NREL
Transforming ENERGY

Winter 2024 Solar Industry Update

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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 Waste and Toxicity

Executive Summary

Global Solar Deployment

- Analysts estimate 350 GW_{dc} of PV was installed globally in 2023 (though recent data have indicated that number could be more like 440 GW_{dc}); global installations are expected to increase to 400 GW_{dc} in 2024 and 590 GW_{dc} by 2027. 2023 estimates may increase as it was recently reported that China installed ~260 GW_{dc} of PV panels in 2023.

U.S. PV Deployment

- Though California residential installations were up through the first nine months of 2023, likely caused by a spike in interconnection applications in the lead up to April 15 change from CA NEM 2.0 to 3.0, interconnection applications have since plummeted well below historical levels.
- According to EIA data, the United States installed 15.8 GW_{ac} of PV in the first 9 months of 2023—a record—up 31% y/y (SEIA reported 19.3 GW_{dc}).
- EIA projects the percentage of U.S. electric capacity additions from solar will grow from 46% in 2022 (18 GW_{ac}) to 54% in 2023 (31 GW_{ac}), 63% in 2024 (44 GW_{ac}), and 71% in 2025 (51 GW_{ac}).
- Other analysts' projections are lower, with a median value of 33 GW_{dc} in 2023, growing to 36 GW_{dc} in 2024 and 40 GW_{dc} in 2025.
- The United States installed approximately 15.1 GWh (4.8 GW_{ac}) of energy storage onto the electric grid in the first 9 months of 2023, +40% (+32%) 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 fell 18% from mid-October ($10.53/kg) to mid-January ($8.70/kg), approaching their lowest levels of the past several years.
- Global module prices reached yet another record low, falling 22% between mid-October and mid-January to $0.11/$W_{dc}$.
- In Q3 2023, the average U.S. module price ($0.33/$W_{dc}$) was down 11% q/q and down 23% y/y but at a 100% premium over the global spot price for monofacial monocrystalline silicon modules.

Global Manufacturing

- BNEF reports that at the end of 2023, global PV manufacturing capacity was between 650 and 750 GW—a growth of 2–3x in the past five years, 90% of which occurred in China. In 2023, global PV production was between 400 and 500 GW.
- Despite global price drops across the PV supply chain, PV manufacturers have generally remained profitable, thanks to increases in sales volumes (particularly for N-type cells).

U.S. PV Imports

- The United States imported 40.6 GW_{dc} of PV modules in Q1–Q3 2023, setting a new single-quarter record of over 15 GW_{dc} of modules imported.
- Most panels imported were exempt from Section 201 duties and were therefore likely bifacial. A significant number of thin-film modules were also imported.
- 2.4 GW_{dc} of cells were imported in Q1–Q3 2023, up 31% y/y.
- The U.S. is not on pace to reach the 5-GW_{dc} quota exemption limit for Section 201 tariffs, although it has exceeded 3 GW_{dc} of imports in a single year for the first time ever.

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

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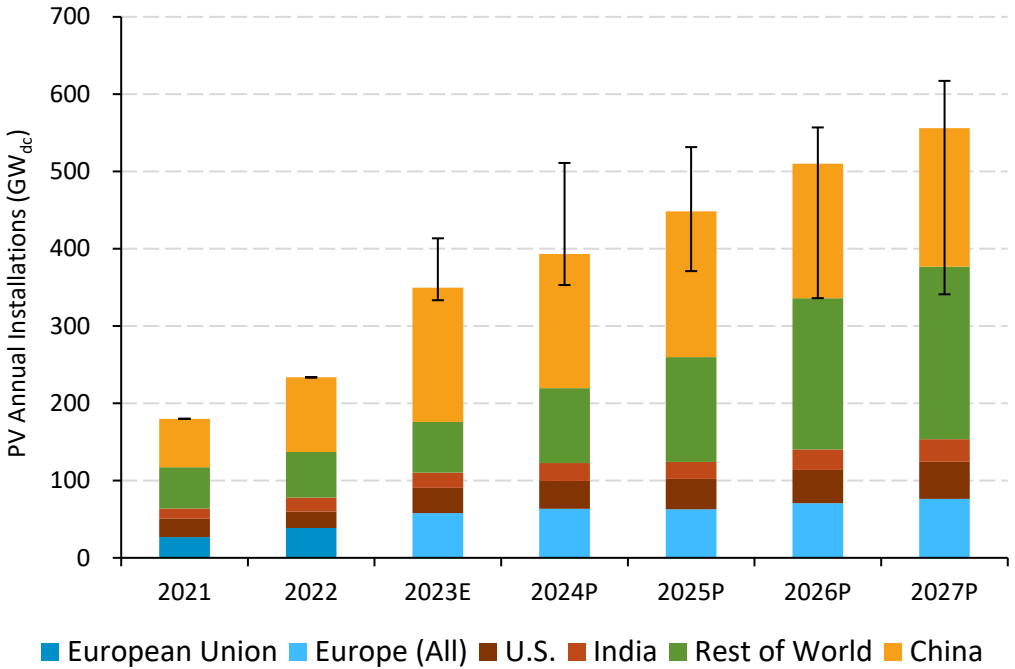
  - **2023 estimates may increase as it was recently reported that China installed ~260 GW_{dc} of PV panels in 2023.**
  - **JMK Research reported that 10 GW_{ac} (12.5 GW_{dc}) of PV was installed in India in 2023—down 28% y/y. Mercom reported that Indian installations were being delayed due to transmission connectivity and long-term access.**

Annual Global PV Deployment

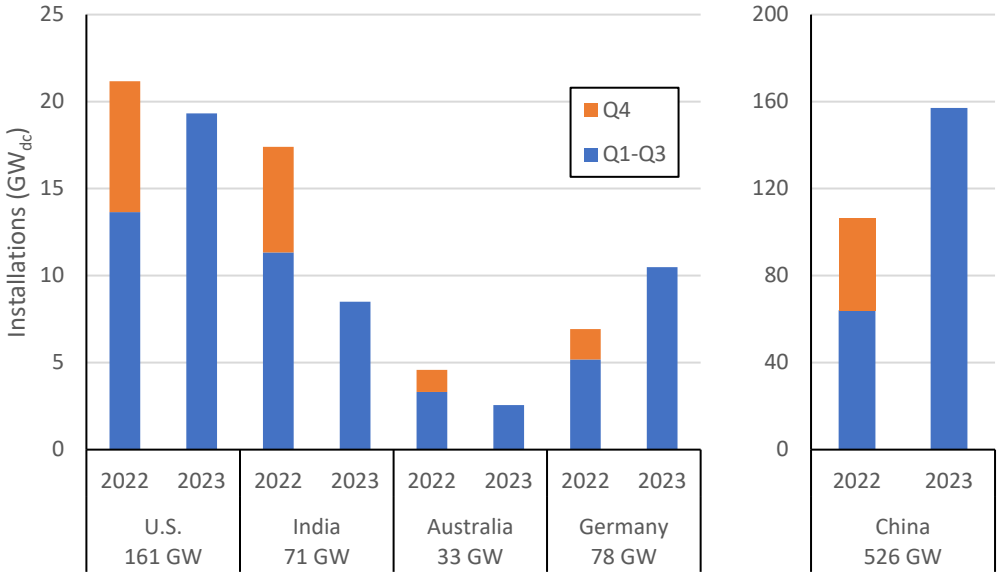


- Analysts estimate about 350 GW_{dc} of PV were installed globally in 2023, up 50% from 2022.
  - **These estimates were made before China announced 2023 PV installs, which could push 2023 global installs to ~440 GW_{dc}.**
- Analysts project continued increases in annual global PV installations:
  - 390 GW_{dc} in 2024 (+12% y/y)
  - 450 GW_{dc} in 2025 (+14% y/y)
  - 510 GW_{dc} in 2026 (+14% y/y)
  - 560 GW_{dc} in 2027 (+9% y/y)
- Among analysts who were covered in the Spring 2023 edition of the *Solar Industry Update*, global projections increased in this edition, e.g., by 2%–31% for 2025 projections.
- The range of projections skews high in the next couple years but very low toward the end of the projection period.
  - One analyst predicts flattening of global deployment growth, resulting in a projection 220 GW_{dc} (40%) below the median in 2027.
- Over the period shown, China is projected to install the most PV (39%), followed by Europe (12%), the United States (9%), and India (6%).

Notes: E = estimate; P = projection. Bar totals represent median global projections across analysts who provide a global projection. Error bars represent high and low global projections. Regional bar segments represent medians of all available regional projections. Where regional medians do not sum to global medians, the differences are reconciled by adjusting the Rest of World segments so the correct global median values are retained.

Sources: BNEF, 4Q 2023 Global PV Market Outlook, 11/22/23; EIA, Annual Energy Outlook 2023, 3/23; Goldman Sachs Equity Research, America's Clean Technology: Solar, 12/17/23; SolarPower Europe, Global Market Outlook For Solar Power 2023–2027, 6/23; Wood Mackenzie, Three Predictions for Global Solar in 2024, 1/24; Wood Mackenzie, Q1 2024 Solar Executive Briefing, 10/23.

International Q1–Q3 2023 Installations



- In the first 9 months of 2023, PV installations increased significantly (y/y) in China (145%), Germany (102%), and the U.S. (42%):
  - China installed ~260 GW_{dc} of PV panels in 2023.
  - Germany installed 14.3 GW_{dc} in 2023.
  - JMK Research reported that 10 GW_{ac} (12.5 GW_{dc}) of PV was installed in India in 2023—down 28% y/y. Mercom reported that Indian installations were being delayed due to transmission connectivity and long-term access.
- At the end of September, these countries had cumulatively installed 869 GW_{dc} of PV.

*China reported 87 GW of PV installations in 2022, 129 GW in the first 9 months of 2023, and 216.9 GW in 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 (11/27/23; 01/29/24). PV Magazine (11/24/23, 12/22/23); PVTech (10/20/24); Wood Mackenzie/SEIA: U.S. Solar Market Insight: Q4 2023.

Concentrating Solar Power Update

- In Q1 2024, India plans on putting out a tender for renewable energy in which over 50% must come from CSP. There is renewed interest in CSP in India to provide a longer-duration source of solar energy. Over a decade ago, India awarded 470 MW of contracts for CSP, but only 200 MW was built. India is planning to address previous issues, such as reducing development risk, increased DNI data availability, and loans covering 70% of the costs. The size of the tender was not provided.
- Recently, there has been a series of CSP spinoff companies that focus on stand-alone thermal energy storage, powered by electricity from wind and solar to provide more cost-competitive long-term thermal energy storage for industrial process heat. Recent companies include Malta, Heatrix, Rondo, and Heatcube. Heatcube has designed a process with salts that solidify at lower temperatures than traditional CSP, which allows them to use less expensive steel for their tanks.
- In December, DEWA inaugurated its 700-MW CSP plant (600-MW trough; 100-MW tower). The facility also includes 250 MW of PV and 5.9 GWh of thermal energy storage capacity.
- In October 2023, GlassPoint announced it will partner with the Ministry of Investment of Saudi Arabia to build a solar manufacturing plant to mass-produce its solar steam technology. At full capacity, the factory will annually produce technology to generate 5,000 tons of solar steam.

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- **Though California residential installations were up through the first 9 months of 2023, likely caused by a spike in interconnection applications in the lead up to April 15 change from CA NEM 2.0 to 3.0, interconnection applications have since plummeted well below historical levels.**
- **According to EIA data, the United States installed 15.8 GW_{ac} of PV in the first 9 months of 2023—a record—up 31% y/y (SEIA reported 19.3 GW_{dc}).**
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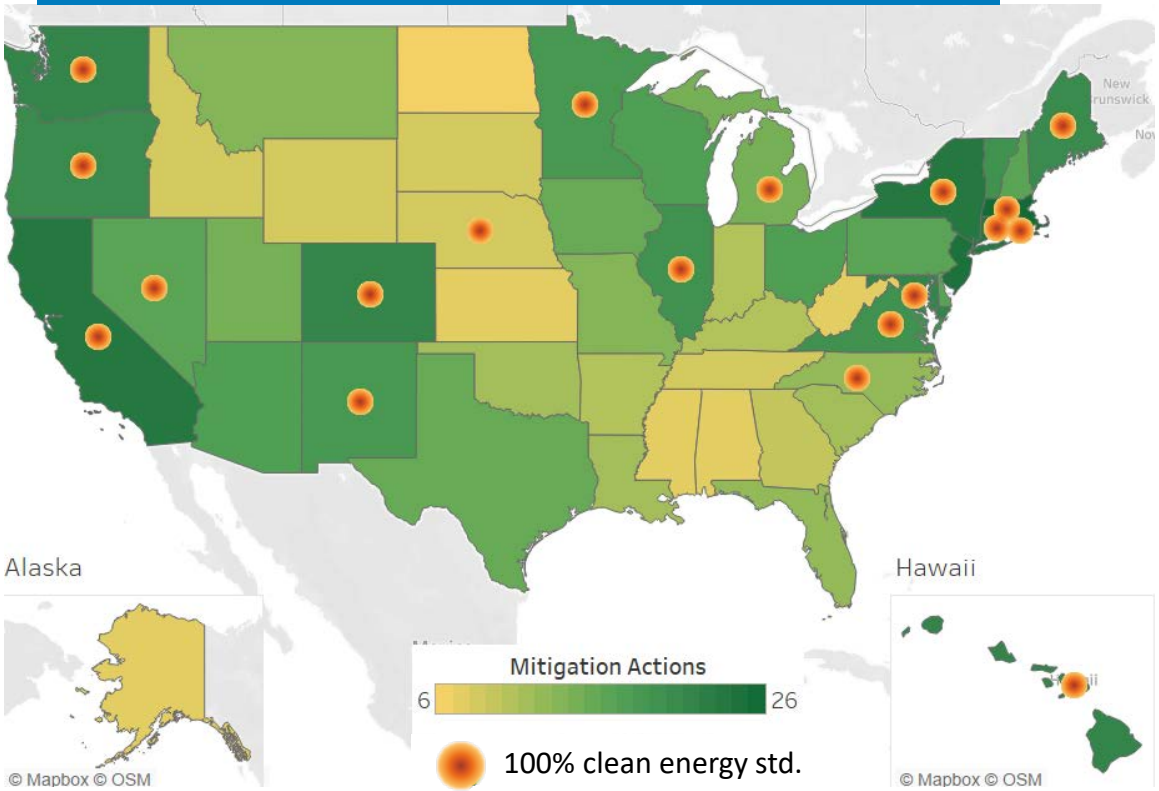
  - **Other analysts' projections are lower, with a median value of 33 GW_{dc} in 2023, growing to 36 GW_{dc} in 2024 and 40 GW_{dc} in 2025.**
- **The United States installed approximately 15.1 GWh (4.8 GW_{ac}) of energy storage onto the electric grid in the first 9 months of 2023, +40% (+32%) y/y, as a result of growth in all sectors.**

States: Q3–Q4 2023 Updates

Map shows the number of mitigation actions (reducing greenhouse gas emissions or removing them from the atmosphere) taken by states, as reported in the Fifth National Climate Assessment. Cities and tribal entities have also taken actions. The circles identify the 18 states (plus Washington, DC) with 100% clean or renewable energy commitments.



Michigan committed to 100% clean electricity by 2040, 2.5 GW of storage by 2030, higher caps on distributed PV, and more. The state is also offering clean energy deployment grants.

Minnesota increased the share of PV installation incentives going to income-qualified customers from 30% to 50%.

The **Washington, DC** metro area targeted 250,000 rooftop PV systems by 2030, equivalent to PV on 24% of single-family homes.

New York announced investments in 1.5 GW of PV plus 4.7 GW of other renewables, the largest-ever state investment in renewable energy, which will meet 12% of electricity demand.

California passed laws promoting PV, battery, and transmission deployment along highways and accelerating distribution grid improvements.

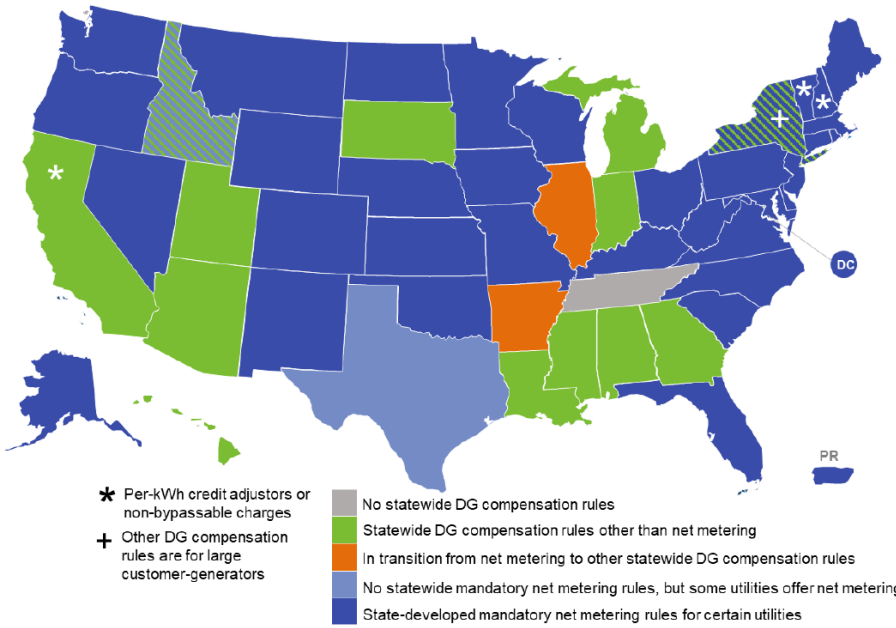
Sources: Canary Media (11/20/23); LBNL, U.S. State Renewables Portfolio & Clean Electricity Standards: 2023 Status Update (6/2023); Minnesota Reformer (11/6/23); PV Magazine (10/24/23, 11/27/23); PV Tech (11/30/23); Solar Power World (10/9/23, 11/28/23); U.S. Government, Fifth National Climate Assessment (2023).

