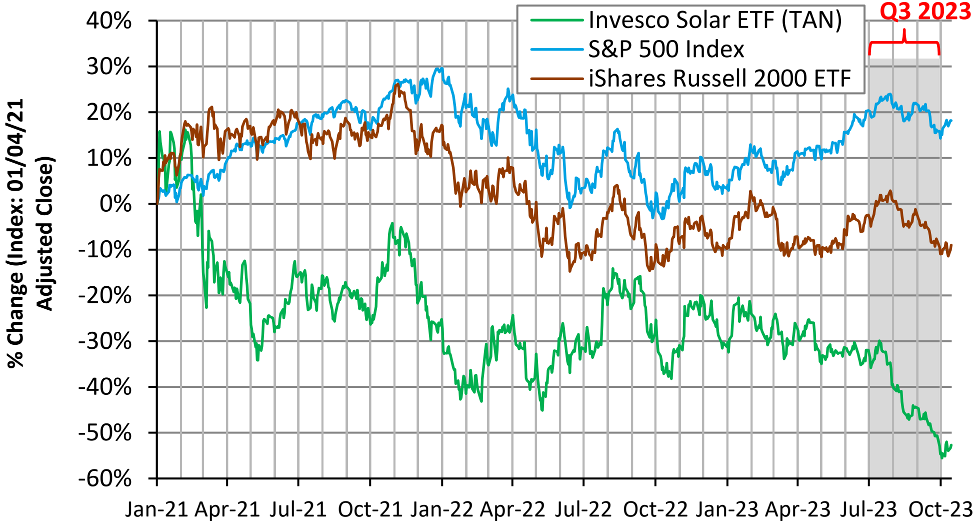
Domestic Clean Energy Announcements Costs



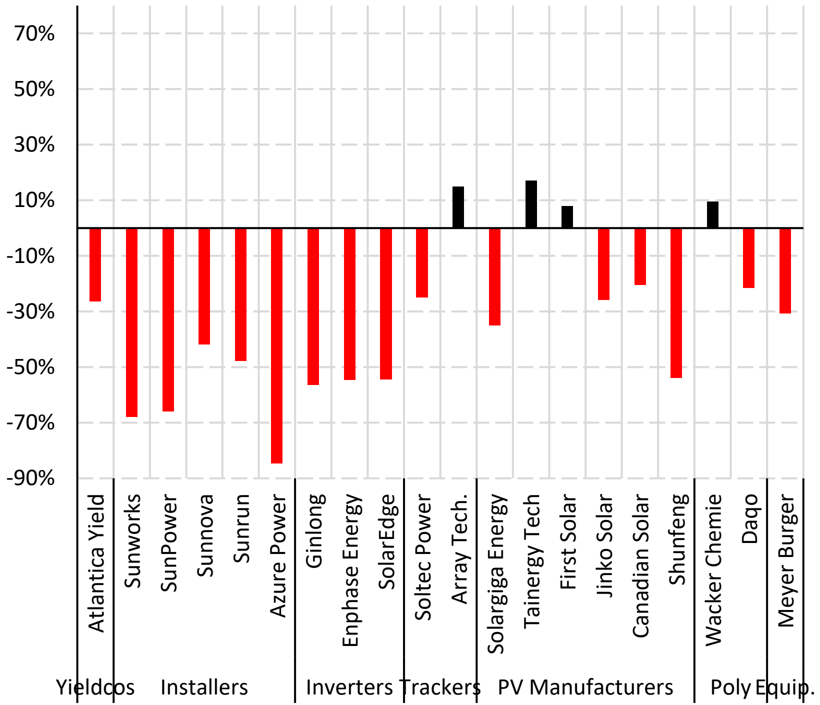
Sources: Internal DOE tracking of public announcements as of 10-23-23. *Not all announcements include facility locations, job, or investment numbers and announcements are conditional on financing, funding, site control, and other factors. See: Building America's Clean Energy Future | Department of Energy

Stock Market Activity

The Invesco Solar ETF fell 27% in Q3 2023 vs. a 4%–6% slide across the broader market. One reason was a net global outflow from renewable energy funds—which reached a record $1.4 billion in Q3 2023. The profitability of many renewable energy companies has been reduced by high interest rates and material costs as well as project delays. Solar companies have also faced overcapacity across the silicon supply chain, large module inventories, and intense competition. In addition, climate-related stocks beyond the renewable energy sector have become increasingly popular.



Individual Stock Performance (Q1-Q3 2023)



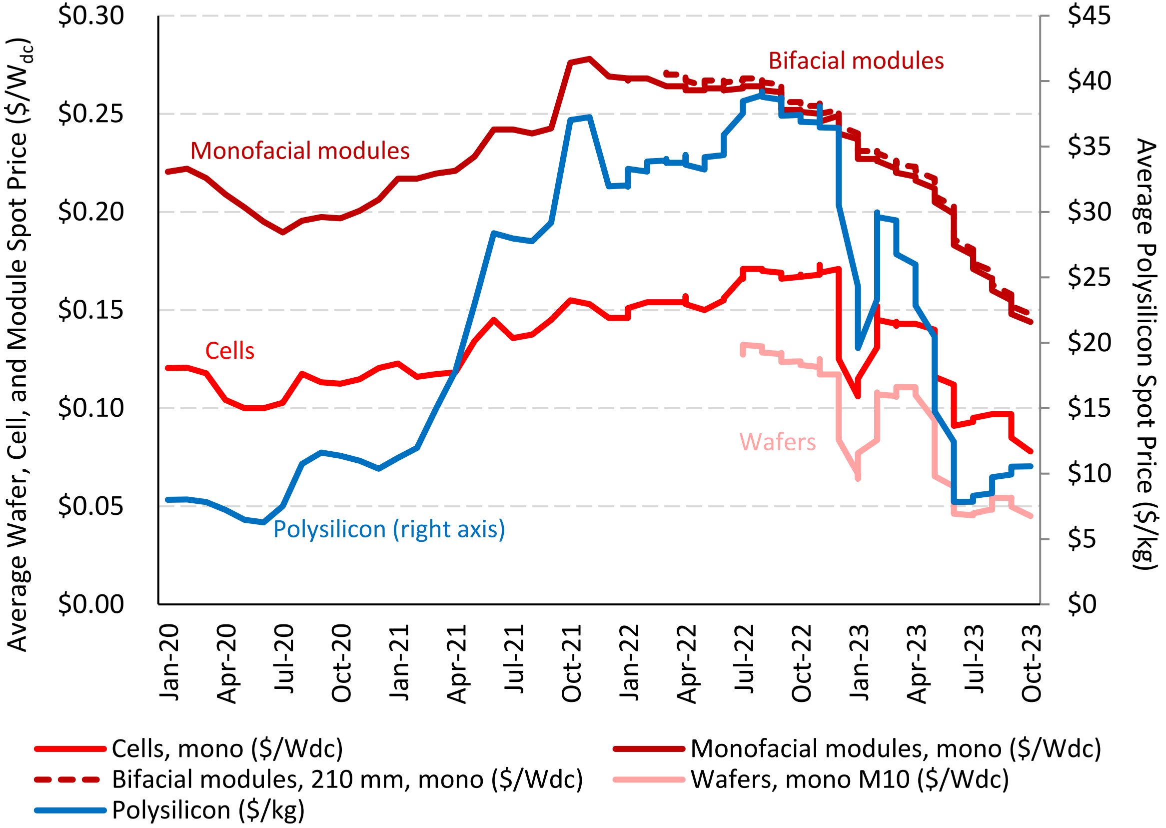
Note: The TAN index is weighted toward particular countries and sectors. As of 10/17/23, 54% of its funds were in U.S. companies and 20% were in Chinese companies. Its top 10 holdings, representing 62% of its value, were Enphase, SolarEdge, First Solar, GCL, Xinyi, Sunrun, Array Technologies, Shoals, Hannon Armstrong, and Encavis.

Sources: Invesco (10/17/23), PV Magazine (9/12/23), Reuters (10/10/23).

Agenda

- **Global polysilicon spot prices rose 35% from late June ($7.84/kg, below the weighted average production cost of $8.2/kg) to early October ($10.55/kg).**
- **Global module prices reached yet another record low, falling 21% between late June and early October to $0.14/W$_{dc}$.**
- **In Q3 2023 (first 2 months), the average U.S. module price ($0.33/W$_{dc}$) was down 11% q/q and down 23% y/y, but at a 98% premium over the global spot price for monofacial monocrystalline silicon modules.**

PV Value Chain Global Spot Pricing

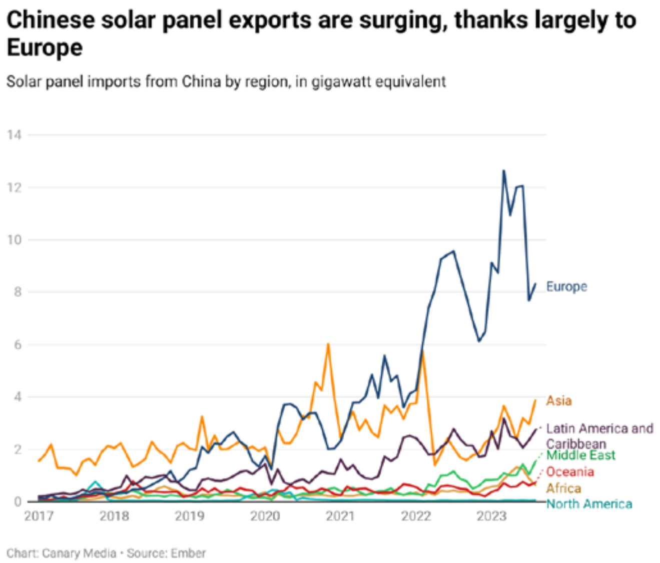


Source: BloombergNEF, Solar Spot Price Index (10/13/23); BloombergNEF, Bimonthly PV Index (9/19/23).

- Global polysilicon spot prices rose 35% from late June ($7.84/kg, below the weighted average production cost of $8.2/kg) to early October ($10.55/kg).
  - China's polysilicon production increased 91% between H1 2022 and H1 2023.
  - Additional polysilicon factories are scheduled to come online in H2 2023.
- During the same period, global prices decreased for wafers (3%) and cells (14%).
- Global module prices reached yet another record low, falling 21% between late June and early October to $0.14/W$_{dc}$.
  - Large module inventories and expectation of still-lower prices in Europe and Brazil as well as intense competition among manufacturers depressed demand and prices.
  - These low module prices threaten the profitability of many module manufacturers.

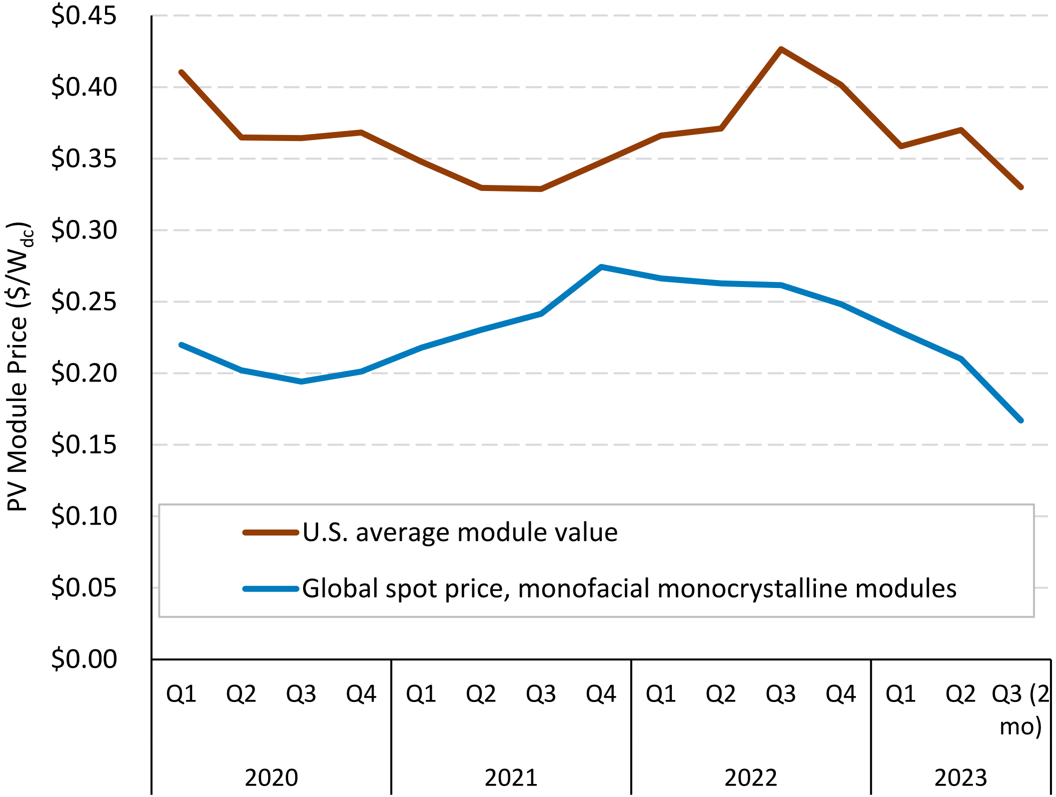
Europe PV Module Oversupply

- Between 40 and 100 GW of unsold modules in European stores, mainly in Rotterdam, Netherlands.
- The European Solar Manufacturing Council (ESMC) wrote an open letter calling for the EU to protect European manufacturers against "intentional and purposeful attack by Chinese PV manufacturers."
  - They called for a ban on forced labor products, incentives for domestic products, and sanctioned acquisition of European stock.
  - European module production has supposedly fallen from 9 GW in 2022 to 1 GW in 2023, and they have more than 500 MW of produced modules in stock that they cannot sell.
- Germany is considering imposing trade barriers on Chinese-imported modules and components.
  - SolarPower Europe has voiced opposition to such trade barriers and instead recommended adjusting the EU State Aid framework, adopting the EU Net-Zero Industry Act, or creating a Solar Manufacturing Bank.
- Norwegian Crystals went bankrupt in August, and Norsun announced a temporary halt and layoffs in September.



Sources: pv magazine, PVTech 1 & 2, Canary Media, Bernreuter and pv magazine

Module Prices: Global vs. United States

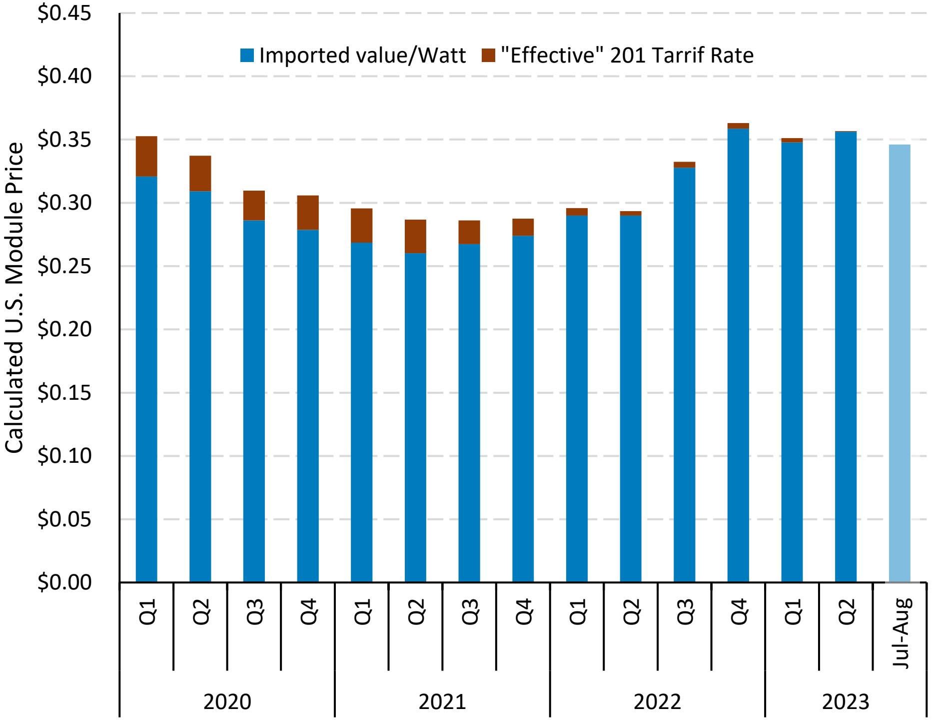


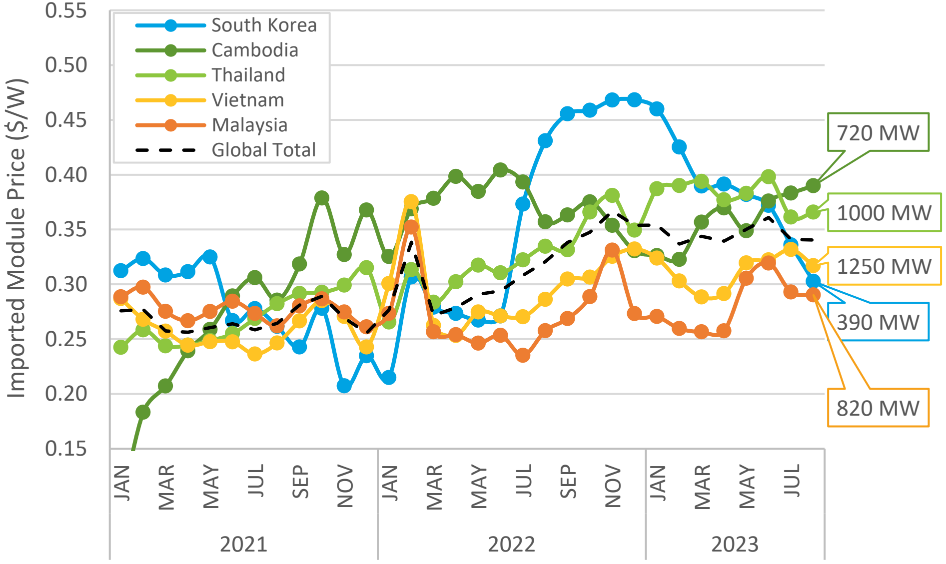
- In Q3 2023 (first 2 months), the average U.S. module price ($0.33/$W_{dc}$) was down 11% q/q and down 23% y/y, but at a 98% premium over the global spot price for monofacial monocrystalline silicon modules.
- The directional trend in U.S. module prices realigned with the trend in global module prices, although the difference between the two prices remained the same ($0.16/$W_{dc}$).
  - U.S. prices were depressed by oversupply and large distributor inventories.
  - Detainment periods for imported modules under the Uyghur Forced Labor Prevention Act (UFLPA) have fallen from months to weeks as major manufacturers have documented their avoidance of forced labor, which is freeing up supply and reducing prices.

Source: BloombergNEF, Solar Spot Price Index (10/13/23); BloombergNEF, Bimonthly PV Index (9/19/23); EIA, Monthly Solar Photovoltaic Module Shipments Report (10/17/23); Wood Mackenzie & SEIA, US Solar Market Insight: Q3 2023 (9/23).

Calculated U.S. Module Pricing

- Based on the reported value and capacity of imported PV modules, the average price of a PV module in the United States rose less than a penny q/q in Q2 2023 to $0.36/W and is on track to fall back to $0.35/W in Q3.
  - These price changes have been nonuniform across countries, with prices declining mostly steeply for imports from South Korea after a peak at the end of 2022, while prices from Vietnam, Thailand, Cambodia, and Malaysia have generally risen over that time.





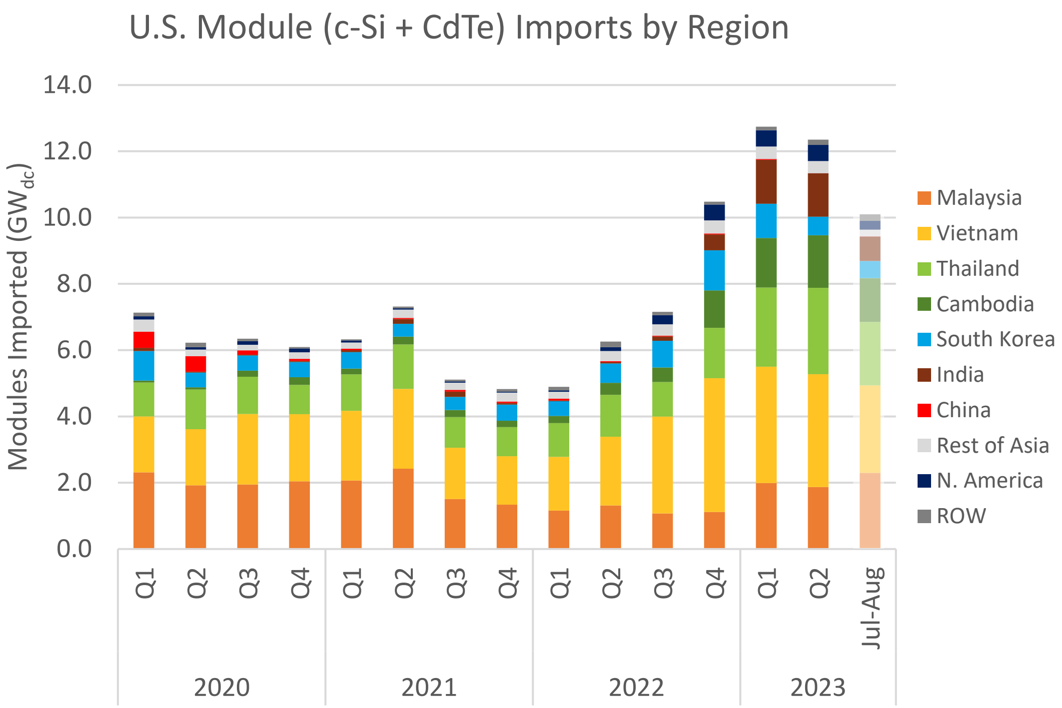
Note: Manual corrections were made to three values due to suspected data entry errors for HTS code 8541430010: Cambodia (February 2022), Malaysia (June 2020), and Vietnam (July 2019).