States: 2023 Year-in-Review

Top State Distributed PV Policy Trends of 2023

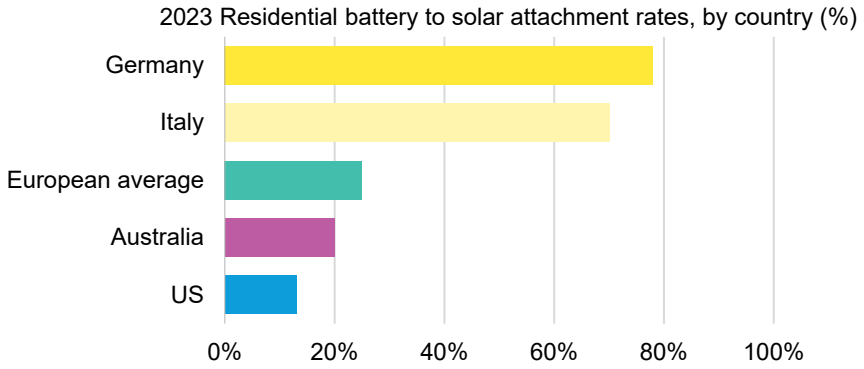
- Net billing tariffs
- Incentives for low- to moderate-income customers
- Time-varying PV-compensation rates
- Lack of new utility-proposed/regulator-accepted fees on PV customers
- Expanded and redesigned state community solar programs
- Required siting specifications for community solar projects
- Higher system size and aggregate capacity limits for PV programs
- Required or allowed application of net excess generation credits to low-income customer accounts
- Tariffs designed to encourage PV plus storage
- Utility-initiated (not state-initiated) proposals for net-metering successor tariffs.

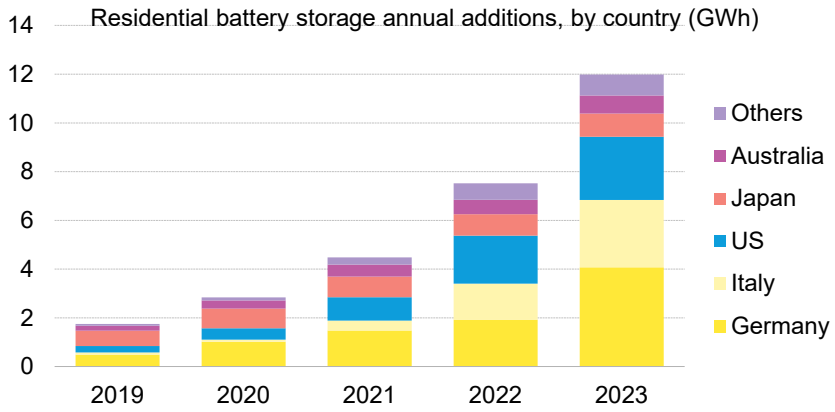
Net Metering and Distributed Generation Compensation Policies as of December 2023



Source: North Carolina Clean Energy Technology Center, The 50 States of Solar: 2023 Policy Review and Q4 2023 Quarterly Report, January 2024. Map reproduced with permission.

Global Residential PV+Storage (BNEF)

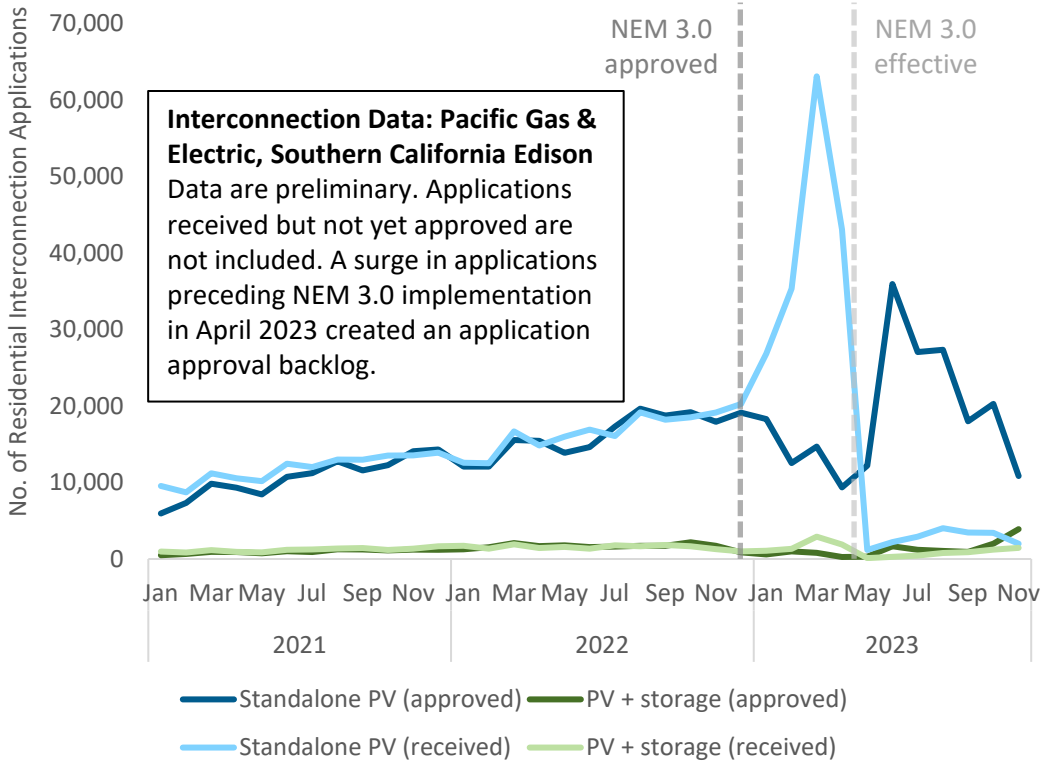




- At the end of 2023, approximately 15 GW/34 GWh of global residential battery storage capacity had been installed, 88% of which was located in five countries: Germany, Italy, Japan, the U.S., and Australia.
- Growth in these markets occurred mostly due to an increase in storage subsidies coinciding with a decrease in PV export tariffs (and often high retail rates).
  - Germany and Italy have provided incentives between 30% and 50% for the cost of storage while decreasing PV export rates to the price of wholesale power. The incentives have scaled back, but self consumption is still a leading driver ($0.30/kWh vs. $0.05/kWh).
- China has a relatively small residential battery market, particularly given its high level of product manufacturing. This is due to low retail rates, low concern for power outages, and low subsidies.
- Products on the market are now lithium iron phosphate batteries, which are safer as well as less expensive than the previously dominant nickel manganese cobalt (which are denser and therefore better suited for EVs).
- The value chain is evolving to integrate hardware components and software (for aggregation and energy trading) into a final product.

Source: BloombergNEF, "Scaling the Residential Energy Storage Market." December 19, 2023.

California's NEM 3.0 Affects Distributed PV Installations

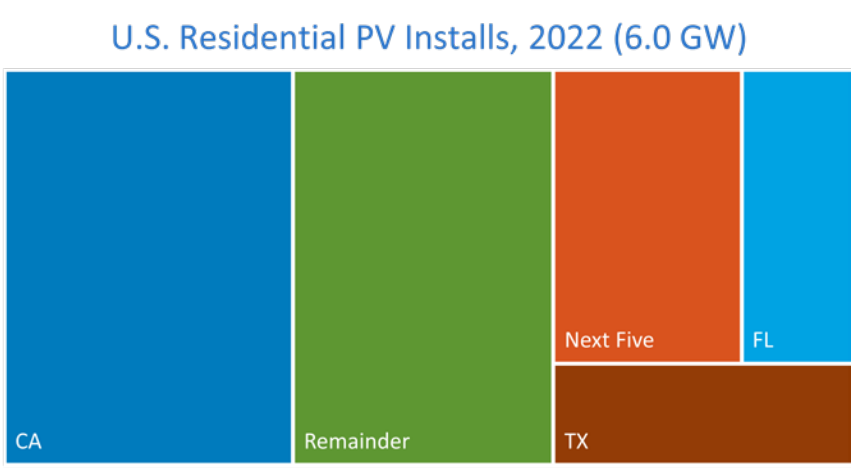


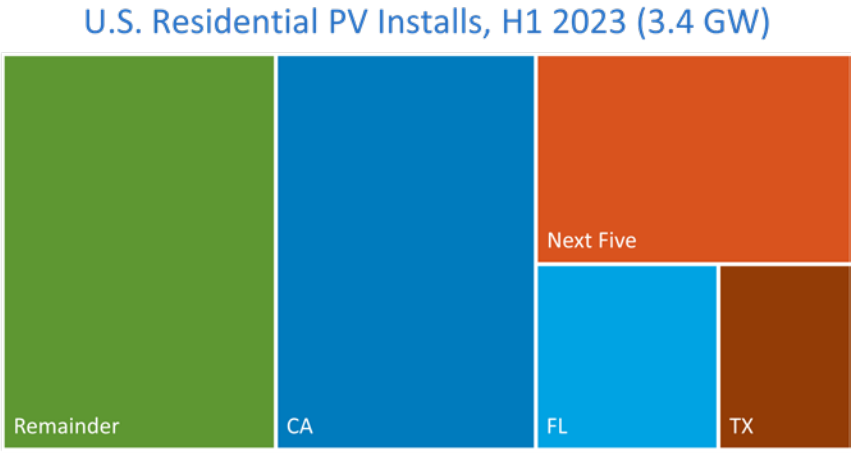
- Implementation of California's Net Billing Tariff (i.e., NEM 3.0) rules on April 15, 2023, has already had a dramatic effect on the residential PV market:
  - Retail export rates under the NEM 2.0 policy were replaced with avoided-cost rates, reducing export compensation by ~75%.
  - Preliminary data show receipt of residential interconnection applications spiking in the lead up to April 15 and then plummeting.
    - It is unclear at this point how much of the drop is attributable to a change in economics vs. depletion of sales pipelines.
  - The NEM 3.0 framework was designed to encourage PV+storage, which can reduce how much energy gets exported. To date, PV+storage applications are still dwarfed by previous stand-alone PV applications.

Sources: California Distributed Generation (11/30/23); Canary Media (12/1/23); PV Tech (12/4/23); Solar Power World (11/30/23); Utility Dive (12/14/23); Wood Mackenzie and SEIA; US Solar Market Insight, Q4 2023.

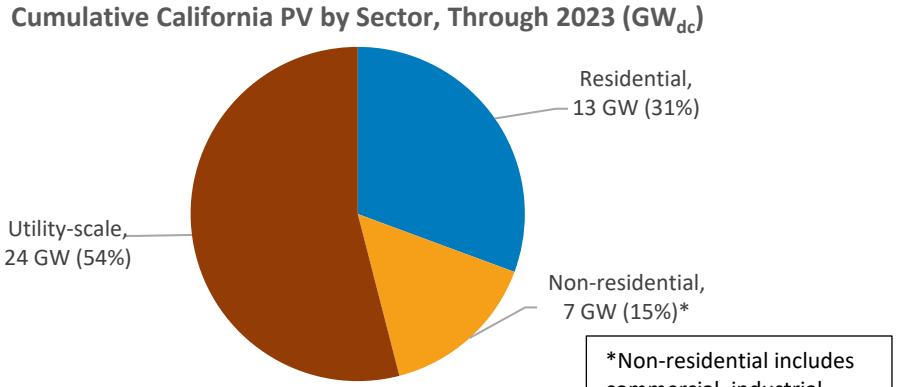
California's NEM 3.0 Affects Distributed PV Installations (cont.)

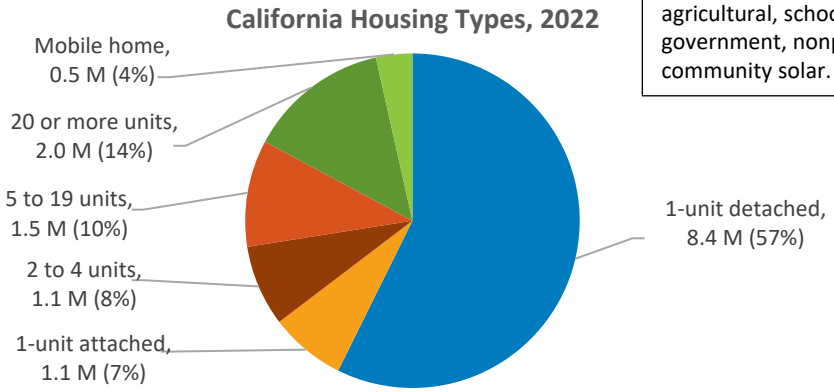
- Though it is too early to assess from installation and application data the true impact of NEM 3.0, a California Solar & Storage Association (CALSSA) survey suggests the impacts will significantly harm solar businesses:
  - Respondents reported that 17,000 solar jobs (22% of all its solar jobs) would be lost by end of 2023.
  - 59% of residential PV and storage contractors responded that they anticipated further layoffs.
- In December 2023, a California appeals court dismissed a challenge to the NEM 3.0 policy from environmental groups, who argued that the policy does not consider the societal benefits of distributed PV as required by law.
- California accounted for one-third of U.S. residential PV capacity installed in 2022.





New California Policies Reduce PV Compensation Further

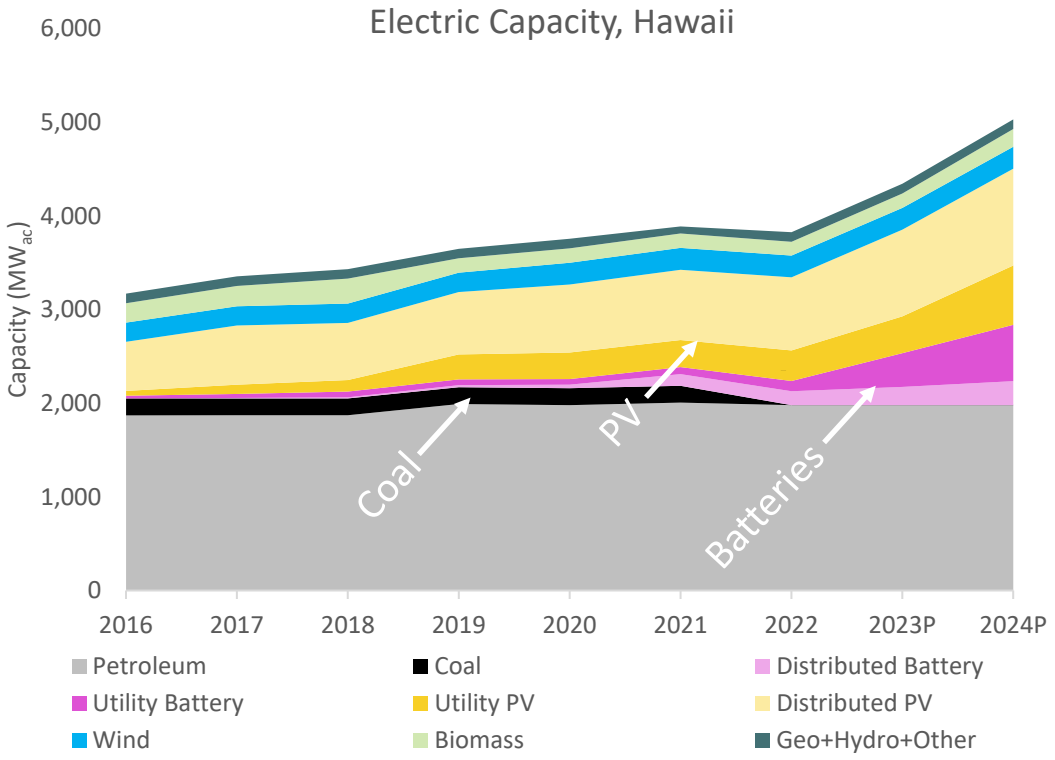




- In November 2023, the California Public Utilities Commission (CPUC) reduced PV compensation for multimeter properties.
  - Customers such as schools, farms, and shopping centers must sell all electricity at reduced rates while buying all electricity at full retail rates.
  - Multifamily housing residents still can self-consume PV electricity, but multifamily common areas (lobbies, garages, and so on) cannot.
  - Residents enrolled in affordable housing programs retain existing rates.
  - The policy applies immediately to new PV customers and is phased in over 20 years for existing customers.
- In a separate decision, CPUC reduced compensation for single-family homes that host PV-plus-storage systems under California's new Net Billing Tariff (i.e., NEM 3.0) by limiting which bill charges can be offset by exporting electricity to the grid during high-value periods such as early evenings.
  - According to one consultant, the policy will reduce compensation to typical PV-plus-storage owners by 10%–15% or about $230 per year.

Sources: Cal Matters (11/16/23); Canary Media (12/4/23); PV Tech (11/17/23); U.S. Census Bureau, American Community Survey, 2022; Wood Mackenzie and SEIA, US Solar Market Insight, Q4 2023.

PV and Batteries Help Replace Coal in Hawaii



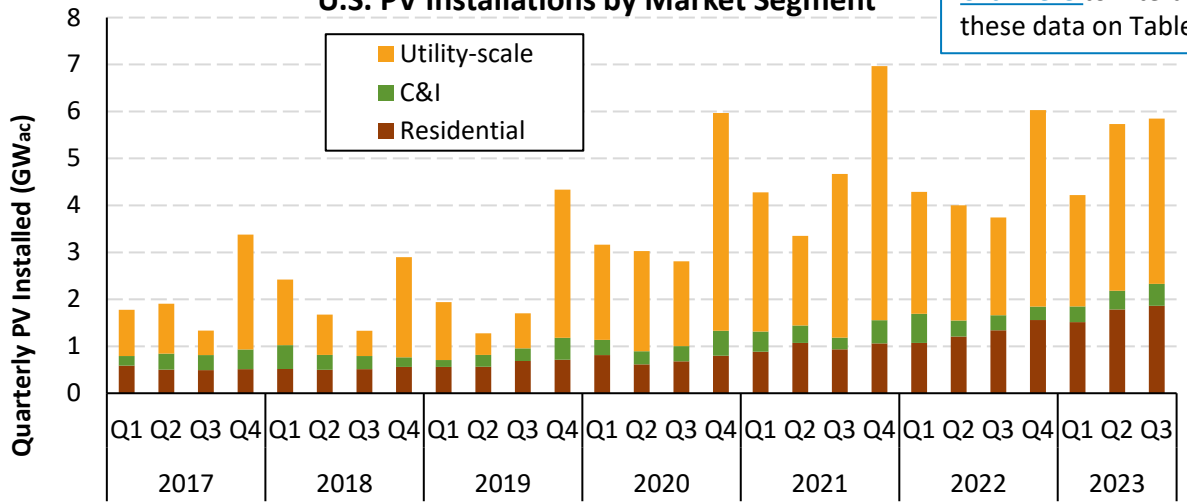
- The 185-MW_{ac} Kapolei energy storage plant on Oahu began operating in December 2023.
  - It helps replace capacity lost when Hawaii retired its 180-MW_{ac} coal plant in 2022, constituting 17% of Oahu's peak capacity.
  - It also provides grid services and black-start capability.
  - It is estimated to reduce curtailment of renewables by 69% for the first 5 years.
- Statewide, battery capacity is projected to increase 230% between 2022 and 2024 (to 860 MW_{ac}), while PV capacity is projected to increase 50% (to 1,700 MW_{ac}).
  - Utility-scale installations are growing fastest.
- Hawaii's electricity market and policies are promoting this shift.
  - Retail electricity rates are the highest in the United States, triple the national average.
  - The state target is 100% clean electricity by 2045.
  - Residential PV growth slowed after net metering ended in 2015.
  - Subsequent distributed energy policies have promoted self-consumption, grid support, and deployment of energy storage.

Sources: Canary Media (1/10/24); EIA, Electric Power Monthly, Dec 2023; EIA, Hawaii Electricity Profile 2022, Nov 2023; Hawaiian Electric (accessed 1/16/24); Hawaii Public Utilities Commission (12/23); Wood Mackenzie, U.S. Energy Storage Monitor, Q4 2023; Wood Mackenzie and SEIA, US Solar Market Insight, Q4 2023.

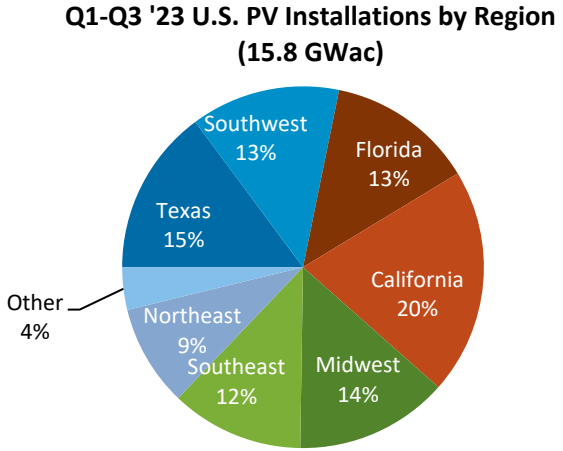
U.S. Installation Breakdown Quarterly: EIA (GW_{ac})

- According to EIA data, the United States installed 15.8 GW_{ac} of PV in the first 9 months of 2023—a record—up 31% y/y (SEIA reported 19.3 GW_{dc}).
  - Residential (5.1 GW_{ac}) remained up significantly YTD, 43% y/y, as did utility-scale (9.4 GW_{ac}—up 32%). Nonresidential was down 6% (1.2 GW_{ac}).

- 46% of U.S. PV capacity installed in the first 9 months was in Texas, Florida, and California.
  - 28 states installed more than 100 MW_{ac}.
  - California's residential market kept growing, Q/Q, throughout the year, not yet showing any slowness caused by the switch to NEM 3.0.



Click here to interactively view these data on Tableau Public.

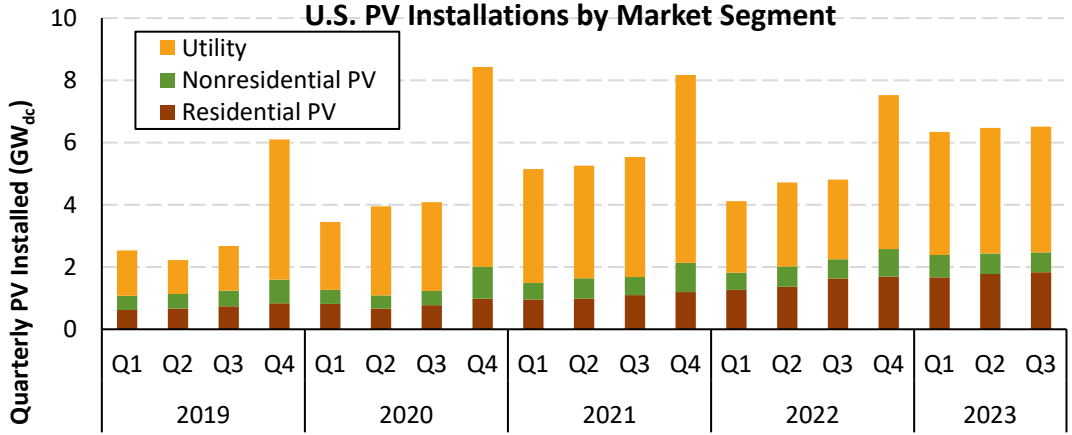


Note: EIA reports values in W_{ac}, which is standard for utilities. The solar industry has traditionally reported in W_{dc}. See the next slide for values reported in W_{dc}.
Sources: EIA, "Electric Power Monthly," forms EIA-023, EIA-826, and EIA-861 (November 2023, February 2022, February 2019).

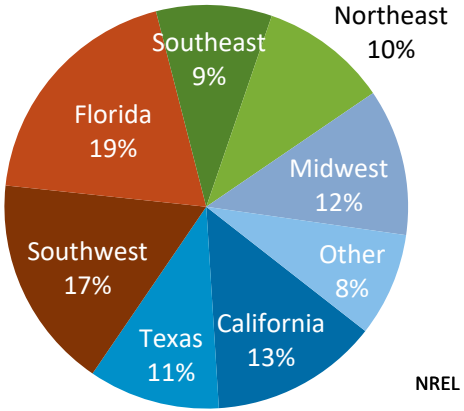
U.S. Installation Breakdown Quarterly: SEIA (GW_{dc})

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

- Wood Mackenzie/SEIA reports a record first 9 months of PV installations, with 19.3 GW_{dc} installed from Q1 to Q3 2023—an increase of 42% y/y.
  - The utility-scale sector, up 59% from 2022 y/y, rebounded from supply chain issues, as supplier diversification and the CBP release of module detentions has brought more modules to waiting project sites.
  - The residential sector, up 24% y/y, has been boosted by the backlog of California project sales that qualified for NEM 2.0 getting installed and interconnected, as well as the Northeast, where sales were boosted by retail rate increases (the Northeast is more exposes to natural gas price increases). The growth is partially offset by rising interest rates that occurred in 2022, which caused declines in sales volumes from loan companies in Arizona, Texas, and Florida.

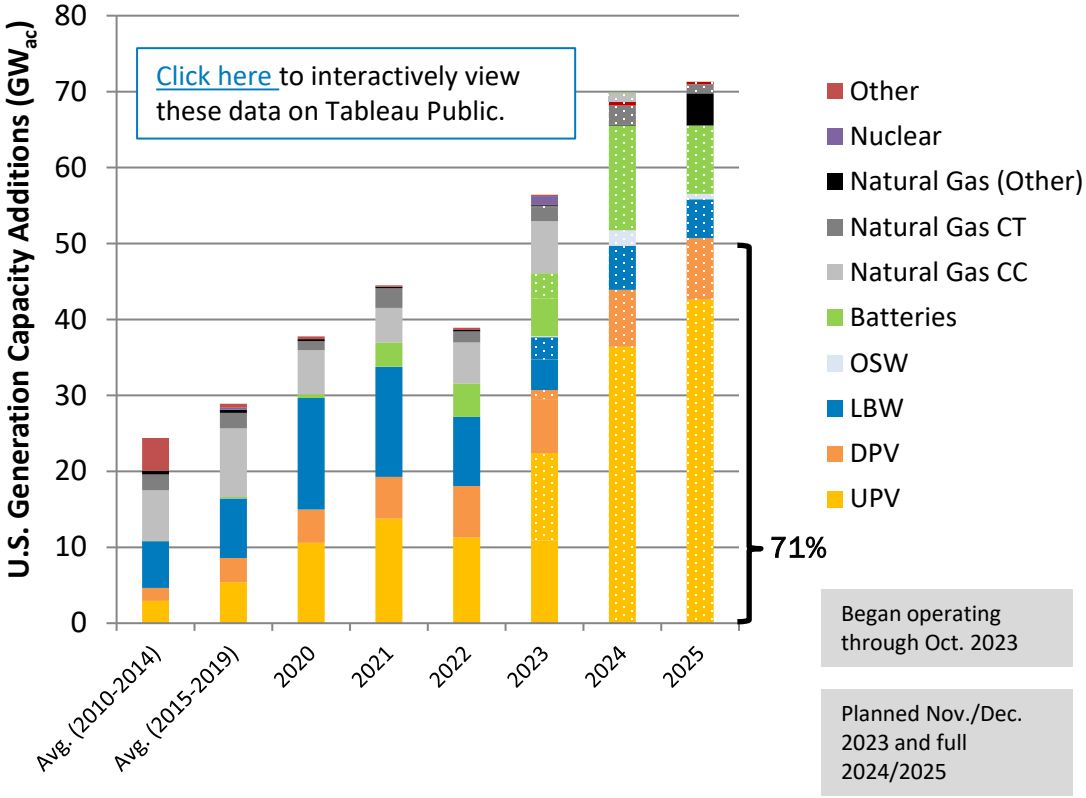


Q1-Q3 23 U.S. PV Installations by Region (19.3 GWdc)



Sources: Wood Mackenzie/SEIA: U.S. Solar Market Insight: Q4 2023.

U.S. Generation Capacity Additions by Source: 2010–2023 and *Planned* 2023–2025



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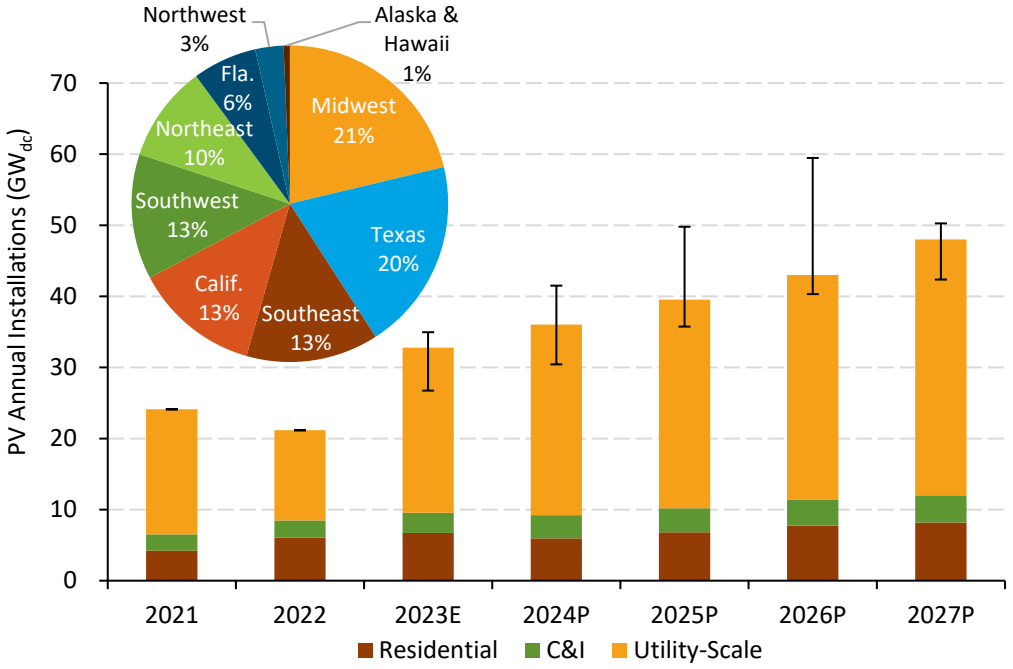
  - Starting in 2023, batteries are projected to be the second-leading source of new generation capacity, followed by land-based and offshore wind (LBW and OSW).
  - Natural gas is projected to account for 16% of new capacity in 2023 but to drop to 4% and 8% in 2024 and 2025, respectively.
- From 2023 to 2025, EIA projects that PV, storage, and wind will add 177 GW_{ac} of capacity additions.

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.

Annual U.S. PV Deployment



- Annual deployment of PV in the United States was estimated to have grown by about 55% between 2022 and 2023, to 33 GW_{dc}.
- Analysts project continued increases in annual U.S. PV installations:
  - 36 GW_{dc} in 2024 (+10% y/y)
  - 40 GW_{dc} in 2025 (+10% y/y)
  - 43 GW_{dc} in 2026 (+9% y/y)
  - 48 GW_{dc} in 2027 (+12% y/y)
- Utility-scale PV drives the 2023–2027 growth, with the highest compound annual growth rate:
  - Utility-scale 12%
  - Commercial and industrial (C&I) 8%
  - Residential 5%
- The variability in deployment projections suggests significant upside potential.
- Over the period shown, deployment is geographically diverse, with Texas, California, and Florida as the top states and considerable capacity in several regions.

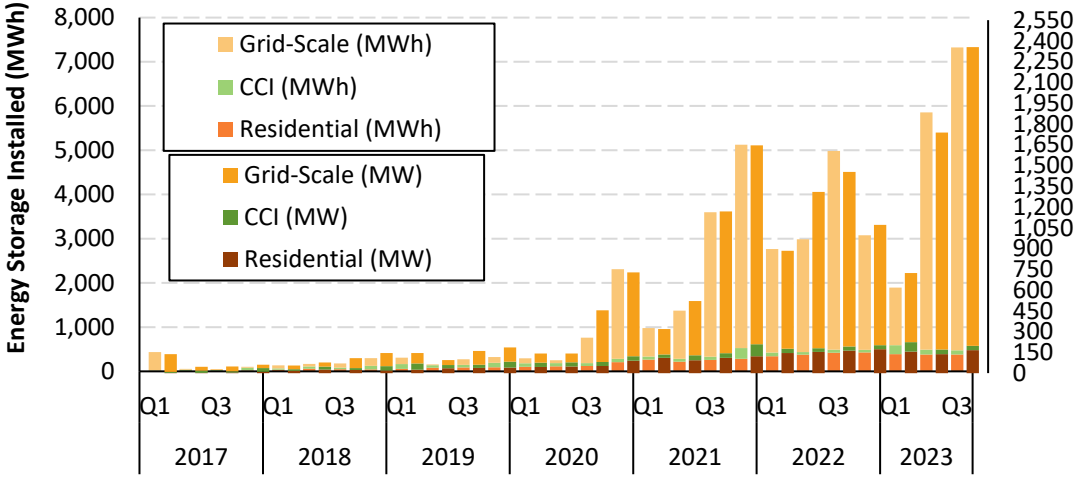
Notes: E = estimate; P = projection. Bars represent median U.S. projections. Error bars represent high and low U.S. projections. Where sector medians do not sum to U.S. medians, the differences are reconciled by multiplying the median percentage contribution from each sector by the total U.S. median values so the correct total U.S. median values are retained. Pie chart shows projected contributions from each region, 2021–2027.

Sources: BNEF, 4Q 2023 Global PV Market Outlook, 11/22/23; EIA, Annual Energy Outlook 2023, 3/23; Goldman Sachs Equity Research, America's Clean Technology: Solar, 12/17/23; SolarPower Europe, Global Market Outlook For Solar Power 2023-2027, 6/23; Wood Mackenzie and SEIA, US Solar Market Insight, Q4 2023.

U.S. Energy Storage Installations by Market Segment

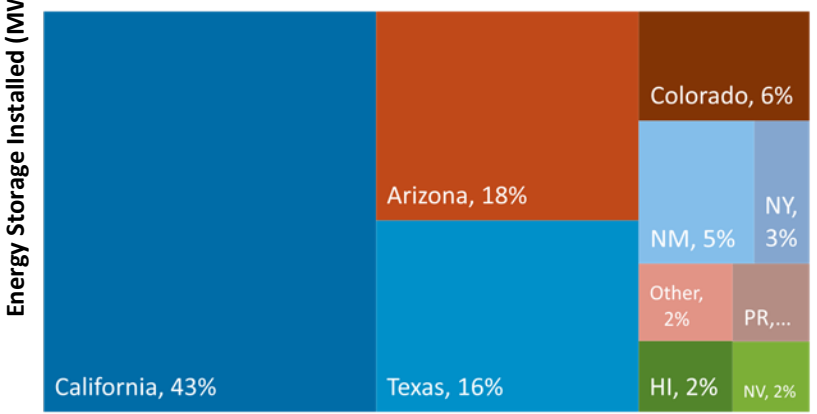
- The United States installed approximately 15.1 GWh (4.8 GW_{ac}) of energy storage onto the electric grid in the first 9 months of 2023, +40% (+32%) y/y, as a result of growth in the grid-scale and CCI sectors.
  - The residential market was relatively flat in part because of California's large market share, which shrank due to a large proportion of PV-only sales to take advantage of an expiring NEM 2.0.
  - SMUD installed 0.5 MW of eventual 200-MW long-duration iron flow battery storage.

U.S. Energy Storage Installations by Market Segment



- In 2023 YTD, two states dominated most energy storage markets:
  - California and Texas represented 62% of grid-scale installations. Arizona was another 21%.
  - California and New York represented 88% of battery energy storage in the CCI market; Massachusetts was a large CCI market, but its SMART program is tapering down.
  - California and Puerto Rico represented 62% of residential energy storage installs YTD. Texas and Hawaii also contributed a combined 16%.