Sources: Imports by HTS code: 8541460015(2018-2021)/8541430010(2022-), Customs Value and Second Quantity (watts) from the U.S. International Trade Commission DataWeb, the U.S. Census Bureau USA Trade Online tool, and corrections page.

Agenda

- **The United States imported 25.1 GW_{dc} of PV modules in H1 2023, well over double imports from H1 2022.**
  - Most panels imported were exempt from Section 201 duties and were therefore likely bifacial. A significant number of thin-film modules were also imported.
- **1.5 GW_{dc} of cells were imported in H1 2023, up 28% y/y.**
  - The U.S. is not on pace to reach the 5-GW quota exemption limit for Section 201 tariffs.

Module Imports and Calculated Prices by Region

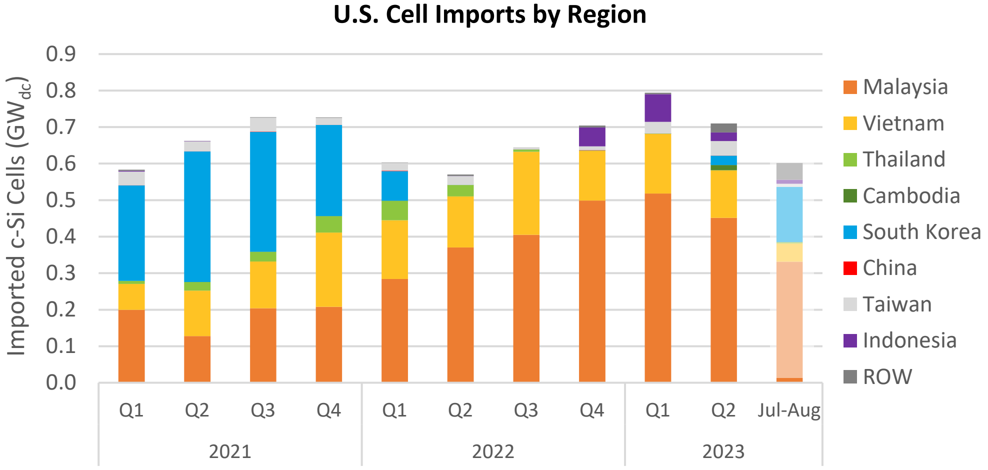


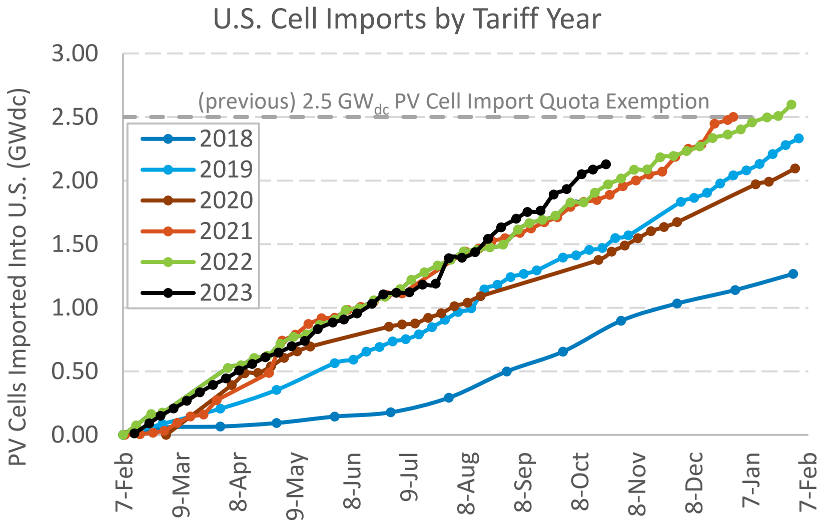
- In Q2 2023, U.S. module imports remained near record-high levels (+200%, or 6 GW y/y), totaling 25.1 GW_{dc} in H1 2023.
  - Import levels decreased after the withhold release order (WRO) on PV cells and modules was announced in late Q2 2021. Additionally, many manufacturers in Southeast Asia had reduced production levels earlier in the year with the announcement of a U.S. anti-circumvention investigation and when the 2-year waiver was announced in June; however, the supply chain appears to be recovering from those disturbances.
  - The slight Q2 q/q decrease was mainly the result of decreased imports from South Korea (−35% q/q, −390 MW), as modest changes across the four main SE Asia importers generally cancelled each other out in Q2.
  - Both Q2 2023 (+99%, +6.25 GW) and H1 2023 (+127%, +14 GW) imports are still up significantly y/y.
- While Q3 is not yet complete, it has already nearly matched Q4 2022 imports.
  - This has been mainly the result of imports from Vietnam and Malaysia, which totaled nearly 2.7 GW (1.9 GW c-Si + 0.8 GW thin film) and 2.3 GW (1.3 GW c-Si + 1 GW thin film), respectively, over July and August.

Sources: Imports by HTS code: 8541460015(2018-2021)/8541430010(2022-) and 8541460035(2018-2021)/8541430080(2022-), Second Quantity (watts) from the U.S. International Trade Commission [DataWeb] as well as the U.S. Census Bureau [USA Trade Online tool] and [corrections page] as of 10/25/23. Manual corrections were made to imports from India in due to suspected data entry errors

c-Si Cell Import Data

- According to U.S. Census data, 1.5 GW_{dc} of cells were imported in H1 2023, an increase of 28% relative to H1 2022. However, quarterly cell imports declined for the first quarter since Q2 2022 in Q2 2023.
  - This was mainly the result of declines in imports from Malaysia (−13%, −67 MW) and Vietnam (−21%, −33 MW) q/q, although imports in Q3 look to be recovering as a result of increased imports from South Korea.
- Despite both the increased quota exemption from 2.5 GW_{dc} to 5.0 GW_{dc} for the Section 201 tariffs in February 2022 and the recent capacity expansions announced in 2023, imports remain on track to just barely exceed those of 2021/2022, according to CBP Commodity Status Reports.





Sources: Imports by HTS code: 8541460025(2018-2021)/8541420010(2022-), , Second Quantity (watts) from U.S. Census Bureau USA Trade Online tool and corrections page as of 10/25/23; U.S. Customs and Border Protection Commodity Status Reports February 2019–October 2023.

Final SE Asia AD/CVD Circumvention Determination

In December, the Department of Commerce issued a preliminary decision to impose anti-circumvention duties on some solar panels and cells produced in Vietnam, Malaysia, Thailand, and Cambodia.

Country	Determination	Company Investigated*	Determination
Malaysia	Circumventing	Hanwha Qcells	Not
		JinkoSolar	Not
Vietnam	Circumventing	Boviet	Not
		Vina Solar	Circumventing
Thailand	Circumventing	Canadian Solar	Circumventing
		Trina	Circumventing
Cambodia	Circumventing	BYD Hong Kong	Circumventing
		New East Solar	~~Not~~ Circumventing

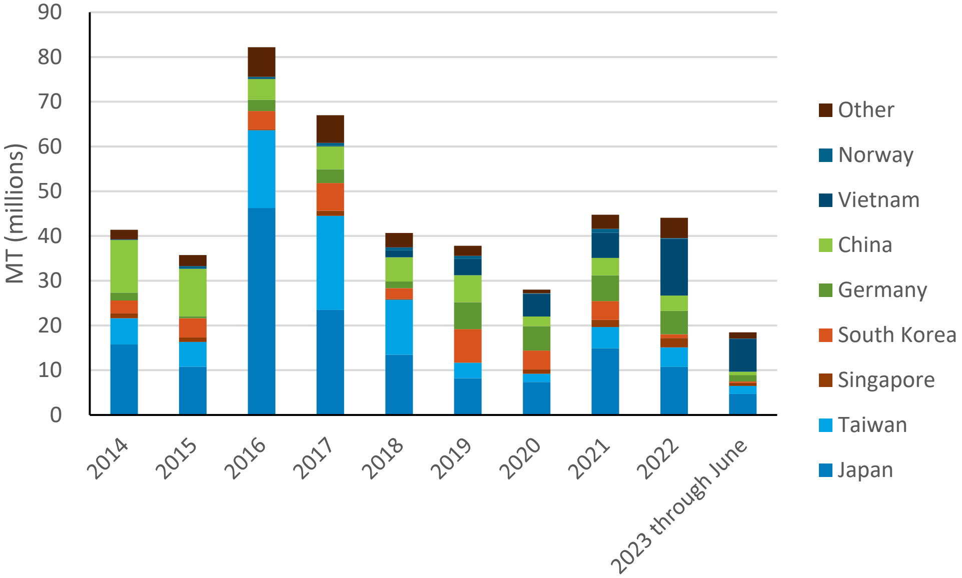
*~~22~~ 20 companies that did not respond to Commerce's request for information were declared in violation by default and may not simply certify that their panels meet the component threshold, but instead be fully reviewed

- The final determination, released on August 18, 2023, upheld all but one of these determinations. *Red indicates a change between preliminary and final decision.*

- Imported SE Asian panels will be treated as Chinese if they are made from wafers produced in China and have more than two other components produced in China. The other components are silver paste, aluminum frames, glass, backsheet, ethylene vinyl acetate sheets, and junction boxes.
- If companies already have a set duty in place for Chinese AD/CVD, then those AD/CVD values will be used (e.g., Canadian Solar's AD/CVD rates are 16%), if not, China-wide rates of 254.19% will be used. Due to the temporary moratorium these rates will not go into effect until June 2024.

U.S. Silicon Exports (>99.99% Purity)

- The U.S. tracks the export of silicon, with a purity exceeding 99.99%, which is used within the semiconductor industry (9N+), for fire-resistant material (4N+. e.g., spray coating), and for PV wafers (9N).