Q1–Q3 2023 U.S. Energy Storage Installations by Region (15.1 GWh)

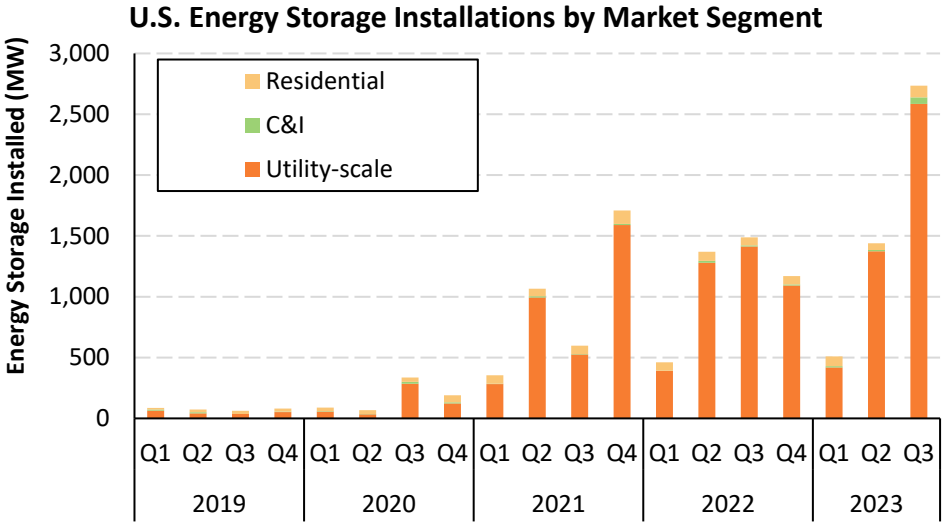


Note: "Grid-scale" refers to all projects deployed on the utility side of the meter, regardless of size or ownership; "CCI" refers to "community-scale, commercial, and industrial."

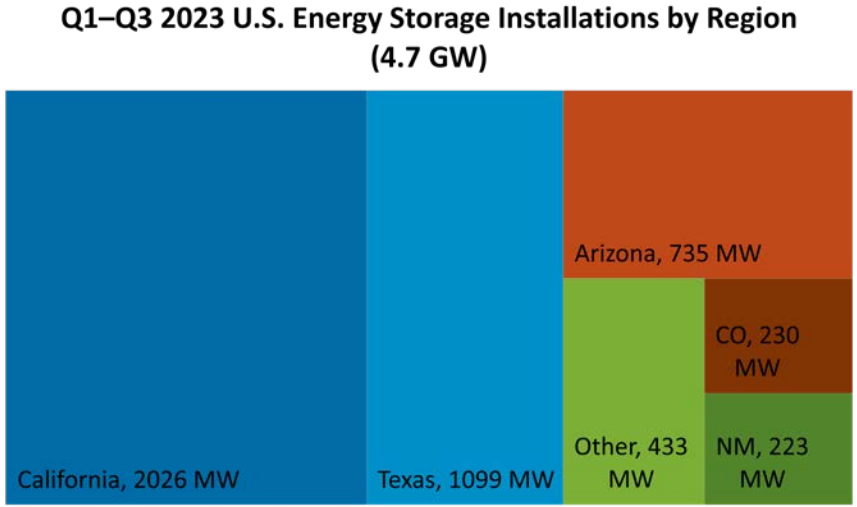
Source: Wood Mackenzie Power & Renewables and Energy Storage Association, U.S. Energy Storage Monitor: Q4 2023.

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

- EIA reports that the United States installed approximately 4.7 GW_{ac} of energy storage onto the electric grid in the first 9 months of 2023—up 39% y/y, bringing total U.S. battery storage capacity to 16.7 GW_{ac} (~43 GWh).

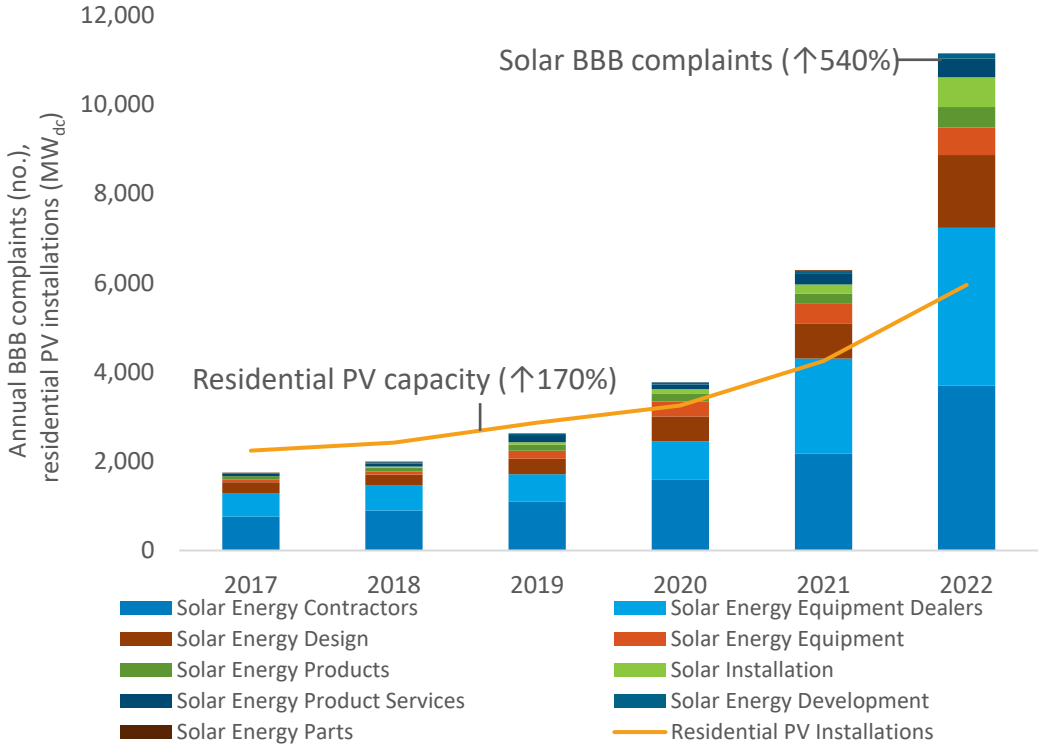


- California represented approximately 43% of battery storage capacity installed in the first 9 months of 2023, followed by Texas (23%).
  - The top five markets represented 91% of installed energy storage capacity.



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

Solar Consumer Complaints—and Protections—On the Rise



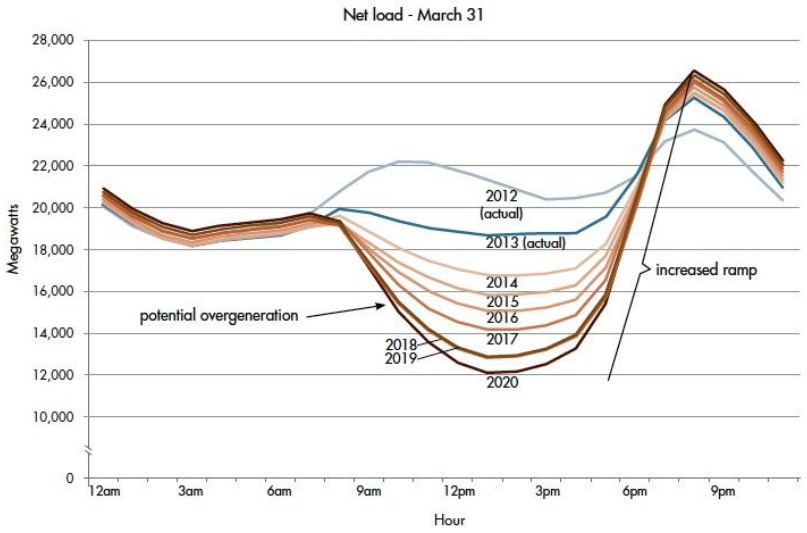
- From 2017 to 2022, annual solar-related complaints to the U.S. Better Business Bureau (BBB) grew 3 times faster than U.S. residential PV capacity:
  - Top complaint categories included "Solar Energy Contractors," "Solar Energy Equipment Dealers," and "Solar Energy Design."
  - Solar-related complaints to the Federal Trade Commission, Consumer Financial Protection Bureau, and many state agencies also increased.
- Common complaints include:
  - Misrepresenting solar costs and benefits
  - Misrepresenting financing terms and government incentives
  - Aggressive sales and marketing tactics
  - Unsolicited robocalls.
- Resources, training, regulations, and legal actions are being instituted to protect consumers and the solar industry's image by, for example:
  - Clean Energy States Alliance (CESA)
  - Interstate Renewable Energy Council (IREC)
  - Solar Energy Industries Association (SEIA)
  - State solar associations
  - Other nonprofit organizations
  - State legislators, regulators, attorneys general.

Sources: BBB, "BBB Complaint and Inquiry Statistics"; CESA, "Program Areas"; Consumer Financial Protection Bureau, "Consumer Complaint Database"; California Public Utilities Commission, "California Solar Consumer Protection Guide"; IREC, "Consumer Protection"; NREL, "Solar Consumer Protection"; SEIA, Consumer Protection Primer, "Solar 101: Consumer Protection," "Solar Business Code"; Solar Power World (8/16/21); Time (9/23, 11/23); Utility Dive (6/22/23); Wood Mackenzie & SEIA, Q3 2023 Solar Market Insight, 9/23.

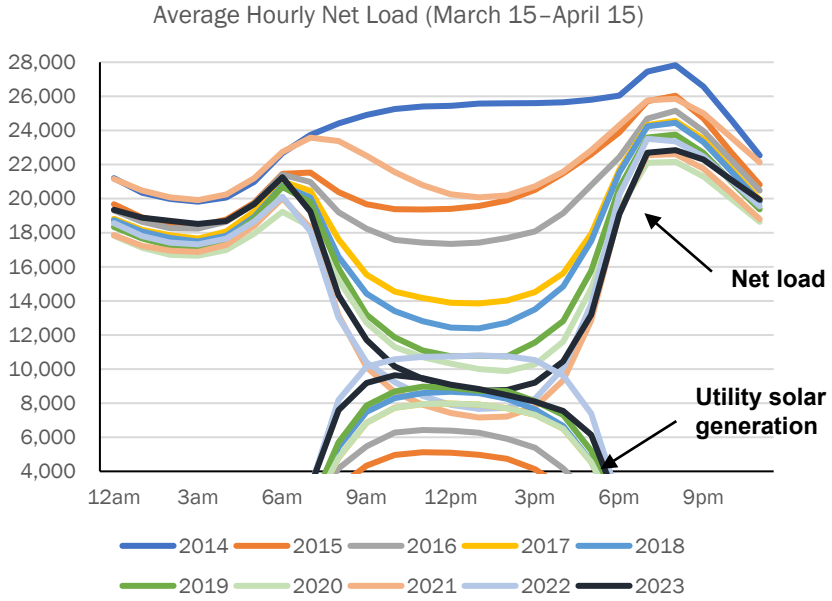
Duck Curve: Predicted vs. Actual

The "Duck Curve" graphic, developed in 2013, predicted that as solar became a larger part of CAISO's electricity mix, there would be potential periods of overgeneration and the need for an increased ramp rate—particularly in the springtime when PV is generating a lot of energy in the middle of the day but demand is low (i.e., not hot enough for AC use). The Duck Curve has generally come to pass—midday net load has dropped more than predicted, though evening peak has not been as great.

Predicted



Actual



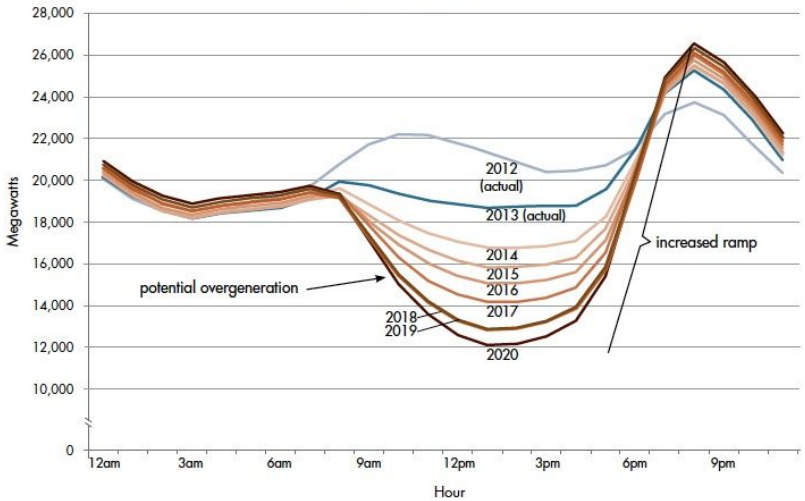
Note: net load = load – solar & wind production. Includes curtailment.
Sources: CAISO: http://www.caiso.com/informed/Pages/ManagingOversupply.aspx; DOE: https://www.energy.gov/eere/articles/confronting-duck-curve-how-address-over-generation-solar-energy.

Duck Curve – Predicted vs. Actual (specific days of year)

Individual days have experienced significantly lower minimum net load and larger evening ramps.

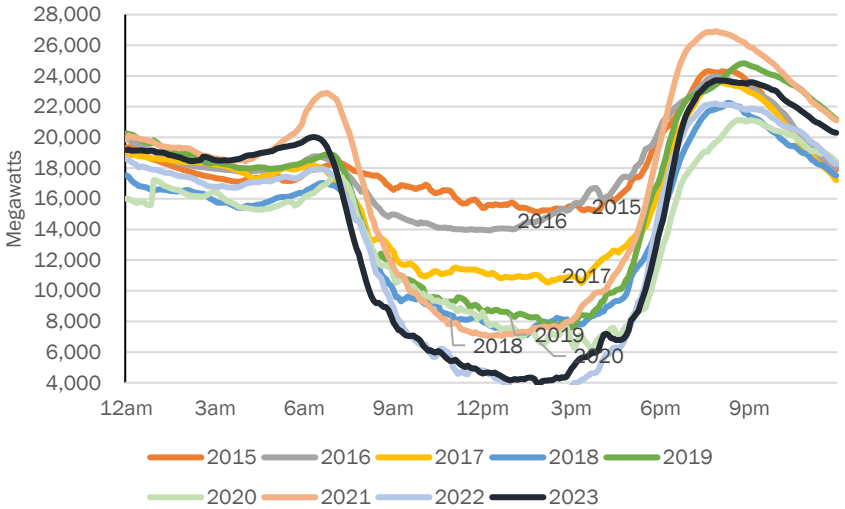
Predicted

Net load - March 31



Actual

Actual CAISO Net Load (individual days from March 15 - April 15



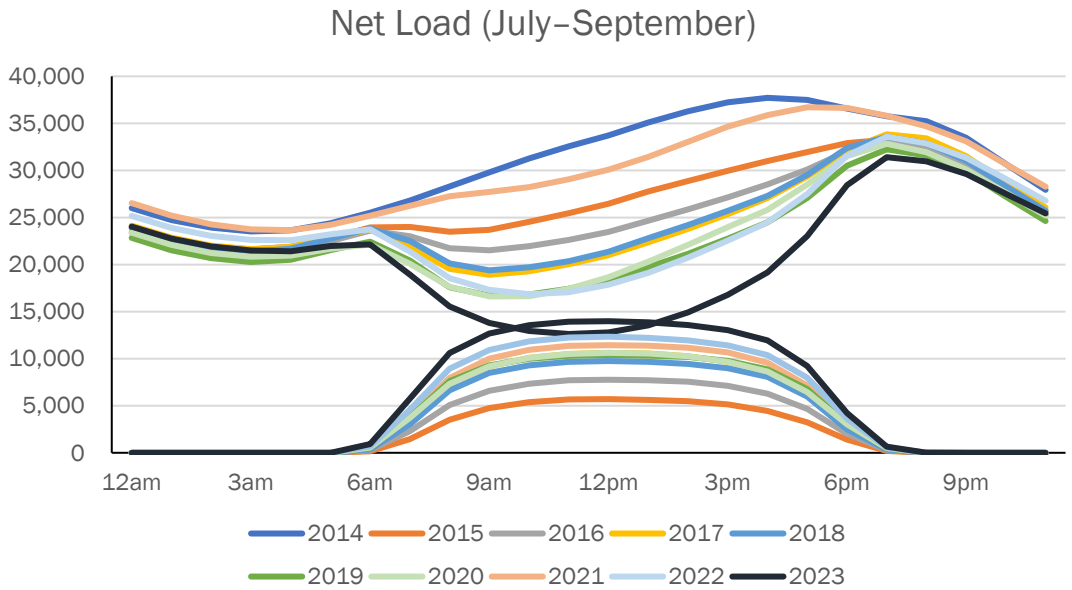
Note: net load = load – solar & wind production.

Sources: CAISO: http://www.caiso.com/informed/Pages/ManagingOversupply.aspx

DOE: https://www.energy.gov/eere/articles/confronting-duck-curve-how-address-over-generation-solar-energy

Duck Curve: Seasonality

The “Duck Curve” problem is most severe at particular times of the year. In the summer, demand for cooling during the middle of the day within CAISO mitigates much of the dip in net load. In other parts of the year, solar does not produce as much. Additionally, other regions do not necessarily have the same solar production and demand profiles to cause such a problem.

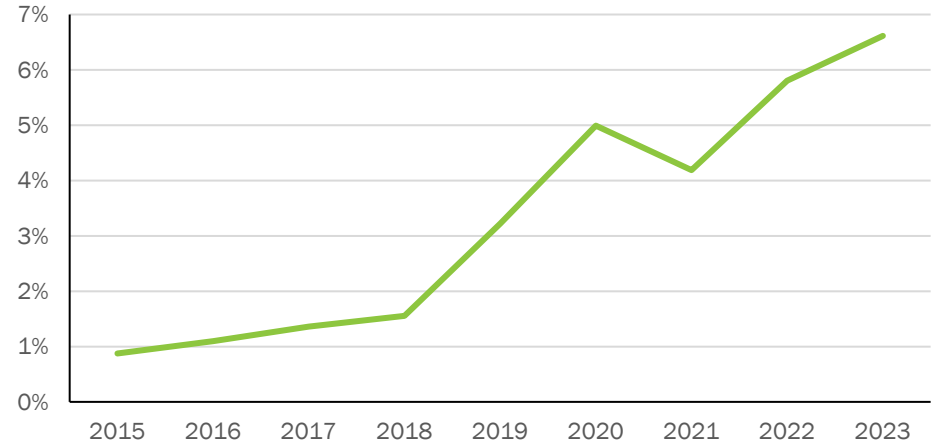


Note: net load = load – solar & wind production.
Sources: CAISO: http://www.caiso.com/informed/Pages/ManagingOversupply.aspx; DOE: https://www.energy.gov/eere/articles/confronting-duck-curve-how-address-over-generation-solar-energy.

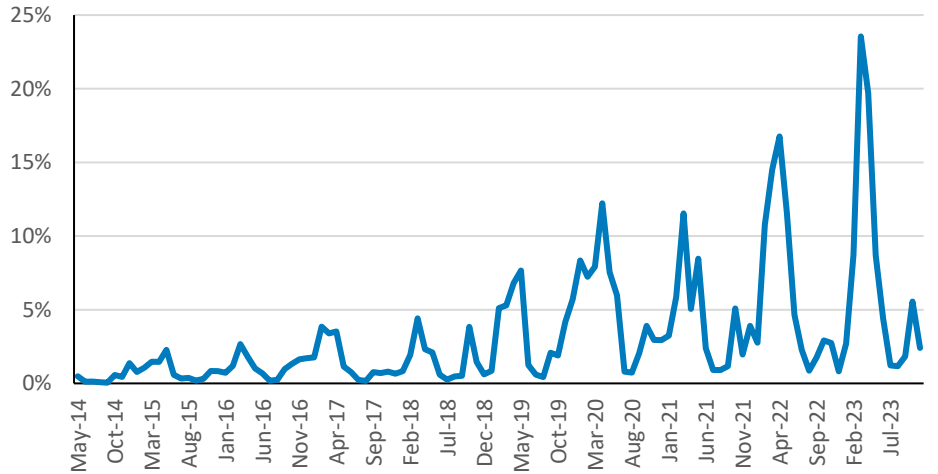
Duck Curve: Curtailment

CAISO has mostly dealt with overproduction through curtailment of solar electricity, but over the course of the year, this has not represented a large amount of energy (though it reached 24% in March 2023). Curtailment has also been driven by other non–Duck Curve factors, such as local transmission and reliability constraints. Ramping, though also an issue, is something that has been managed.

CAISO Solar Curtailment (by % of capacity): Annual

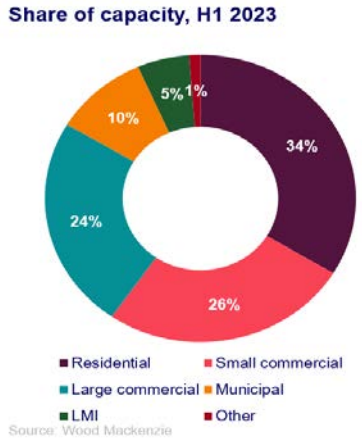


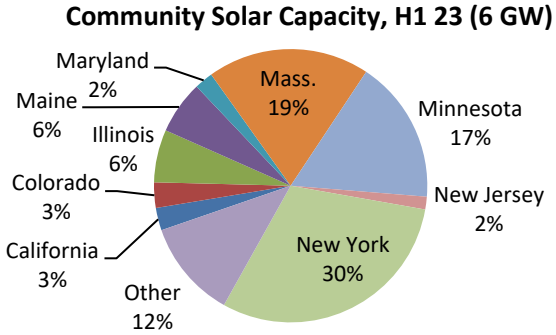
CAISO Solar Curtailment (by % of capacity): Monthly

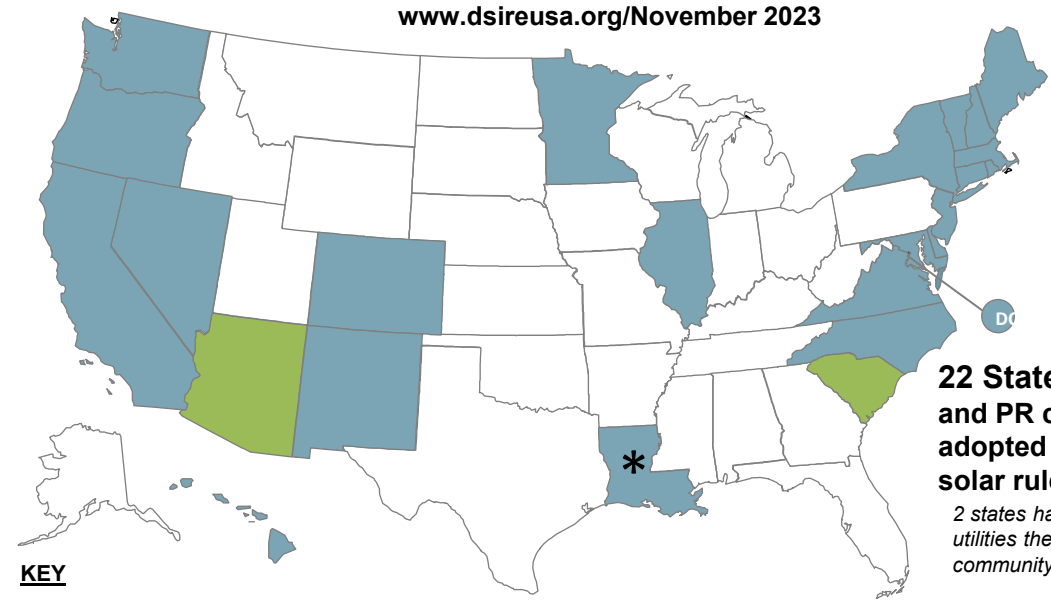


Sources: CAISO: http://www.caiso.com/informed/Pages/ManagingOversupply.aspx

Community Solar Programs in the U.S.







22 States + DC and PR currently have adopted community solar rules

2 states have rules giving utilities the option to create community solar programs

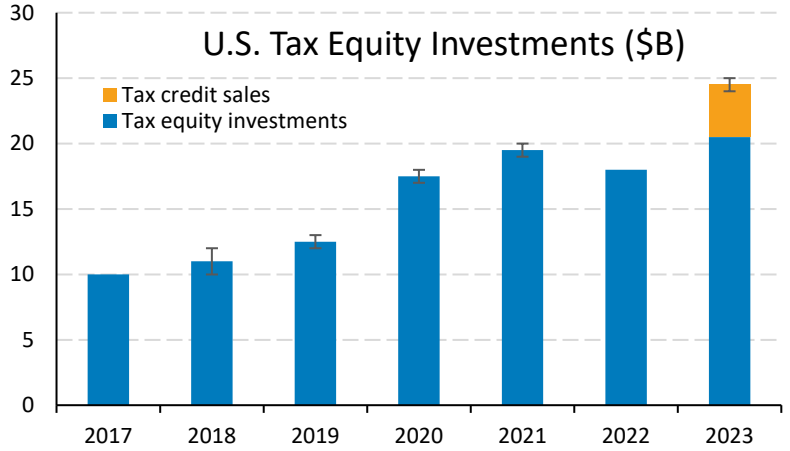
U.S. Territories:

AS	PR
VI	GU

Sources: DSIRE USA; Wood Mackenzie and SEIA.

Cost of Capital, Tax Equity (Norton Rose Fulbright)

- Tax equity investors invested $20–$21 billion in 2023, with some of that volume coming from 2022 transactions that were delayed:
  - The deals were split relatively evenly between wind and solar+storage.
  - Upwards of 40% of solar deals used the PTC, and some transactions involved solar using PTC and batteries using ITC.
- There was also another ~$4B in tax credit sales (which includes some non-generation credits, such as 45X).
  - Investors predicted additionality, as opposed to cannibalization of the tax equity market, caused by tax credit sales.
  - Tax credit sales prices started at 90%–93% but have recently been seen as high as 97%. Price can depend on factors such as insurance products associated with a deal.
  - There are various reasons sponsors would still choose tax equity over a credit sale: additional markup value; monetizing the accelerated depreciation expense; timing of when money is received.
- Tax equity flip yields are up 100 to 200 basis points from summer 2022 (up to an estimated 8%–9% level), as interest rates have increased and there is more demand for tax equity than supply.



- In July 2023, the federal government issued proposed rules to large banks, similar to those passed internationally (i.e., "Basel III"). These rules would require banks with tax equity investments to quadruple the required cash on their balance sheet (i.e., capital requirements) for making tax equity investments compared to what they do now. This would increase the cost of tax equity and drive some funders out of the market. The regulations would impact PTC transactions less than ITC transactions. Banks are hoping the regulators will make changes for the final rules; however, if there is no resolution, banks may pause funding midyear. Currently clauses are being put in transactions that would allow banks to back out if the final rules are unfavorable. The proposed rules would not take effect until 2025.

Sources: Norton Rose Fulbright Cost of Capital: 2024 Outlook; Proposed Basel II Rules.

Cost of Capital, Bank Debt (Norton Rose Fulbright)

- Bank debt was >$115B in 2023 from 226 deals—similar to 2022, another record year. Regional banks are beginning to lend again after issues in 2022 (e.g., Silicon Valley Bank).
- Banks are lending plain “vanilla” projects at 7% with a bank margin of 175 points—in June 2022, the same loan would be 3.5%–4.0%.
    - A merchant deal would increase the cost by 75–150 basis points.
- The debt service coverage ratio (DSCR) is 1.25 (P50)/1.0 (P99) for solar projects, 1.15 for storage projects, and 1.3–1.4 (P50)/1.0 (P99) for wind projects.
    - For merchant projects, the DSCR increases to 1.75 (P50) for solar, 2.0 for storage, and 1.8–2.0 (P50)/1.4-1.5 (P99) for wind.

Note: P50 represents an average level of energy production (or 50% likelihood to generate that much or more electricity), and P99 represents a production level that the project has a 99% chance of exceeding.
Source: Norton Rose Fulbright Cost of Capital: 2024 Outlook.

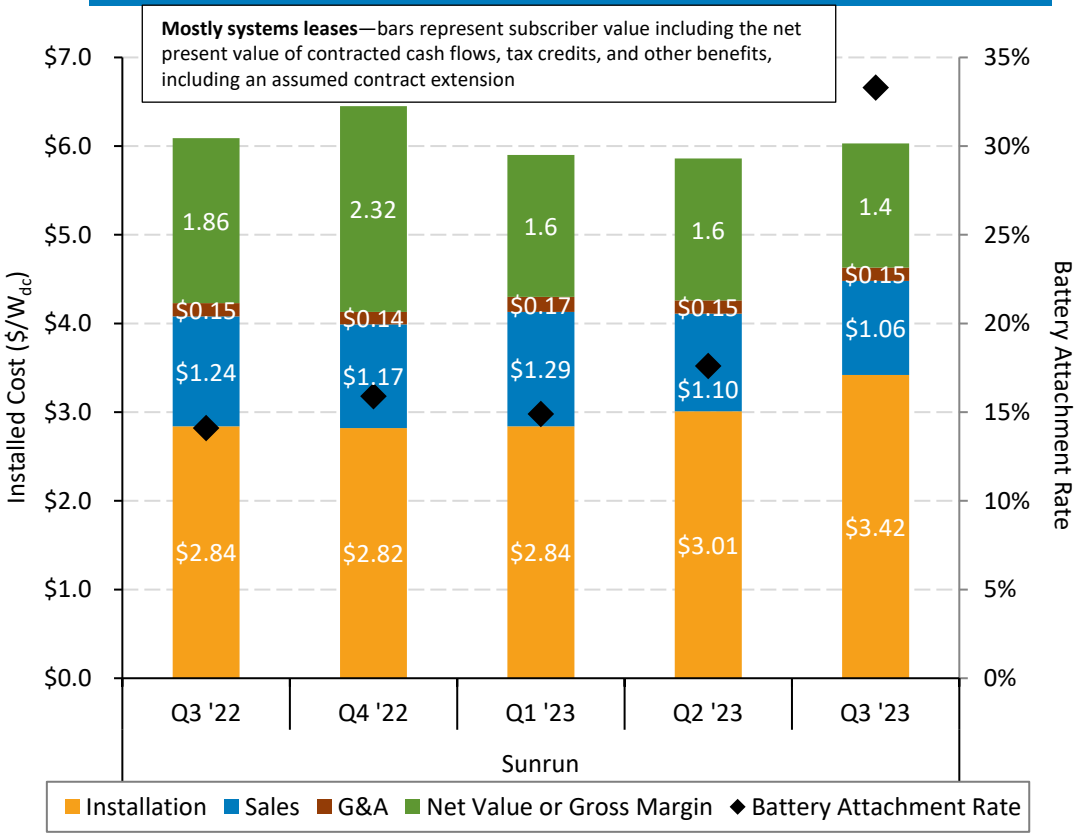
Agenda

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 Waste and Toxicity

From H2 2022 to H2 2023 (partial), the median reported distributed PV system price in Arizona, California, Massachusetts, and New York:

- Decreased 0.2% to \$4.25/W_{dc} for systems 2.5 to 10 kW
- Decreased 4% to \$3.66/W_{dc} for systems 10 to 100 kW
- Increased 2% to \$2.49/W_{dc} for systems 100 to 500 kW
- Increased 7% to \$1.92/W_{dc} for systems 500 kW to 5 MW.

Large Residential Installer Cost and Value, Q3 2023



Source: Corporate filings

Large residential installer Sunrun reported a system value change of -1% y/y and +3% q/q.

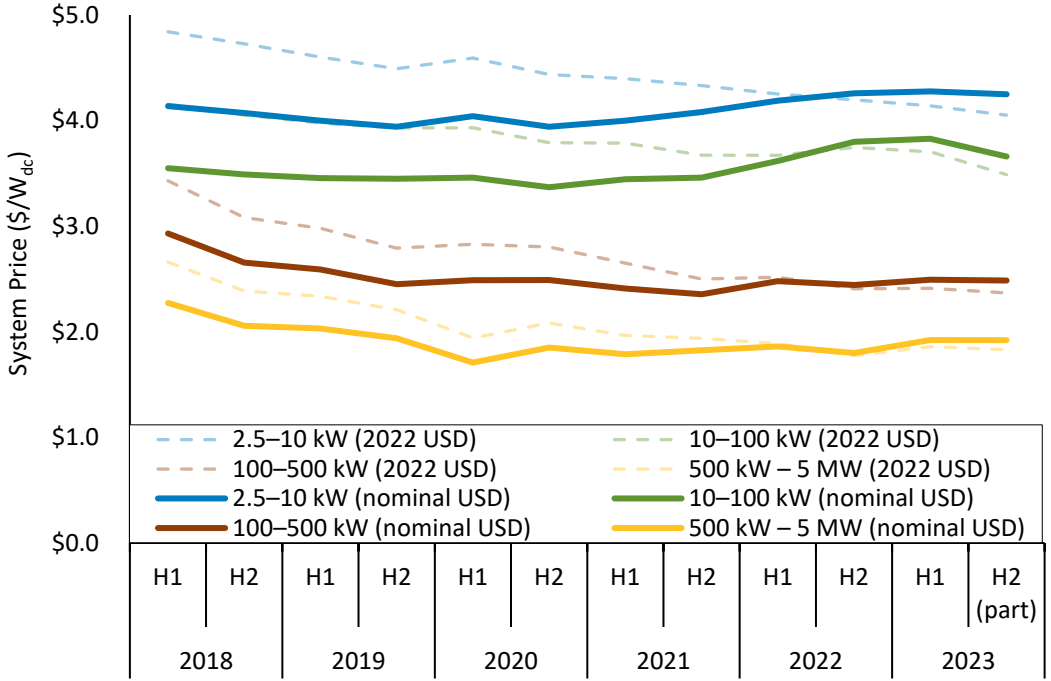
Factors reported as supporting higher system value and/or costs (for Sunrun, SunPower, and Sunnova):

- Increasing inflation and interest rates
- Increasing retail electricity rates
- Increasing battery attachment rates (batteries add cost but can yield higher margins):
  - Sunrun rate rose from 18% to 33% q/q (100% in HI and PR, 44% in CA, 4% elsewhere)
  - Up to 85%+ recent rate in California and 40%+ nationwide
  - Sunrun reports "rapidly transitioning to a storage-first company."

Factors reported as supporting lower PV system costs and/or higher margins now and in future:

- Forthcoming Investment Tax Credit adders
- 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
- Process cost cutting via artificial intelligence

Distributed PV System Pricing From Select States



2023 MW data YTD: Arizona (290), California (1,566), Massachusetts (77), New York (596).
Note: System prices above $10/W and below $0.75/W were removed from the data set. There were not enough reported prices for systems above 5 MW in the data set to show a trend over time.
Sources: Arizona Goes Solar (1/2/24); California Distributed Generation (11/30/23); Massachusetts Lists of Qualified Generation Units (12/6/23); Solar Electric Programs Reported by NYSERDA (1/4/24).

From H2 2022 to H2 2023 (partial), the median reported distributed PV system price—**in nominal U.S. dollars (USD)**—across Arizona, California, Massachusetts, and New York:

- Decreased 0.2% to \$4.25/W_{dc} for systems 2.5 to 10 kW
- Decreased 4% to \$3.66/W_{dc} for systems 10 to 100 kW
- Increased 2% to \$2.49/W_{dc} for systems 100 to 500 kW
- Increased 7% to \$1.92/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:

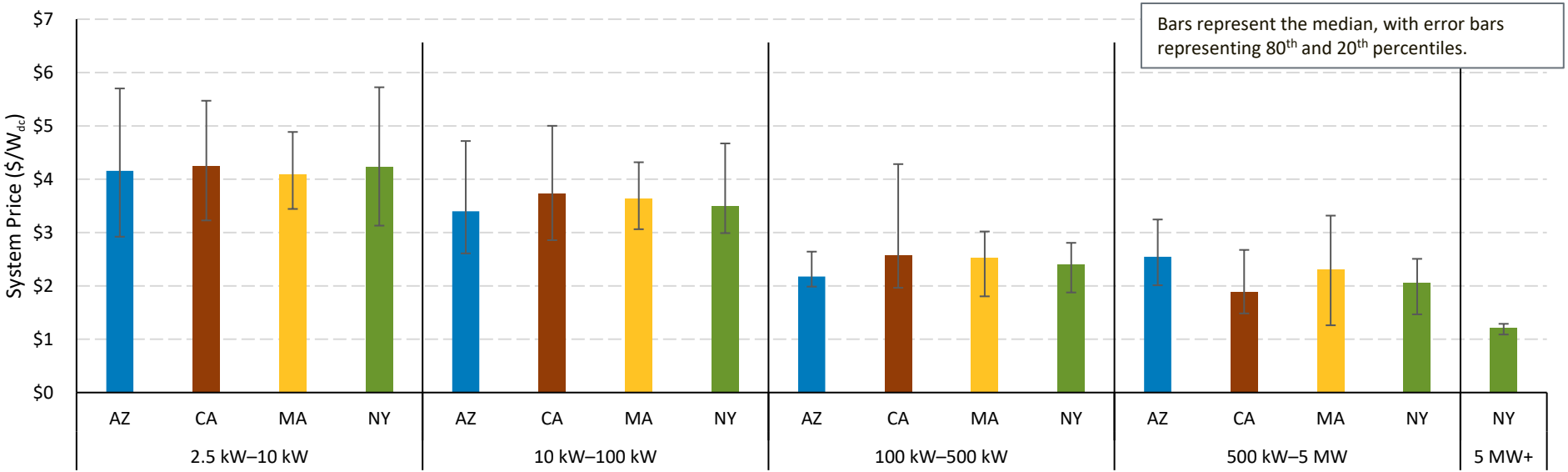
- Decreased 3% for systems 2.5 to 10 kW
- Decreased 7% for systems 10 to 100 kW
- Decreased 2% for systems 100 to 500 kW
- Increased 3% for systems 500 kW to 5 MW.