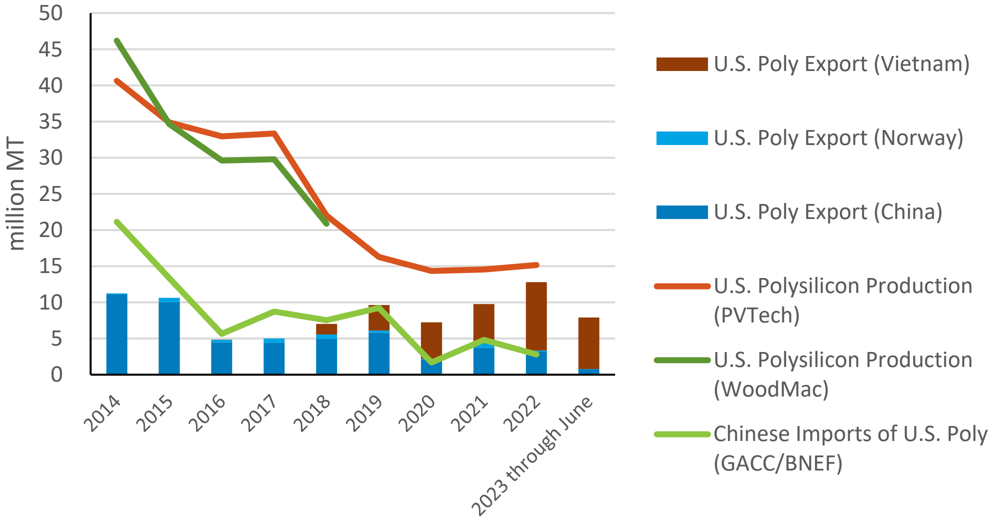


Source: U.S. Census Bureau.

- In 2014, China finalized duties of more than 50% on solar-grade polysilicon (6N+) imported from the U.S., including closing a loophole in September of that year that had previously exempted duties if the polysilicon was used in the production of exported goods (like PV modules).
- Despite the Chinese tariffs, which continue to be in place, U.S. silicon exports significantly increased in 2016, aided by the opening of the largest U.S. polysilicon manufacturing plant—the 20,000 MT Wacker facility in Tennessee, which received a 48C credit.
  - Hemlock abandoned a multibillion-dollar polysilicon plant in Tennessee in 2014 before it opened due to the implementation of the Chinese tariffs. Hemlock received a 48C credit for a plant in Michigan.
- From 2015 through 2022, 56% of U.S. exports went to Japan, Taiwan, and Singapore, likely for use in the semiconductor industry.
- Shipments to Vietnam have grown in recent years, likely due to the rapid expansion of its PV wafer manufacturing capacity.

Estimates of U.S. Polysilicon Market

- Chinese duties significantly cut U.S. PV-grade polysilicon production, but estimates vary by how much.

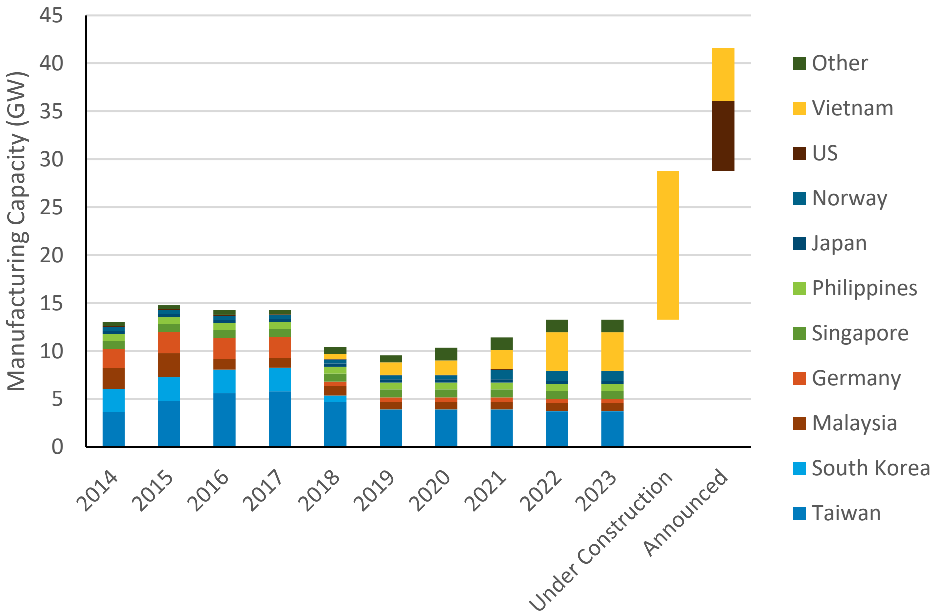


Note: U.S. poly exports include silicon exports of greater than 99.99% from the following states with active or previously active polysilicon production: Michigan, Tennessee, Washington, Montana, and Texas.

Sources: U.S. Census Bureau, PVTech Market Research (May 2023), China's General Administration of Customs(GACC); BNEF, "Bimonthly PV Index, July 2023"; Wood Mackenzie, "U.S. Solar Market Insight" 2014-2018.

- In addition to the duties, China also significantly expanded its domestic polysilicon manufacturing capacity at this time.
  - PVTech/WoodMac estimate production fell from 40,000 MT to 15,000 MT.
  - Chinese import data fell from 21,000 MT to 7,000 MT.
  - U.S. export data to China fell from 11,000 MT to 5,000 MT.
- PVTech/WoodMac data would imply that from 2014 to 2018, virtually all non-Chinese PV wafer manufacturing used U.S. polysilicon, there was a large amount of U.S. polysilicon in inventory, or they are erroneously including semiconductor-grade silicon in their production estimates.
- Silicon shipped to Vietnam increased by more than 5X from 2018 to 2022, aided by the 7X increase in Vietnamese wafer manufacturing capacity and the difficulties with U.S. buyers purchasing products with Chinese wafers.
- In 2020, the China and the United States agreed to a Phase 1 trade deal that included the purchase of U.S. polysilicon—that has not appeared to increase U.S. exports of polysilicon to China.

Non-Chinese Wafer Manufacturing Capacity



- Bloomberg tracked approximately 10–15 GW of manufacturing capacity outside of China (which they estimate to be 480 GW in 2023).
- Vietnamese wafer manufacturing capacity increased from 500 MW to 4 GW from 2018 to 2022. Another 15.5 GW is under construction and another 5.5 GW has been announced, which would provide more than enough of a market for U.S. polysilicon, assuming they are competitive.
- BNEF reported average polysilicon price to be $9.72/kg at the end of August 2023, down from $39/kg the previous August.
  - If Chinese polysilicon is allowed to be used in products heading to the U.S. (either through proper documentation of a supply chain outside of Xinjiang or through a lack of enforcement), U.S. polysilicon would face tremendous price pressure.

Source: BNEF.

Agenda

1	Global Solar Deployment
2	U.S. PV Deployment
3	PV System Pricing
4	Global Manufacturing
5	Component Pricing
6	U.S. PV Imports
7	**PV Domestic Content**

- **This section summarizes NREL analysis of the percentage of domestically produced content in the U.S. PV supply chain before the passage of the Inflation Reduction Act.**

IRA Domestic Content Bonus: Guidance for Manufactured Products

- In May, the U.S. Treasury and IRS issued initial guidance on how to qualify for the domestic content bonus:
  - 100% of ***steel products*** must be U.S.-made.
  - Through 2024, 40% of ***manufactured products*** total direct costs must be U.S.-made (this number rises to 55% by 2027).
- The "Adjusted Percentage Rule" is used for evaluating domestic content in ***manufactured products***.*
  - This rule only considers direct costs (defined as direct labor and material/components).
  - Direct labor costs for products manufactured in the U.S. only count as domestic value if all material/components in the product are of U.S. origin.
- To evaluate the U.S. ability to meet domestic content criteria ***prior*** to IRA, we present an assessment of the **2021 U.S. PV market** in the following slides. Sankey diagrams are used to illustrate domestic value in different products for different market sectors, which are generated from a more detailed spreadsheet.

*See slides 16-21 in the Summer 2023 Industry Update for more detail and examples on how the Adjusted Percentage Rule is used to calculate the domestic content percentage for manufactured products

Two Types of Domestic Content Analysis

"Total costs" diagrams

- Captures costs for steel products and manufactured products only (no installation labor, interconnection, etc.).
- All indirect costs are grouped together (utilities, equipment, margin, etc.).
- All labor and indirect costs for domestic facilities are classified as domestic (to illustrate broader domestic economic value).
- All other value is designated "imported."

Steel products:
- Ground-mount racking
- Other structural balance of system (SBOS)

"Direct costs" diagrams

- Only captures manufactured products (i.e., no steel products).
- Represents costs for direct labor and material/components only, even for imported products.
- Labor is only designated as domestic for products that have 100% domestic material/components.
- All non-domestic value is designated as "other."

Manufactured products:
- PV modules
- Inverters
- Electrical balance of system (EBOS)
- Trackers
- Roof racking

2021 Market Features and Simplifications

Market Sectors in 2021

- Utility: 17 GW installed
  - Approximately all utility systems use single-axis trackers.
  - 15.3 GW of trackers are made in U.S. (domestic components assumed).
  - All other SBOS estimated to be domestic.
- Commercial: 2.4 GW installed
  - Approximately 60% of commercial systems use flat-roof racks, 40% are ground-mounted.
  - All commercial racking and SBOS estimated to be domestic.
- Residential: 4.2 GW installed
  - Approximately all residential systems use c-Si modules.
  - All residential racking estimated to be domestic.
  - Estimates 60% of systems use microinverters, 40% use string inverters with DC-optimizers. Approx. 0.5 GW are U.S.-assembled with imported components.

PV Technology in 2021

c-Si modules: 18.9 GW installed

- All c-Si module components estimated to be imported.
- All 3 GW of U.S.-assembled c-Si modules estimated to go to residential sector.