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):
  - -5% in Arizona, no change in California, +4% in Massachusetts, -1% in New York.



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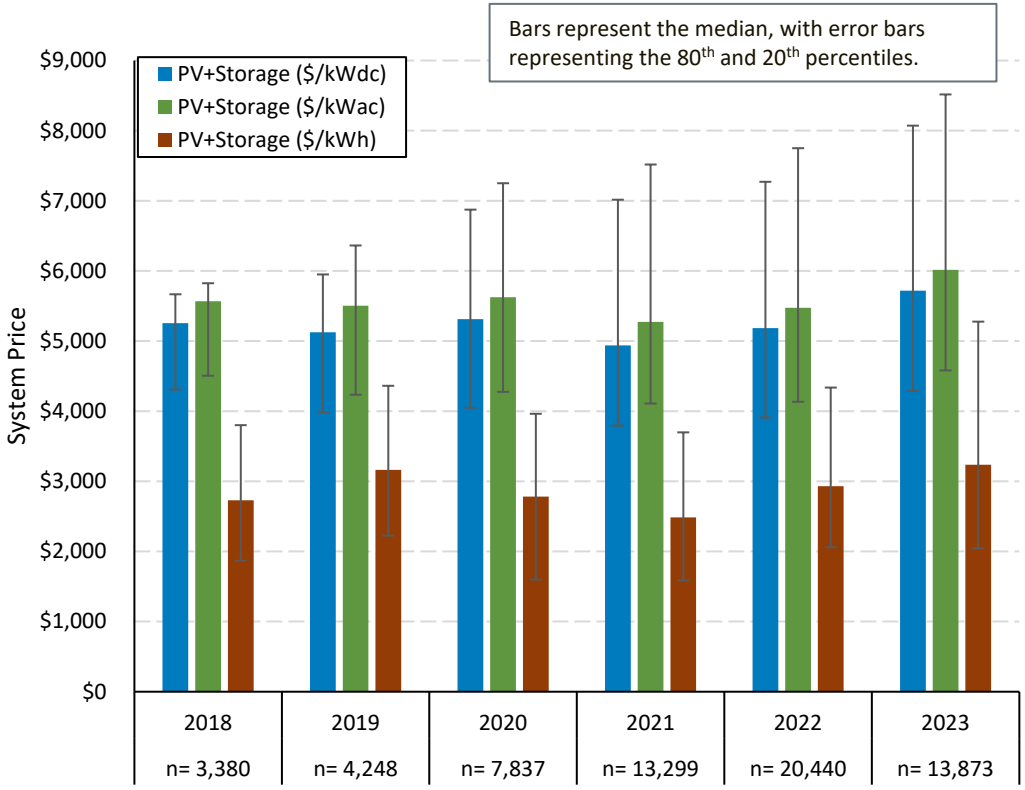
Sources: Arizona Goes Solar (1/2/24); California Distributed Generation (11/30/23); Massachusetts Lists of Qualified Generation Units (12/6/23); Solar Electric Programs Reported by NYSERDA (1/4/24).

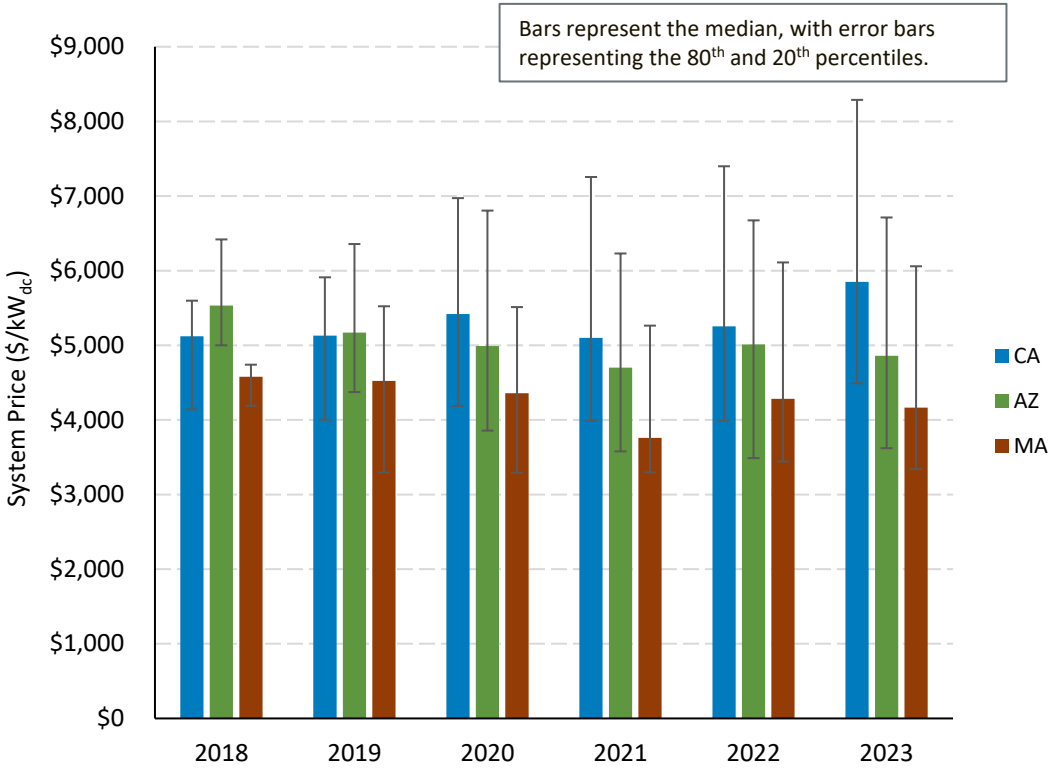
Residential U.S. PV+Storage Pricing



- In 2023 YTD, residential PV+storage systems in Arizona, California, and Massachusetts had a median system price of $3,235/kWh, or $6,015/$kW_{ac}$ ($5,719/$kW_{dc}$)—an increase of about 10% 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 (16), California (106), Massachusetts (7).
Sources: Arizona Goes Solar (1/2/24); California Distributed Generation (11/30/23); Massachusetts Lists of Qualified Generation Units (12/6/23).

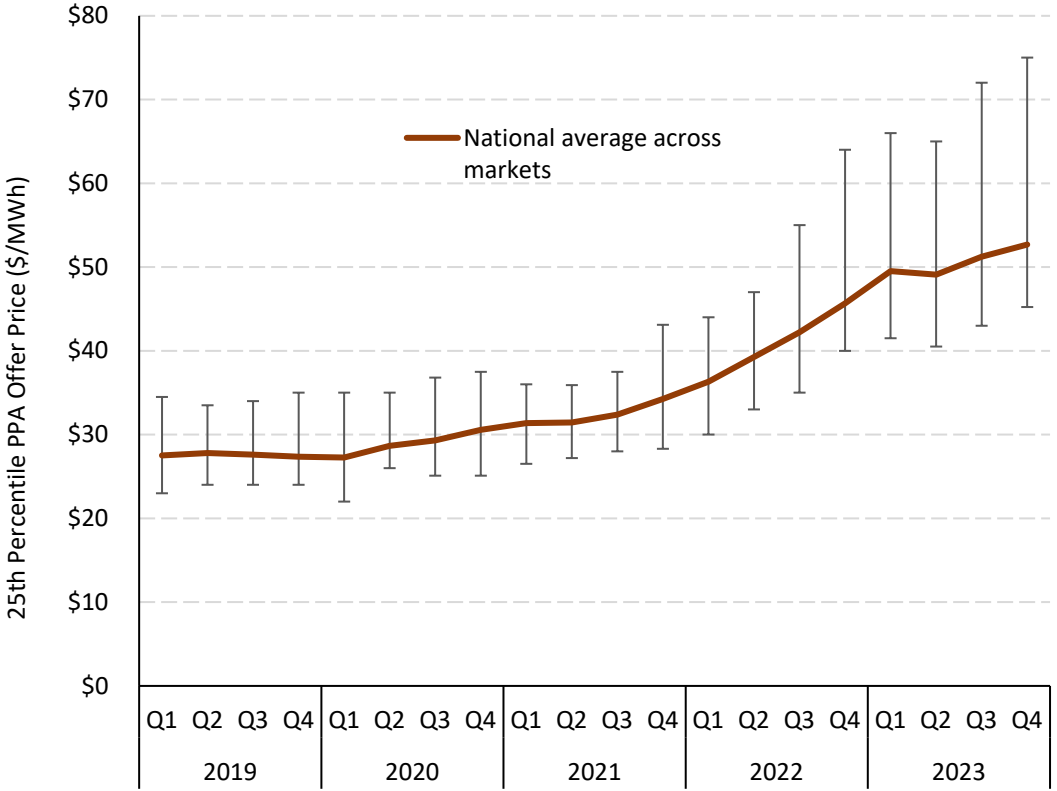
Residential U.S. PV+Storage Pricing



- 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 (11%) while decreasing in Massachusetts (3%) and Arizona (3%).

2023 YTD residential PV+storage sample, after data cleaning (MW_{dc}): Arizona (16), California (106), Massachusetts (7).
Sources: Arizona Goes Solar (1/2/24); California Distributed Generation (11/30/23); Massachusetts Lists of Qualified Generation Units (12/6/23).

U.S. Solar PPA Pricing (LevelTen)

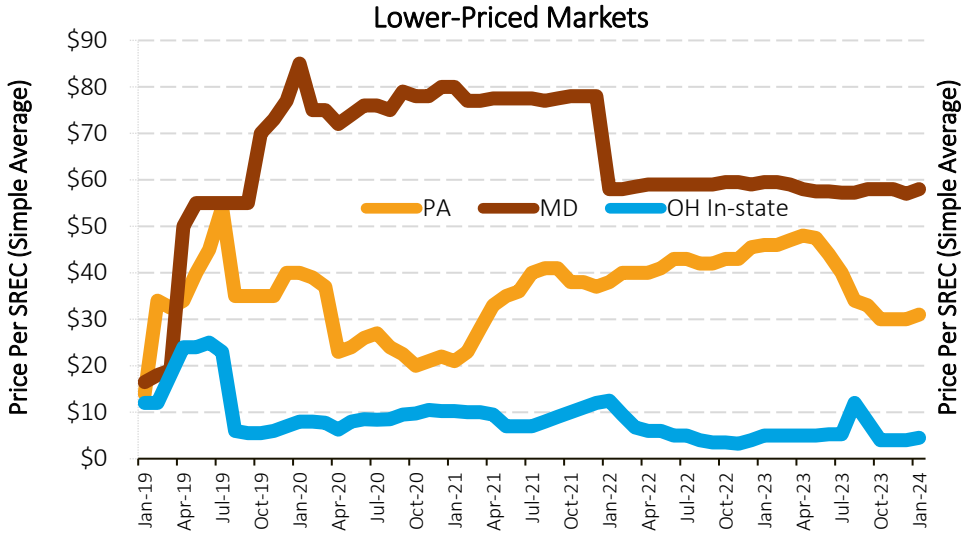


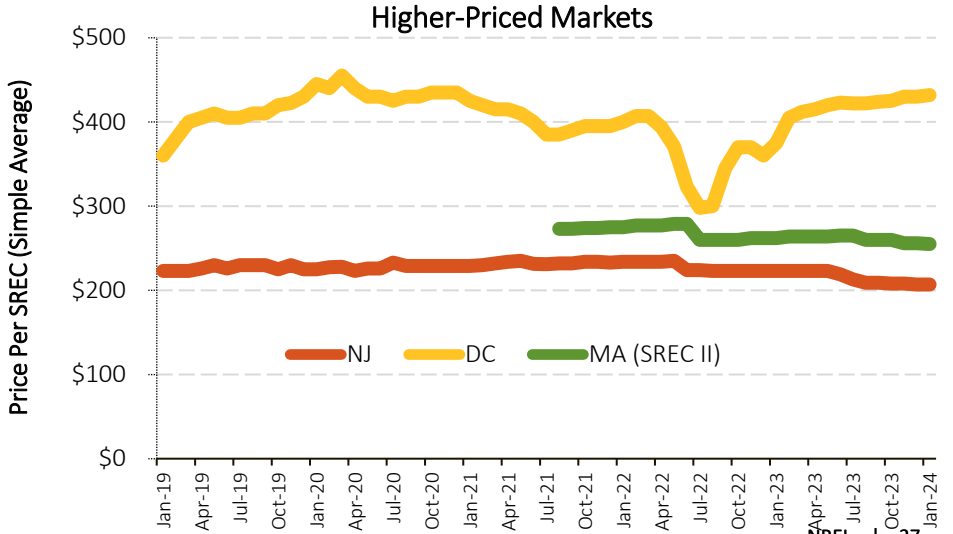
- LevelTen reports that following a modest dip in prices in Q2, U.S. utility-scale PV PPA prices increased for the second straight quarter, increasing 3% q/q and 15% y/y in Q4 2023.
- Market-level trends diverged with some experiencing price declines and others seeing price increases:
  - ERCOT pricing was relatively low due in part to low interconnection costs and low REC pricing. Conversely, PJM pricing was relatively high due to higher interconnection and REC pricing.
- PPA prices were pushed down by a more efficient solar supply chain and lower module prices; however, high interest rates negated any benefits of lower equipment pricing.

Source: LevelTen, PPA Price Index.

SREC Pricing

- Solar renewable energy certificate (SREC) pricing has been relatively flat in 2023, particularly for legacy programs such as New Jersey and Massachusetts, which are not accepting new projects.
- However, potential programmatic or supply/demand changes can still impact markets. A bill currently being debated in Pennsylvania's state House would increase its RPS from 8% to 30% and the solar carveout from 0.5% to 4.0% by 2030.





Source: SRECTrade, https://www.srectrade.com/, accessed 01/31/31.

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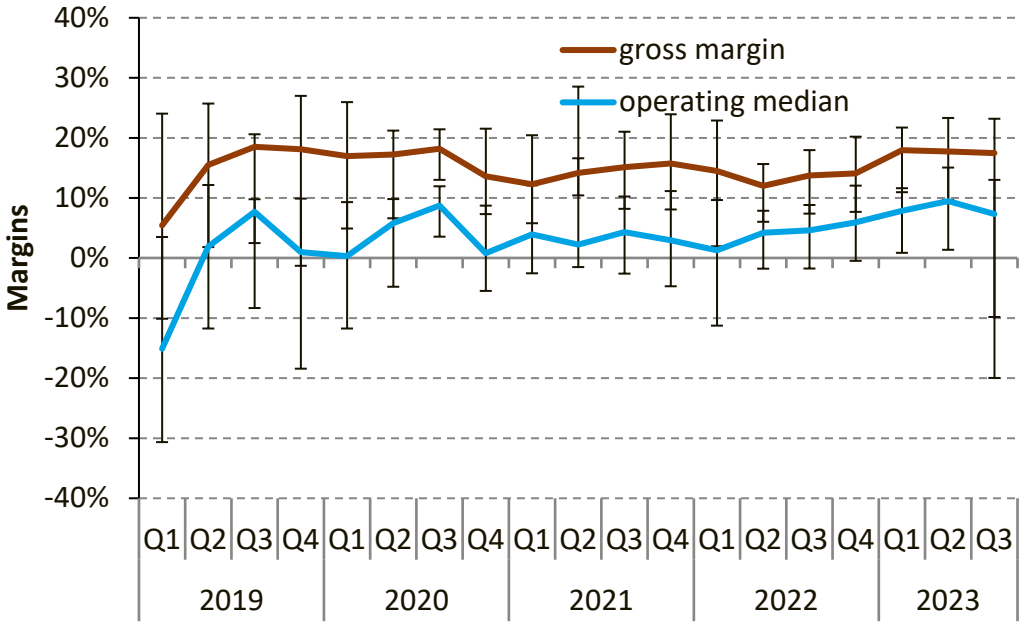
- **BNEF reports that at the end of 2023, global PV manufacturing capacity was between 650 and 750 GW—a growth of 2–3x in the past 5 years, 90% of which occurred in China. In 2023, global PV production was between 400 and 500 GW.**
- **Despite global price drops across the PV supply chain, PV manufacturers have generally remained profitable, thanks to increases in sales volumes (particularly for N-type cells).**

PV Manufacturers' Margins



- Despite global price drops across the PV supply chain, PV manufacturers have generally remained profitable, thanks to increases in sales volumes (particularly for N-type cells):
  - Lower pricing upstream also means lower costs downstream.
  - At the end of Q3 2023, over half of Canadian Solar capacity and Jinko Solar production (57%) used N-type cell architecture.
  - Jinko reported mass-produced TopCon cell efficiencies reaching 25.6%.