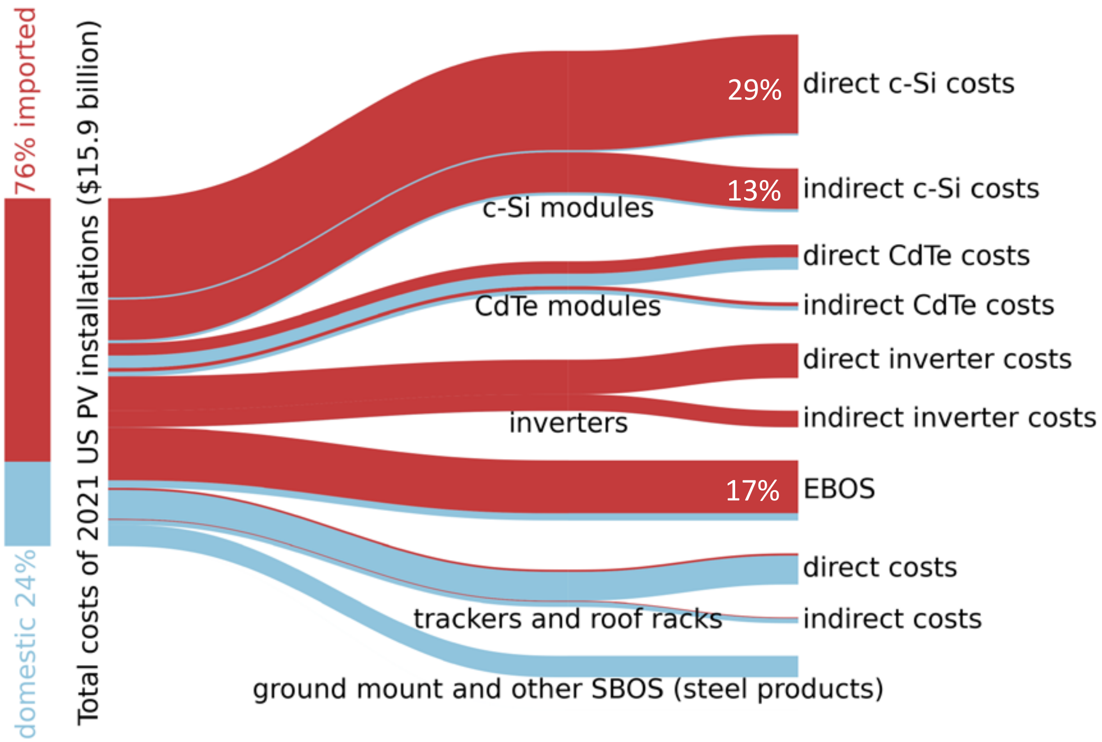
CdTe modules: 4.7 GW installed

- Approximately 75% of components in U.S.-CdTe modules (2.8 GW) are domestic.
- All CdTe modules estimated to be installed in utility sector.

Inverters and EBOS

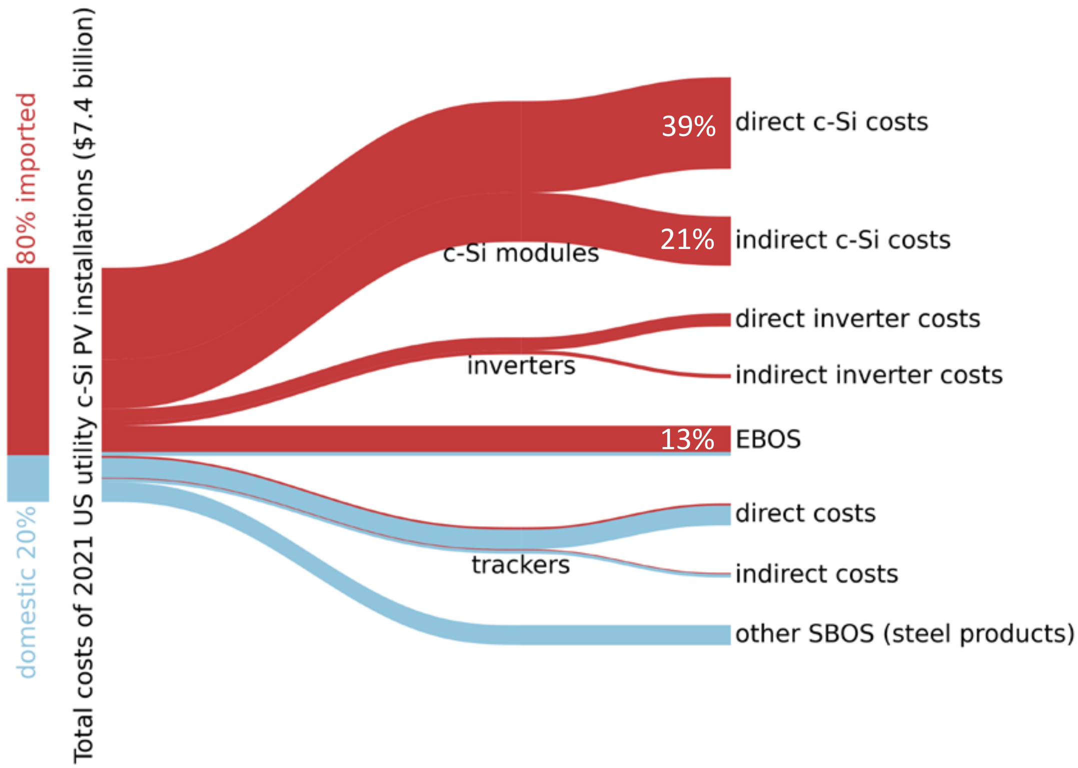
- All utility and commercial inverters estimated to be imported.
- All EBOS besides combiner boxes assumed to be imported.

Total Costs:
U.S. PV Market in 2021



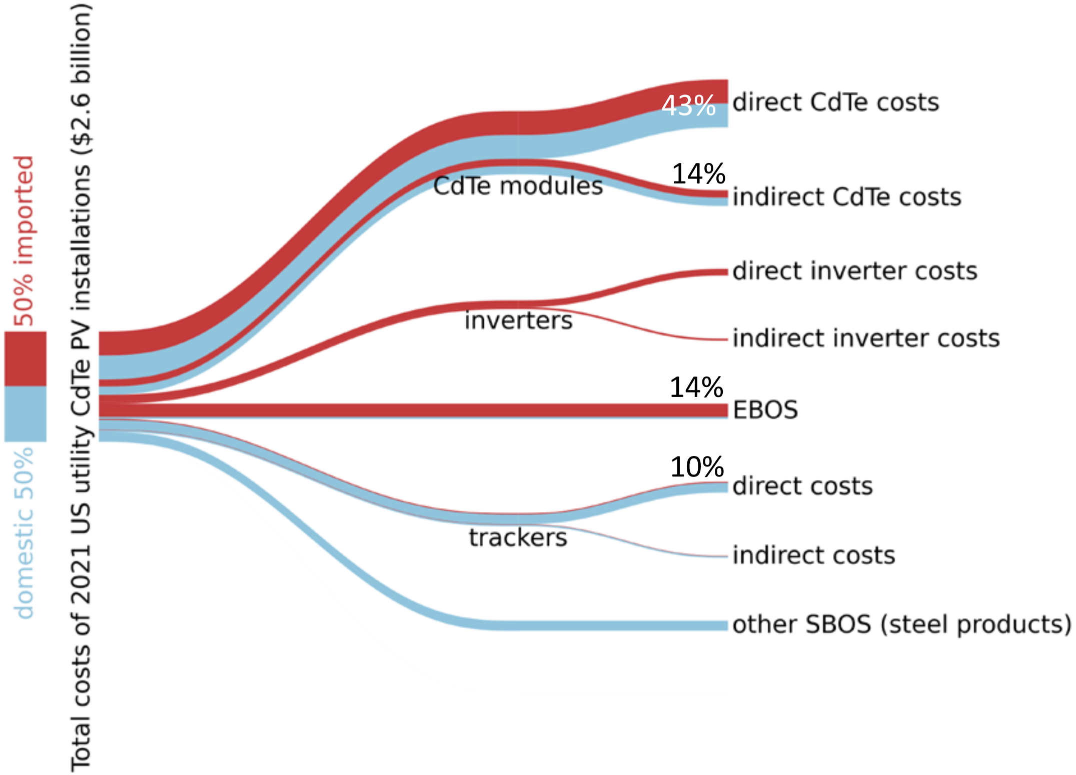
- Total costs across the entire 2021 U.S. market (all system types)
  - Weighted by installs per sector (total 23.6 GW).
  - 24% average domestic value; significantly below criteria for domestic content bonus.
    - This percentage includes indirect costs and steel products.
  - Most imported value is coming from silicon modules, inverters, and EBOS.
  - Direct costs are larger contribution to total than indirect costs.

Total Costs:
c-Si Utility Systems in 2021



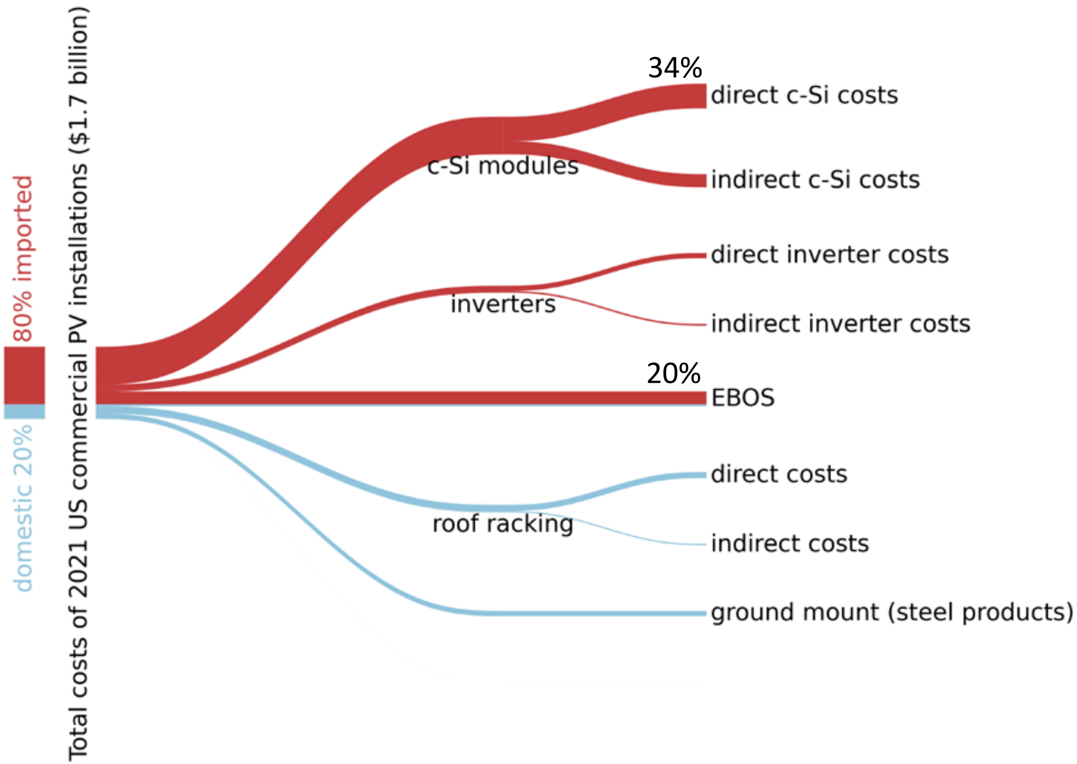
- Total of 12.3 GW.
- 20% average domestic value; significantly below criteria for domestic content bonus.
  - This percentage includes indirect costs and steel products.
- This represents an average system (i.e., 90% of a domestic tracker).
- Most imported value is coming from silicon modules, inverters, and EBOS.
- c-Si modules have largest contribution of indirect costs.