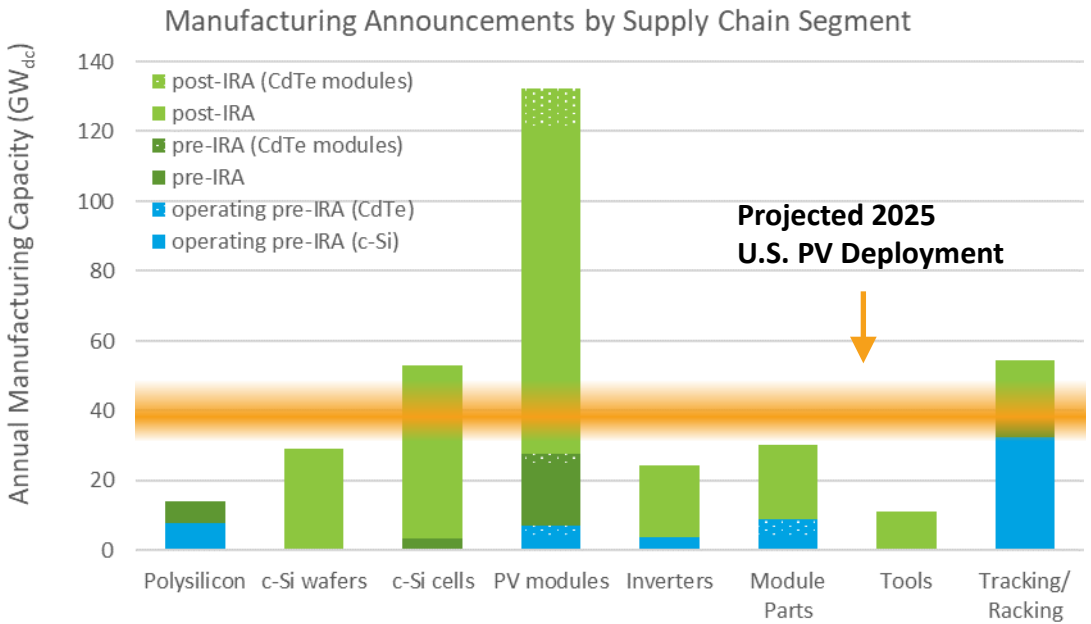
Lines represent the median, with error bars representing 80th and 20th percentiles for the following companies in Q3 2023: Canadian Solar, First Solar, JA Solar, Jinko Solar, LONGi, Maxeon, Motech Industries, REC Silicon, Renesola, Risen, Shanghai Aiko, Shanghai Aerospace, Tongwei, Trina Solar, and United Renewable Energy.

Note: Gross margin = revenue minus 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).

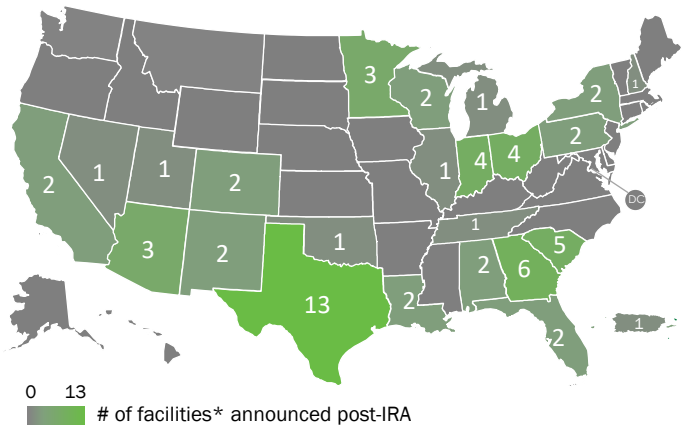
Sources: Company figures based on public filings and finance.yahoo.com.

IRA Impacts on U.S. Solar PV Manufacturing Capacity

- Since the passage of the IRA, >250 GW of manufacturing capacity has been announced across the solar supply chain, representing more than 27,000 potential jobs and more than $14 billion in announced investments across 80 new facilities or expansions.*
  - 105 GW of solar module capacity (including 11 GW of CdTe)
  - 49 GW of c-Si cell capacity
  - 29 GW of c-Si wafer capacity
  - 69 GW of BOS (including glass, encapsulant, backsheet, junction boxes, inverters, trackers, and tracker components)*
  - Another 35 GW of solar manufacturing capacity had been announced since the start of the Biden administration prior to the passage of the IRA.



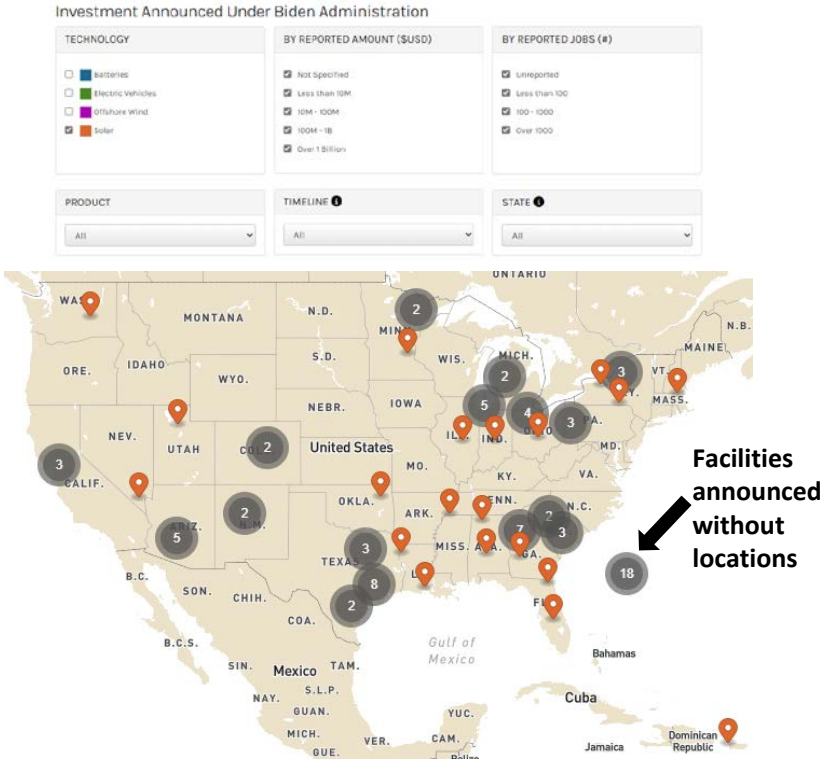
These announcements post-IRA represent potential investment in 23 states and Puerto Rico.



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:
  - Array Technologies announced solar tracker plans for Albuquerque, New Mexico
  - Canadian Solar announced plans for 5 GW of cells in Jeffersonville, Indiana
  - Heliene announced plans to expand in Mountain Iron, Minnesota
  - NSG Glass North America announced plans to make glass for First Solar in Rossford, Ohio
  - Priefert Steel (Nevados) announced solar tracker plans for Mount Pleasant, Texas
  - SMA Solar announced plans to make 3.5 GW of inverters in the U.S.
  - Soltec announced plans to make trackers within the U.S.
  - Waaree Energies announced a location for its module manufacturing in Brookshire, Texas, and announced plans to make c-Si cells within the U.S. by 2025.

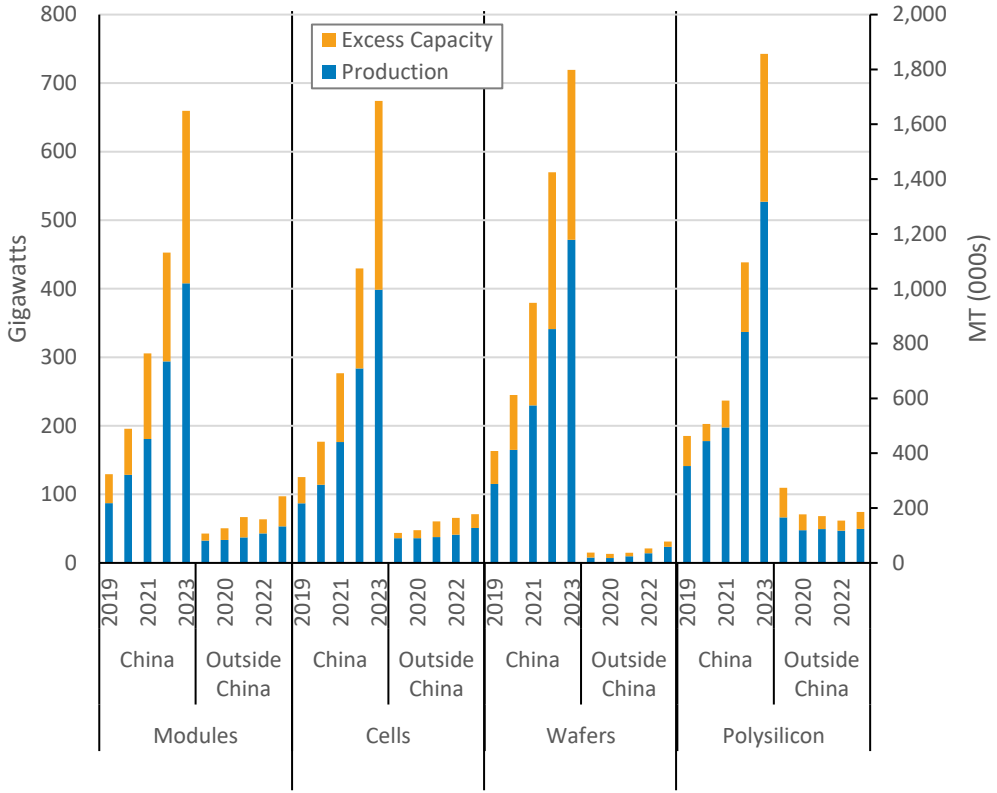


https://www.energy.gov/invest, updated 1/11/24

- In less positive manufacturing news, Enphase Energy also announced that it plans to close its recently-opened Wisconsin facility in 2024.

Source: Internal DOE tracking of announcements, PV Tech.

Growth in Global PV Manufacturing Capacity

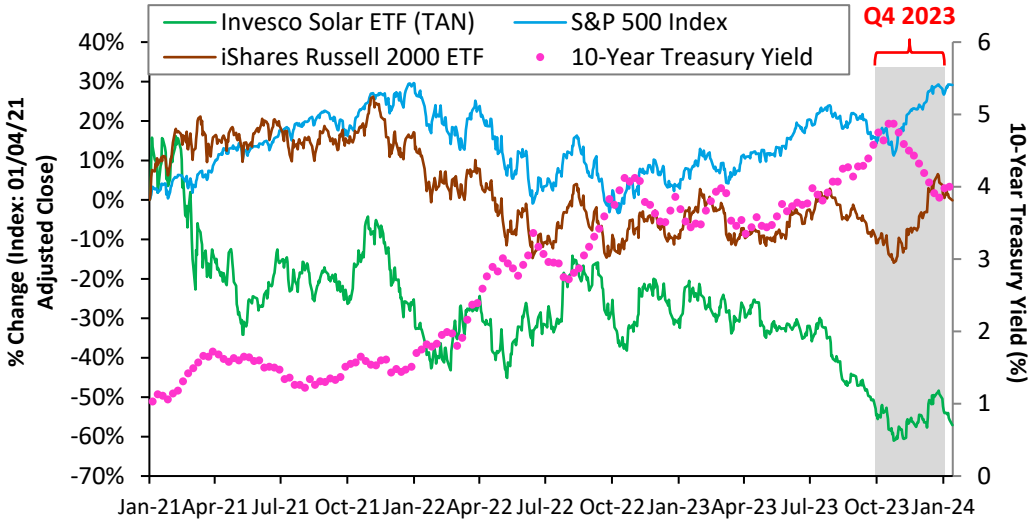


- PVTech and Goldman Sachs report that at the end of 2023, approximate global PV manufacturing capacity was between 650 and 750 GW. In 2023, global PV production was between 400 and 500 GW.
- In the past 5 years, PV manufacturing capacity has grown 2–3x, with more than 90% of the growth occurring in China:
  - 20% (wafer) to 40% (polysilicon) of new manufacturing capacity came online in 2023.
- The ratio of production as a percent of manufacturing capacity fell slightly in 2023; however, some of that might be explained by the large amount of manufacturing capacity ramping up.
- Historically, the previous years' manufacturing capacity has been a good indicator of the next year's production, across manufacturing steps. However,r analysts project that it may take a few years for the industry to produce at the 2023 level of global manufacturing capacity.

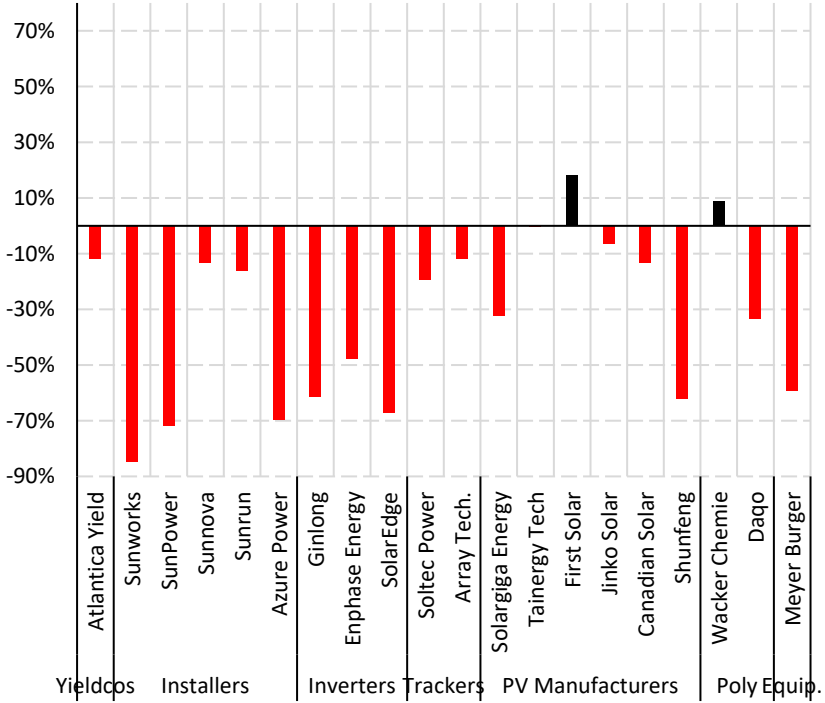
Note: Data represent median values from multiple sources.
Sources: Goldman Sachs (12/17/23), PVTech Research, "PV Manufacturing & Technology Quarterly Report - Release 31 - November 2023."

Stock Market Activity

The Invesco Solar ETF rose 8% in Q4 2023 (-26% for the year) vs. an 11%–15% increase across the broader market (+16% to +25% for the year). Rising interest rates weighed on solar stocks for much of the year, reducing profitability. A 5-percentage point increase in interest rates can increase solar energy costs by one-third. Additional headwinds included California's NEM 3.0 policy, high labor costs, and large installer inventories of PV equipment. Potential tailwinds going forward include falling interest rates, strong demand for solar energy worldwide, and rapidly rising utility rates.



Individual Stock Performance (Q1–Q4 2023)



Note: The TAN index is weighted toward particular countries and sectors. As of 1/16/24, 55% of its funds were in U.S. companies and 17% were in Chinese companies. Its top 10 holdings, representing 62% of its value, were First Solar, Enphase, SolarEdge, Sunrun, GCL, Hannon Armstrong, Xinyi, Shoals, Array Technologies, and Encavis.

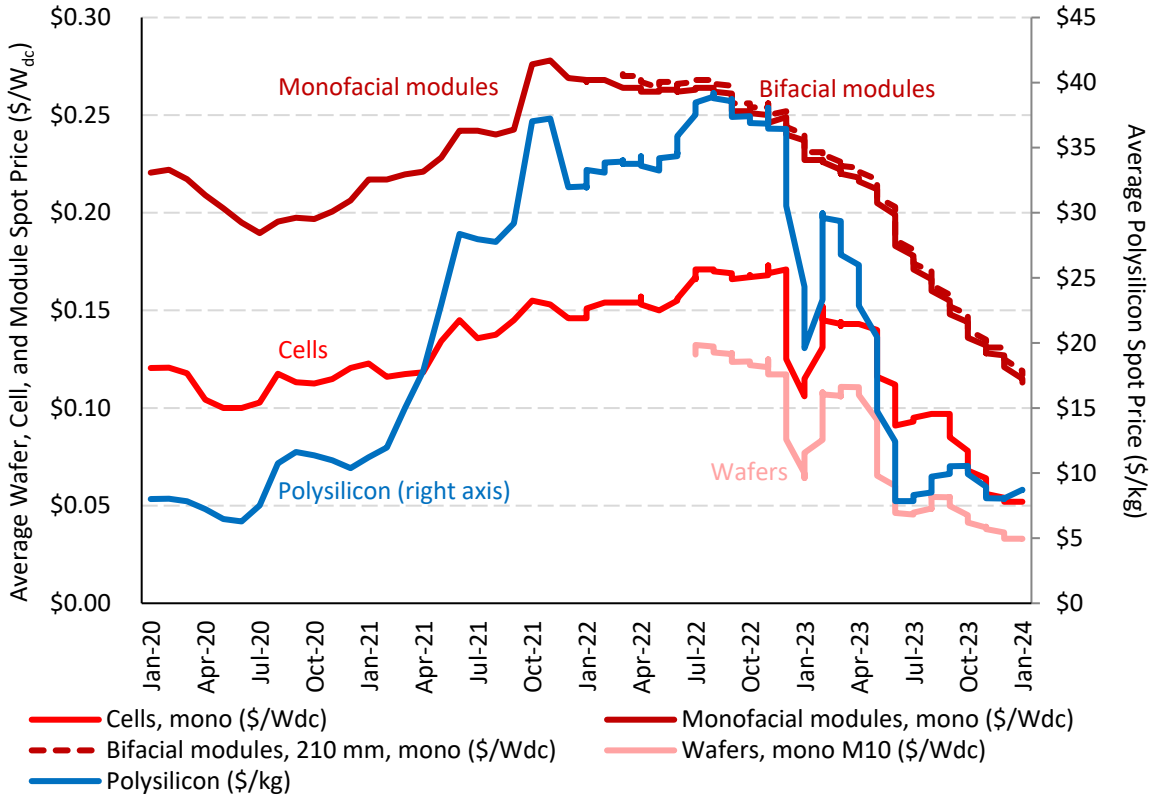
Sources: CNBC (11/15/23); Federal Reserve Bank of St. Louis (accessed 1/16/24); IEA, Projected Costs of Generating Electricity, 2020; Invesco (1/16/24); Nasdaq (1/13/24); Yahoo Finance (accessed 1/16/24).