Total Costs: CdTe Utility Systems in 2021



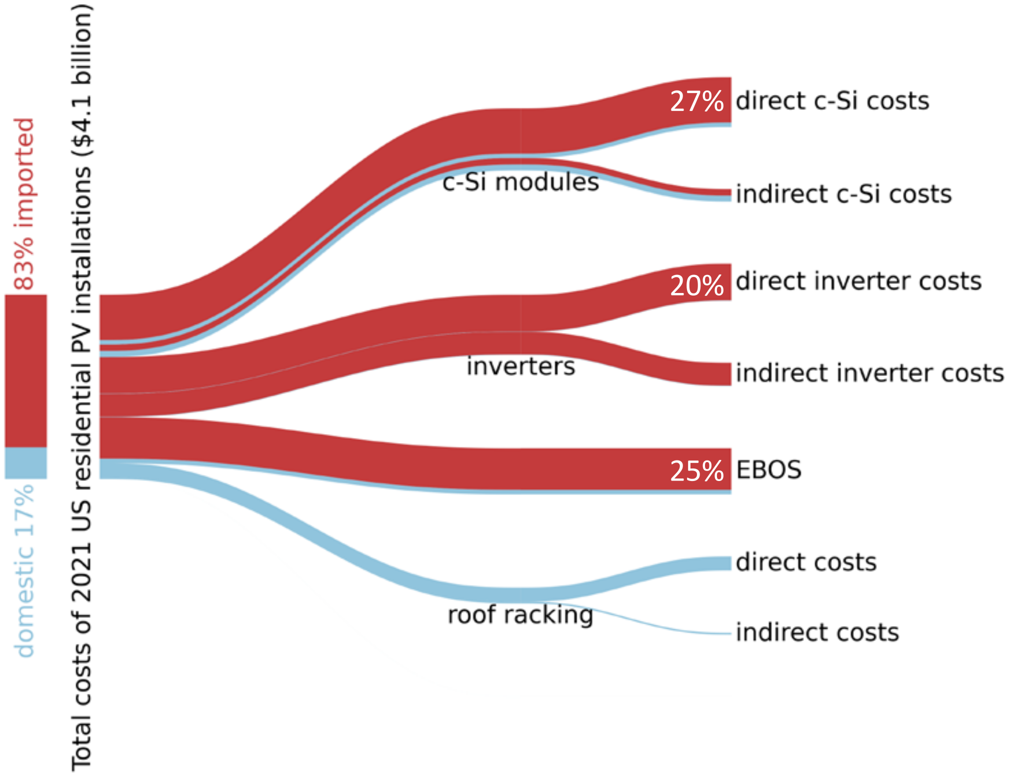
- Total of 4.7 GW.
- 50% average domestic value; exceeds 2024 criteria for domestic content bonus.
  - This percentage includes indirect costs and steel products.
- Keep in mind, this represents an average system (i.e., 60% of a domestic CdTe module).
- Most imported value is coming from inverters, EBOS, and 40% of CdTe modules, which are imported.

Total Costs: Commercial Systems in 2021



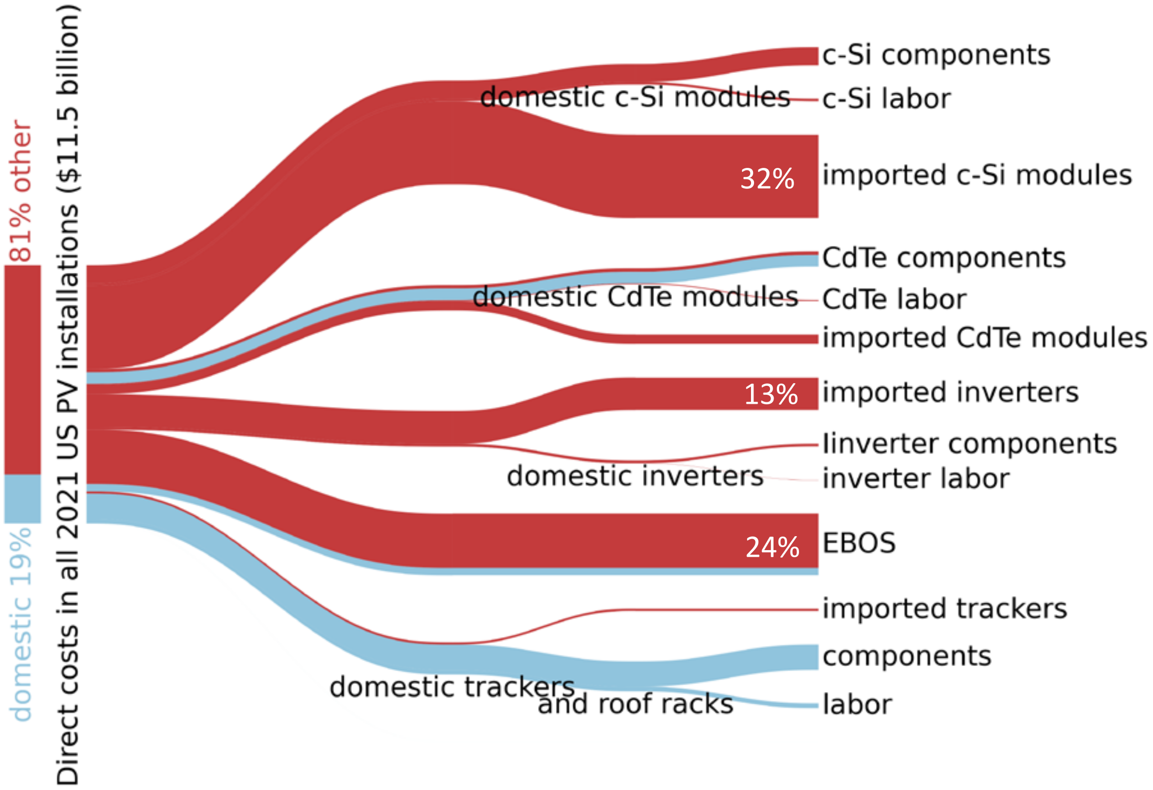
- Total of 2.4 GW.
- 20% average domestic value; significantly below criteria for domestic content bonus.
  - This percentage includes indirect costs and steel products.
- Most imported value is coming from silicon modules, inverters, and EBOS.

Total Costs: Residential Systems in 2021



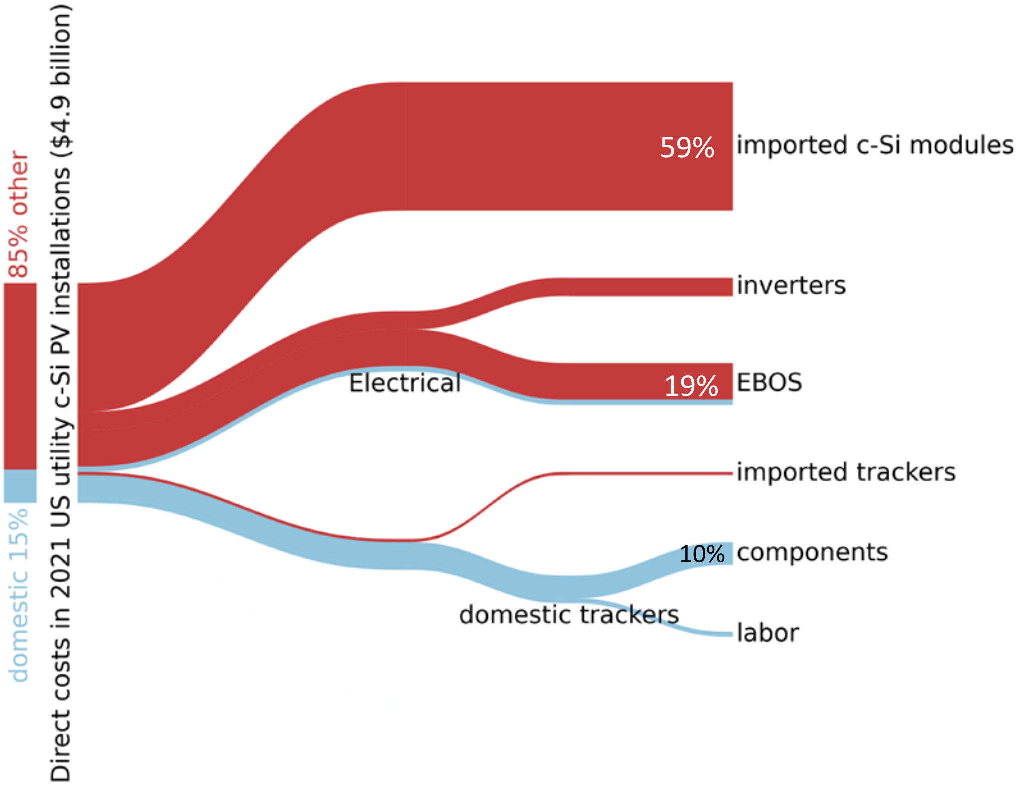
- Total of 4.2 GW.
- 17% average domestic value; significantly below criteria for domestic content bonus.
  - This percentage includes indirect costs (no steel products in residential systems).
- This represents an average system (i.e., 71% of a domestic c-Si module).
- While 3 GW of these modules are U.S.-assembled, none of the module components are domestic.
- The absence of steel products and greater expense of residential c-Si modules and inverters contribute to the large fraction of imported value.

Total 2021 Market (Direct Costs Only)



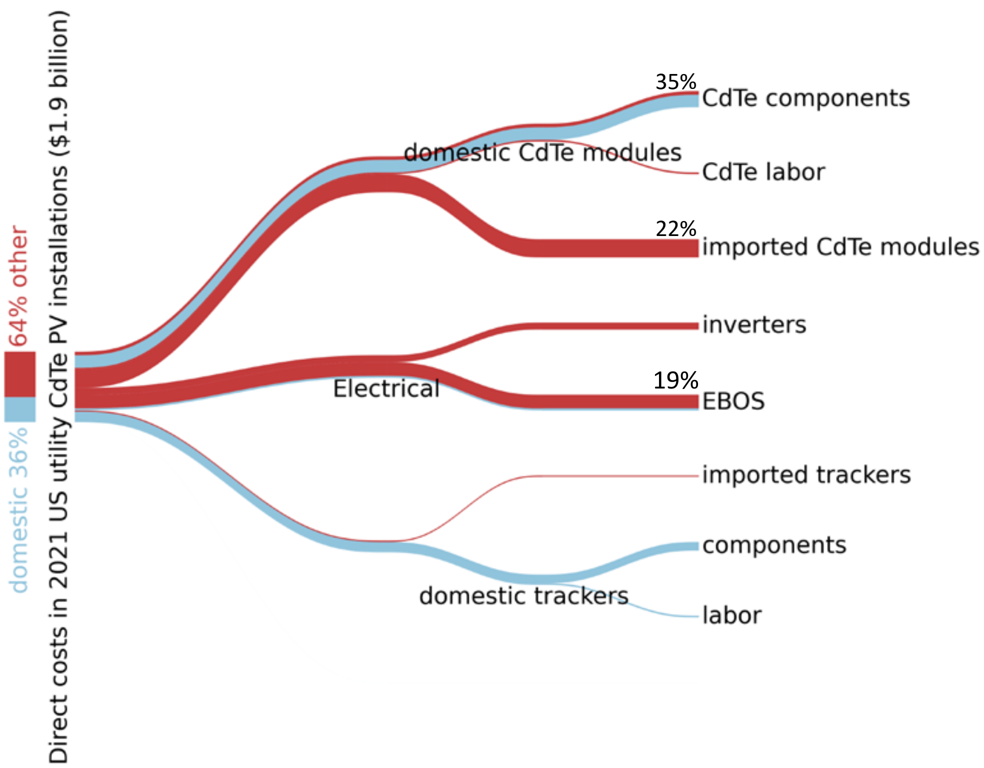
- Total **direct** costs across the entire 2021 U.S. market (all system types).
  - Weighted by installs per sector (total 23.6 GW).
  - 19% average domestic value; significantly below criteria for domestic content bonus.
    - Steel products *not* included in this version.
  - Non-domestic value mostly coming from silicon modules and EBOS.
  - Domestic silicon modules are not assigned any domestic value because all input materials/components are imported.

2021 c-Si Utility Systems (Direct Costs Only)



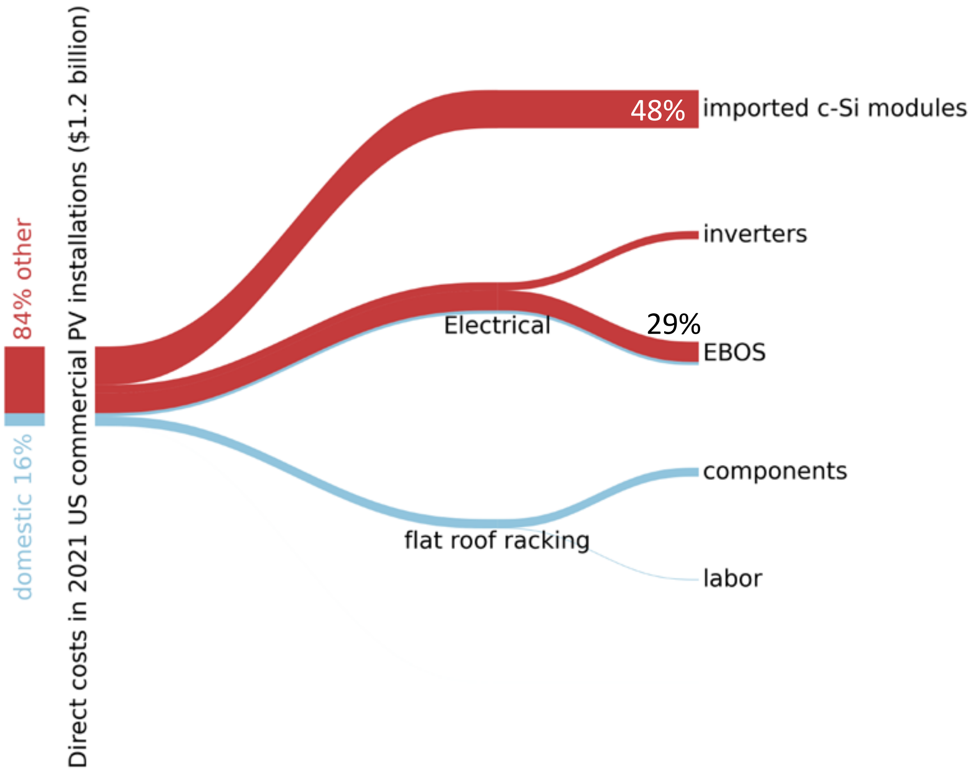
- Total of 12.3 GW.
- 15% average domestic value; significantly below criteria for domestic content bonus.
  - This version does *not* include steel products.
- This represents an average system (i.e., 90% of a domestic tracker).
- Non-domestic value is mostly coming from silicon modules, inverters, and EBOS.
- Domestic value is mostly coming from trackers and combiner boxes.

2021 CdTe Utility Systems (Direct Costs Only)



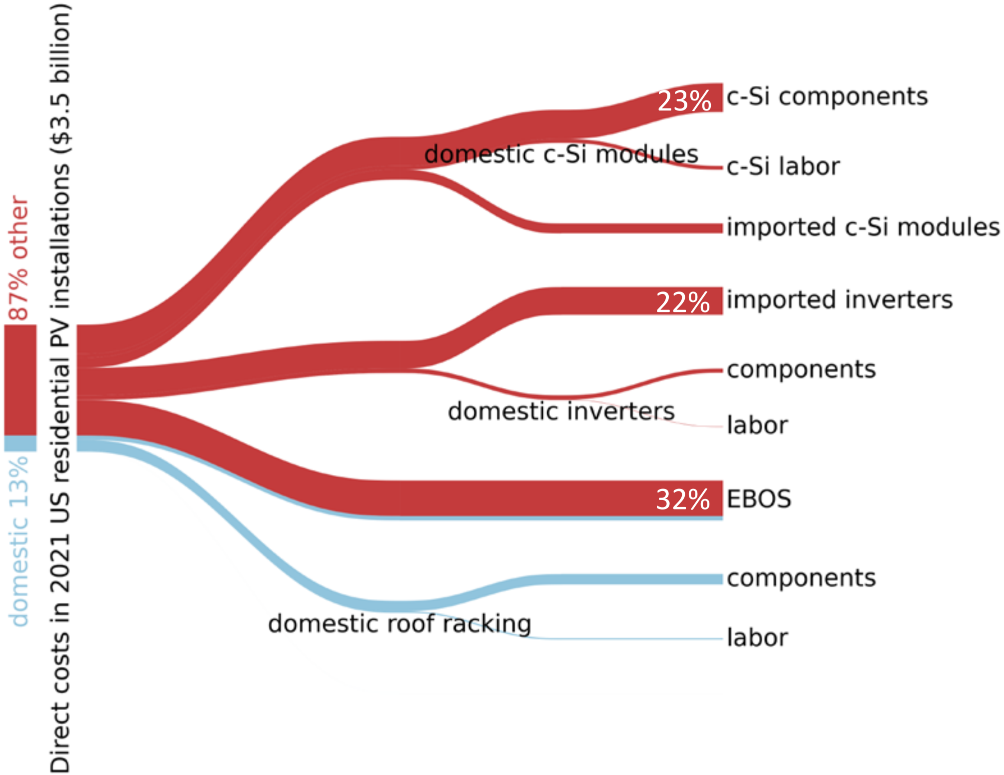
- Total of 4.7 GW.
- 36% average domestic value; does not meet criteria for domestic content bonus.
  - This version does *not* include indirect costs, steel products, or domestic CdTe labor.
- Keep in mind, this represents an average system.
  - 60% of a domestic CdTe module.
  - 90% of a domestic tracker.
- Most imported value is coming from inverters, EBOS, and the 40% of CdTe modules that are imported.

2021 Commercial Systems (Direct Costs Only)



- Total of 2.4 GW.
- 16% average domestic value; significantly below criteria for domestic content bonus.
- Steel products (ground-mount racking) are not included in this version, which makes modules and inverters have a larger impact.

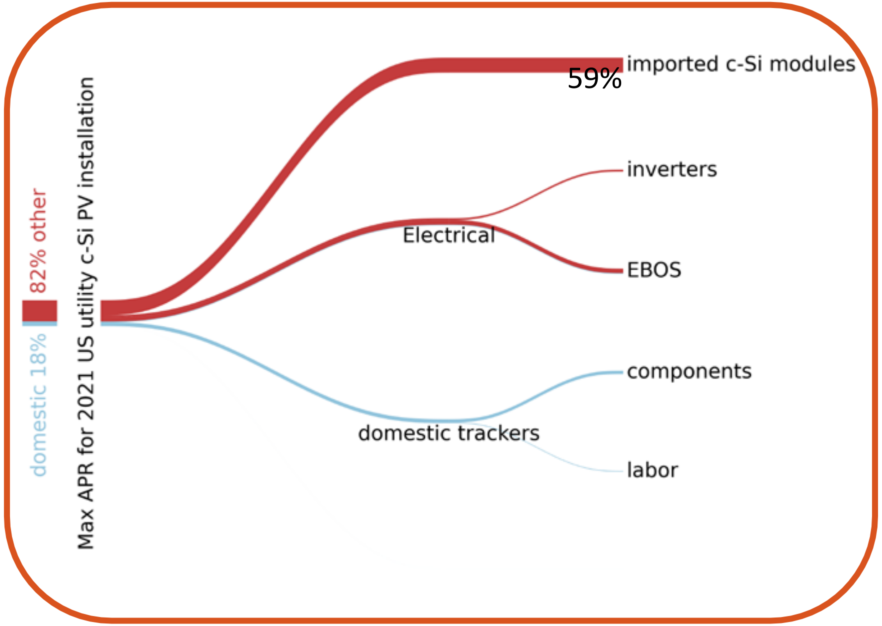
2021 Residential Systems (Direct Costs Only)



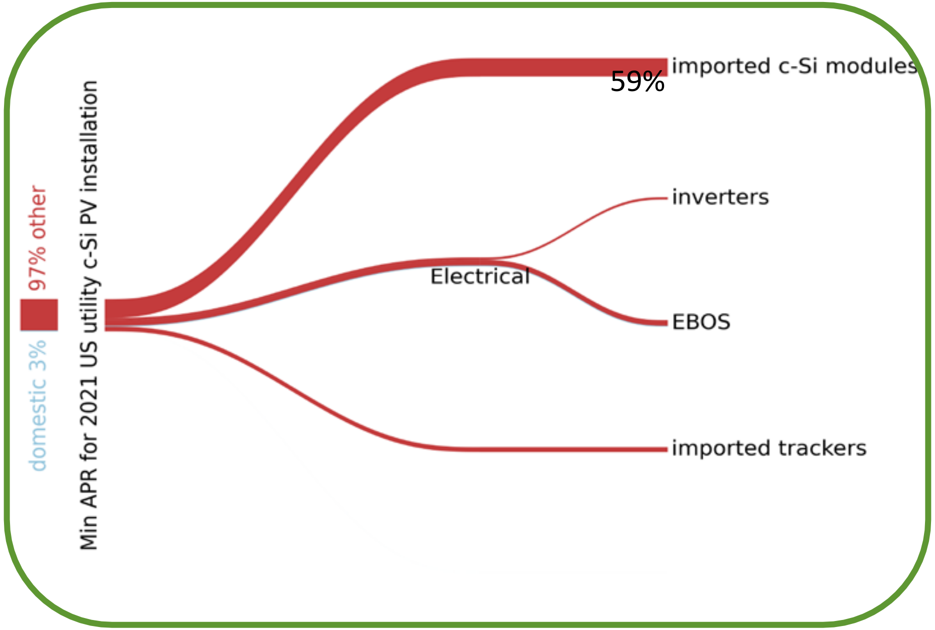
- Total of 4.2 GW.
- 17% average domestic value; significantly below criteria for domestic content bonus.
  - This percentage includes indirect costs (no steel products in residential systems).
- This represents an average system (i.e., 71% of a domestic c-Si module).
- While 3 GW of these modules are U.S.-assembled, none of the module components are domestic.
- The absence of steel products and greater expense of residential c-Si modules and inverters contribute to the large fraction of imported value.

c-Si Utility Systems: Sourcing Permutations

Maximum domestic content in 2021: 18%



Minimum domestic content in 2021: 3%

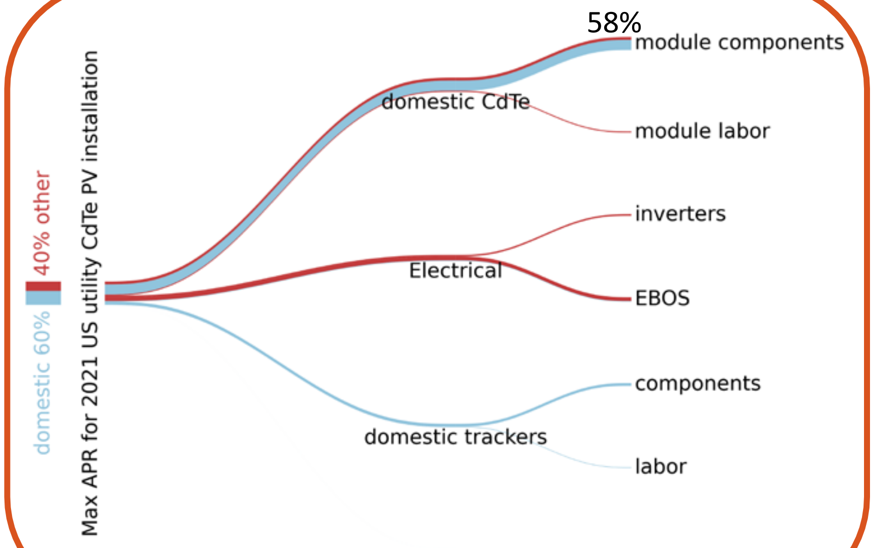


These diagrams show how much the domestic content in c-Si utility systems can vary depending on common 2021 sourcing options. Diagrams use the adjusted percentage rule (APR) and **direct costs only**.

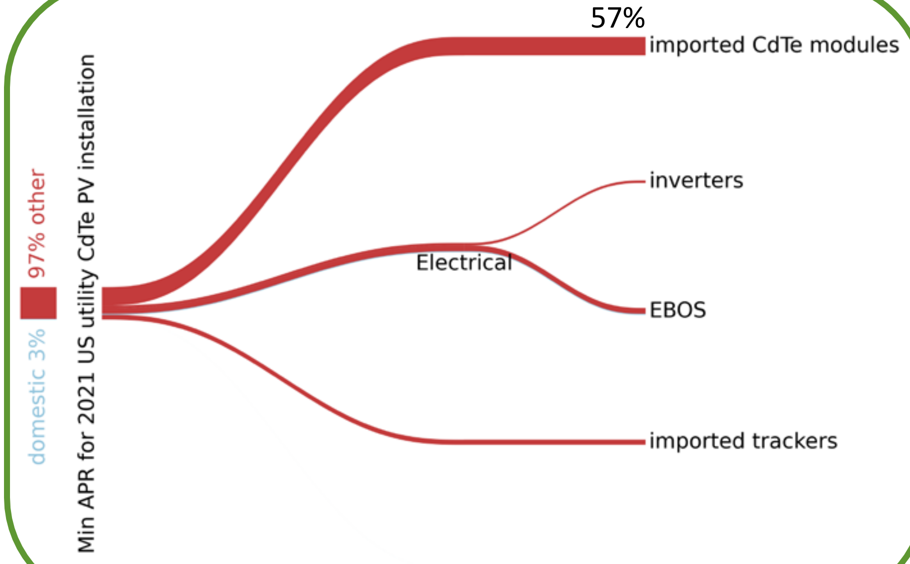
- Most significant variable: **tracker sourcing**.

CdTe Utility Systems: Sourcing Permutations

Maximum domestic content in 2021: 60%



Minimum domestic content in 2021: 3%

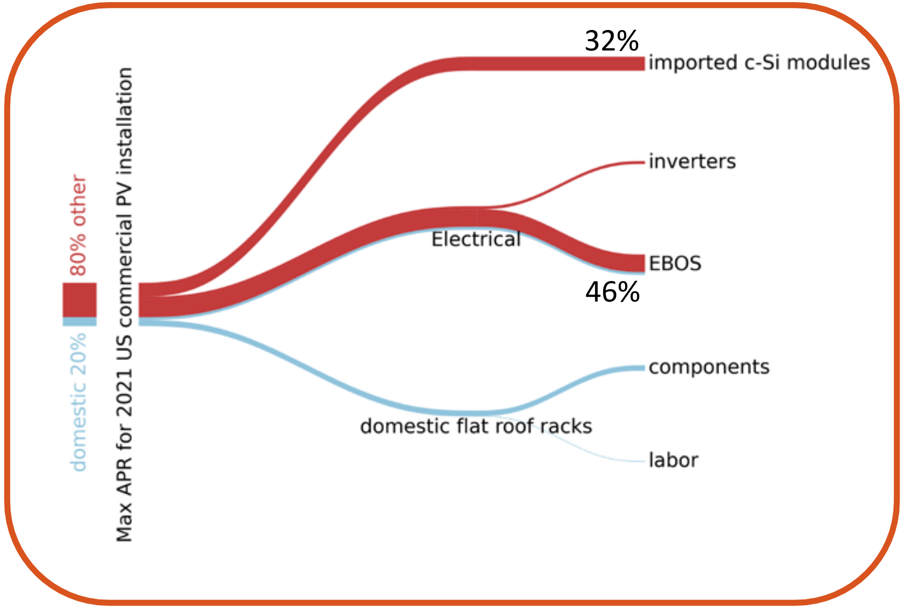


These diagrams show how much the domestic content in CdTe utility systems can vary depending on common 2021 sourcing options. Diagrams use the adjusted percentage rule (APR) and **direct costs only**.

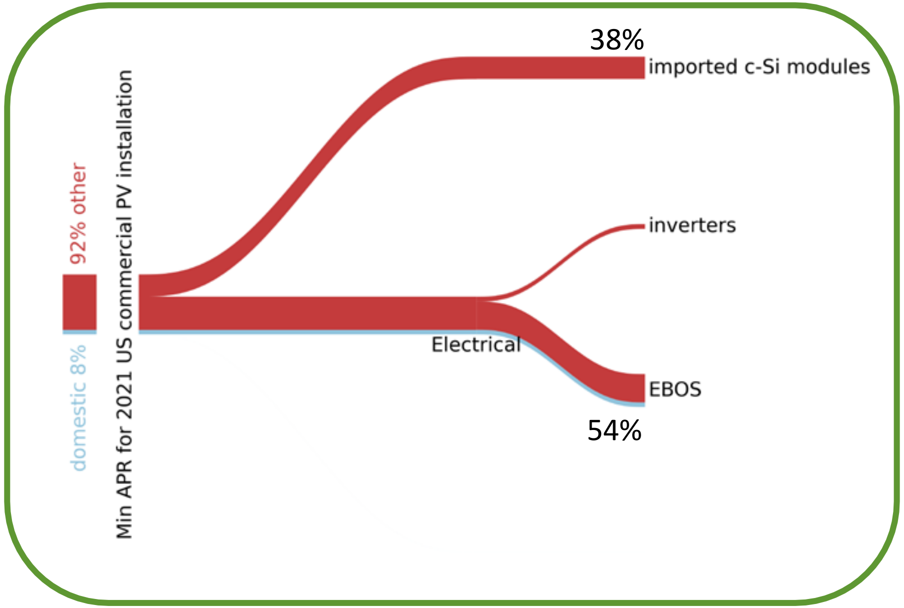
- Most significant variable: **CdTe module sourcing** and **tracker sourcing**.

c-Si Commercial Systems: Racking Permutations

Maximum domestic content in 2021: 20%



Minimum domestic content in 2021: 8%



These diagrams show how much the domestic content in c-Si commercial systems can vary based on common 2021 racking types. Diagrams use the adjusted percentage rule (APR) and **direct costs only**.

- Most significant variable: type of **racking/mounting**, since steel products are not counted.

Thank You

www.nrel.gov

NREL/PR-7A40-88026

Special thanks to Nate Blair, Daniella Frank, Madeline Geocaris, and Adam Warren.

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government.

NREL Transforming ENERGY

List of Acronyms and Abbreviations

AD: antidumping
ac: alternating current
ASP: average selling price
BESS: battery energy storage system
BOS: balance of system
BNEF: Bloomberg New Energy Finance
CAISO: California Independent System Operator
CapEx: capital expenditures
C&I: commercial and industrial
CBP: U.S. Customs and Border Protection
CdTe: cadmium telluride
CPI: consumer price index
c-Si: crystalline silicon
CSP: concentrating solar power
CVD: countervailing
dc: direct current
DOE: U.S. Department of Energy
EBOS: electrical balance of system
EIA: U.S. Energy Information Administration
EPC: engineering, procurement, construction
ERCOT: Electric Reliability Council of Texas
ETF: exchange traded fund
FERC: Federal Energy Regulatory Commission
GW: gigawatt
GWh: gigawatt-hour
H1: first half of year
H2: second half of year
HTS: harmonized tariff schedule
IEA: International Energy Agency
ILR: inverter loading ratio
IRA: Inflation Reduction Act
IRS: Internal Revenue Service
ISO: independent system operator
ITC: investment tax credit
kW: kilowatt
kWh: kilowatt-hour
LBNL: Lawrence Berkeley National Laboratory
LCOE: levelized cost of energy
LMI: low- and moderate-income
MISO: Midcontinent Independent System Operator
mono c-Si: monocrystalline
MMP: modeled market price
MSP: minimum sustainable price
MW: megawatt
MWh: megawatt-hour
NDC: Nationally Determined Contribution
NEM: net energy metering
NREL: National Renewable Energy Laboratory
PPA: power purchase agreement
PTC: production tax credit
PV: photovoltaics
Q: quarter
q/q: quarter 0ver quarter
R&D: research and development
SBOS: structural balance of system
SEIA: Solar Energy Industries Association
SPP: Southwest Power Pool
SREC: solar renewable energy certificate
TAN: Invesco Solar ETF
TOPCon: tunnel oxide passivated contact
TPO: third-party owned
UFLPA: Uyghur Forced Labor Prevention Act
USD: U.S. dollars
W: watt
WRO: withhold release order
y/y: year over year
YTD: year to date