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 Waste and Toxicity

- **Global polysilicon spot prices fell 18% from mid-October ($10.53/kg) to mid-January ($8.70/kg), approaching their lowest levels of the past several years.**
- **Global module prices reached yet another record low, falling 22% between mid-October and mid-January to $0.11/$W_{dc}$.**
- **In Q3 2023, the average U.S. module price ($0.33/$W_{dc}$) was down 11% q/q and down 23% y/y but at a 100% premium over the global spot price for monofacial monocrystalline silicon modules.**

PV Value Chain Global Spot Pricing



Global polysilicon spot prices fell 18% from mid-October ($10.53/kg) to mid-January ($8.70/kg), approaching their lowest levels of the past several years:

- Additional polysilicon capacity scheduled to come online in 2024 far exceeds the increase in expected polysilicon demand, further increasing global polysilicon overcapacity.

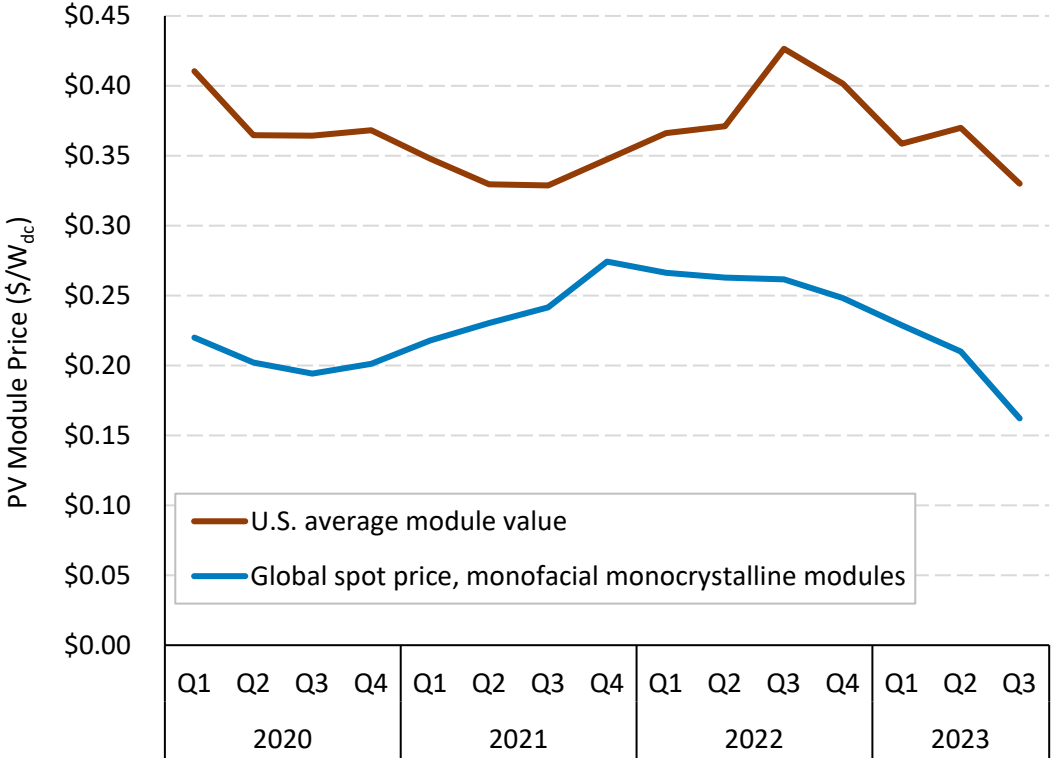
During the same period, global prices decreased for wafers (27%) and cells (33%).

Global module prices reached yet another record low, falling 22% between mid-October and mid-January to $0.11/W$_{dc}$:

- Decreasing supply chain costs, increasing module manufacturing capacity, and large module inventories in Europe as well as intense competition among manufacturers depressed demand and prices.

Sources: BloombergNEF, Solar Spot Price Index (1/17/24); PV Magazine (9/25/23, 11/23/23, 11/28/23, 12/19/23); PV Tech (10/20/23).

Module Prices: Global vs. United States



In Q3 2023, the average U.S. module price ($0.33/$W_{dc}$) was down 11% q/q and down 23% y/y but at a 100% premium over the global spot price for monofacial monocrystalline silicon modules.

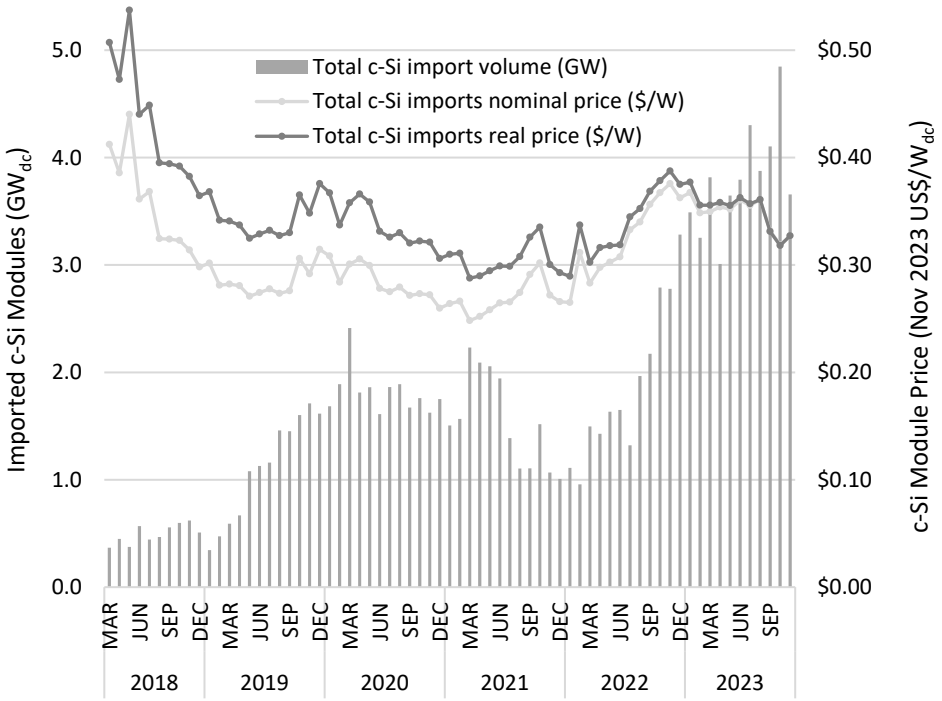
The directional trend in U.S. module prices realigned with the trend in global module prices, although the difference between the two prices remained about the same ($0.16–$0.17/W_{dc}).

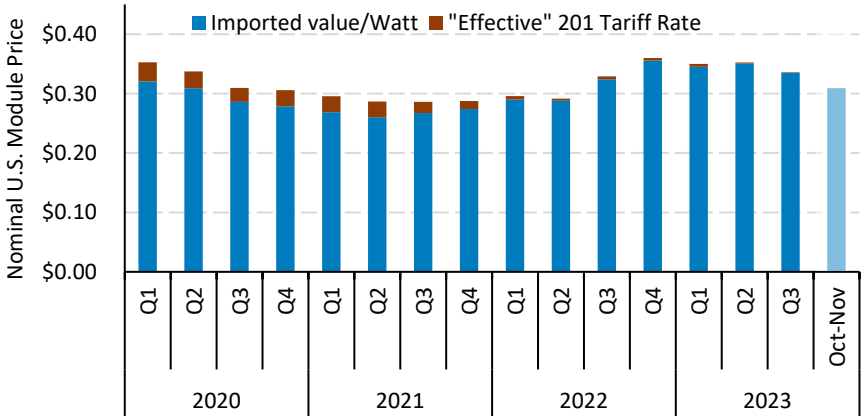
- The U.S. premium has been maintained by tariffs on Chinese modules as well as friction on Southeast Asian module imports due to the antidumping and countervailing duties (AD/CVD) investigation as well as module detainment under the Uyghur Forced Labor Prevention Act (UFLPA).
- Decreasing UFLPA detainment periods have contributed to recent declines in U.S. module prices.

Sources: BloombergNEF, Solar Spot Price Index (1/17/24); EIA, Monthly Solar Photovoltaic Module Shipments Report (1/19/24); Wood Mackenzie and SEIA, US Solar Market Insight: Q3 2023 (9/23); Wood Mackenzie and SEIA, US Solar Market Insight: Q4 2023 (12/23).

Calculated U.S. Module Pricing

- As module imports rose at the end of 2022, prices rose with them, but in Q3 2023, prices began to fall—although they are still well within historical norms (in both real and nominal price).
  - Based on the reported value and capacity of imported PV modules, the average price of a PV module in the United States fell less than a cent q/q in Q3 2023 to $0.34/W and is on track to fall back to $0.31/W in Q4, while the effective Section 201 tariff has fallen below $0.01/W.
  - Price fluctuations continue to vary by country, with module prices from South Korea experiencing the most significant changes and those from Malaysia remaining the steadiest.

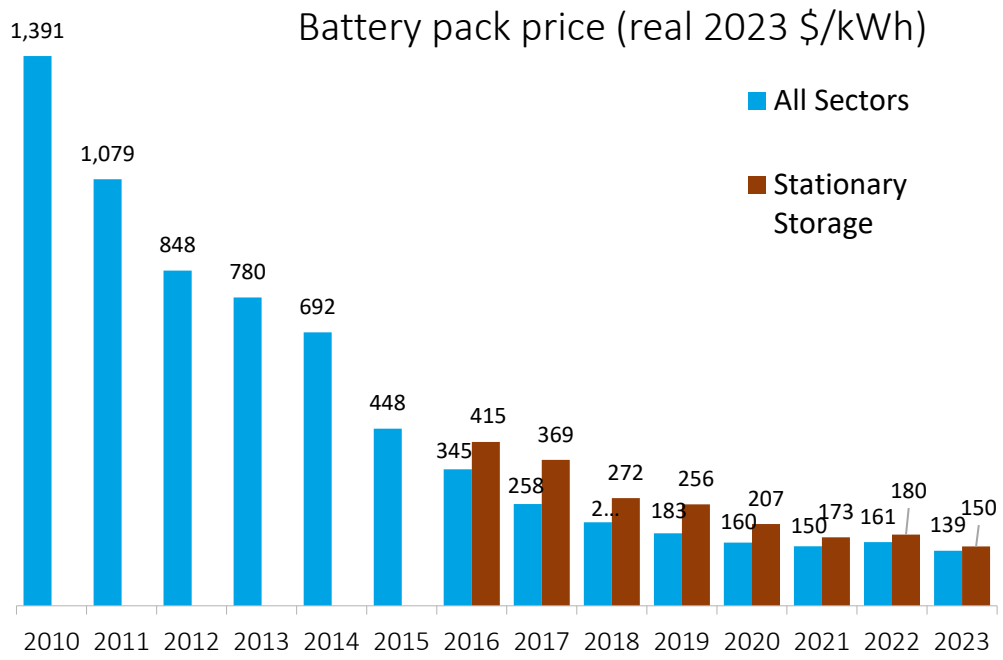




Note: Manual corrections were made to three values due to suspected data entry errors for HTS code 8541430010: Cambodia (February 2022), Malaysia (June 2020), and Vietnam (July 2019); nominal price = the price paid at the time of transaction (i.e., not adjusted for inflation); real price = the price adjusted for inflation.

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. Manual corrections were made to imports from India due to suspected data entry errors.

Average Lithium-Ion Battery Pack Price, 2010–2023



- After a small increase in 2022, battery pack prices continued their historical downward trend in 2023, falling 90% from 2010 to 2023, and 14% between 2022 and 2023.
  - From 2016 to 2023, average battery pack prices within the stationary storage sector decreased 64% and 17% from 2022 to 2023.
  - BNEF reported the lowest price to date: $82/kWh in China.
- BloombergNEF cited falling raw material and component prices due to large increases in manufacturing capacity throughout the supply chain. Additionally, despite a growth in demand, it may have been lower than expected.
- BloombergNEF reported that large stationary storage providers are entering multiyear cell supply agreements while allowing flexibility to take advantage of low Chinese prices.

Source: BloombergNEF, "2023 Lithium-Ion Battery Price Survey."

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1 Global Solar Deployment

2 U.S. PV Deployment

3 PV System Pricing

4 Global Manufacturing

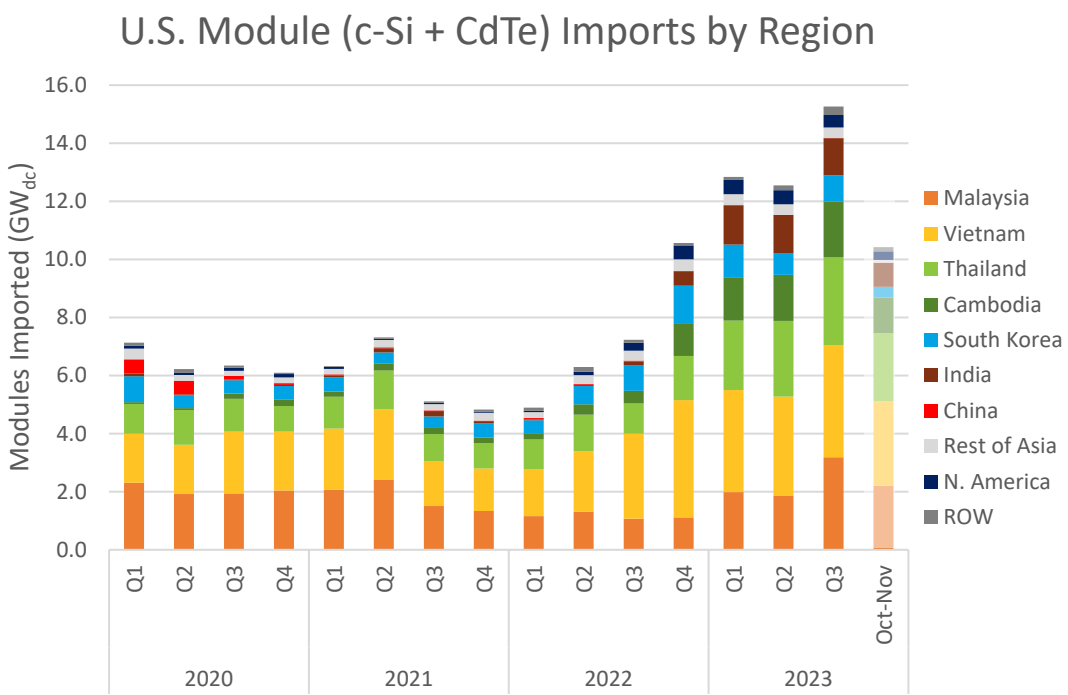
5 Component Pricing

6 **U.S. PV Imports**

7 PV Waste and Toxicity

- **The United States imported 40.6 GW_{dc} of PV modules in Q1–Q3 2023, setting a new single-quarter record of over 15 GW_{dc} of modules imported.**
  - Most panels imported were exempt from Section 201 duties and were therefore likely bifacial. A significant number of thin-film modules were also imported.
- **2.4 GW_{dc} of cells were imported in Q1–Q3 2023, up 31% y/y.**
  - The U.S. is not on pace to reach the 5-GW_{dc} quota exemption limit for Section 201 tariffs, although it has exceeded 3 GW_{dc} of imports in a single year for the first time.

Module Imports and Calculated Prices by Region

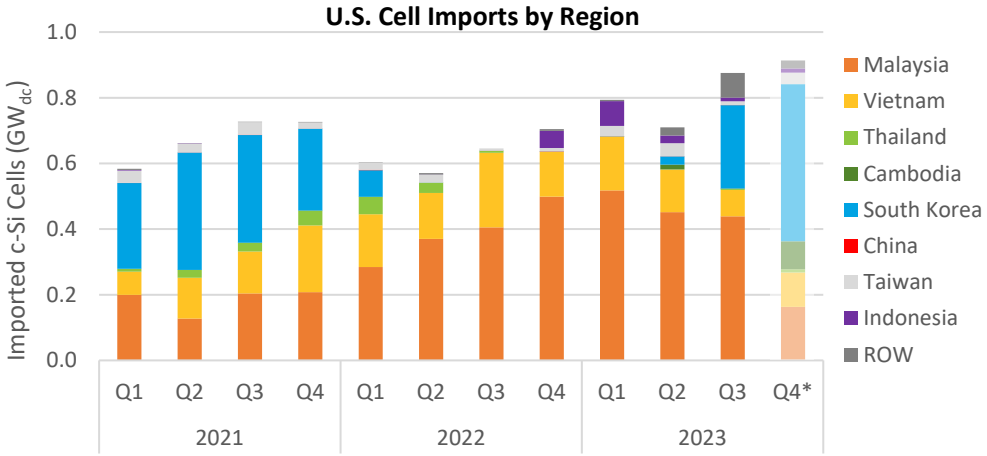


- In Q3 2023, U.S. module imports achieved new record-high levels at 15.3 GW_{dc} (+111%, or 8 GW_{dc} y/y), totaling 40.6 GW_{dc} in Q1–Q3 2023.
  - Import levels decreased after the withhold release order (WRO) on PV cells and modules was announced in late Q2 2021. Additionally, many manufacturers 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 have recovered from those disturbances.
  - The Q3 q/q increase (+22%, +2.72 GW_{dc}) was mainly the result of increased imports from Malaysia (+71% q/q, +1.3 GW_{dc}) as well as more modest increases from the other southeast Asian countries of import.
- Though Q4 is not yet complete, it looks to be another strong quarter for module imports.
  - This has been mainly the result of imports from Vietnam, Malaysia, and Thailand all exceeding 2 GW_{dc} in just 2 months, with Vietnam at nearly 3 GW (2.3 GW_{dc} c-Si and 0.7 GW_{dc}).

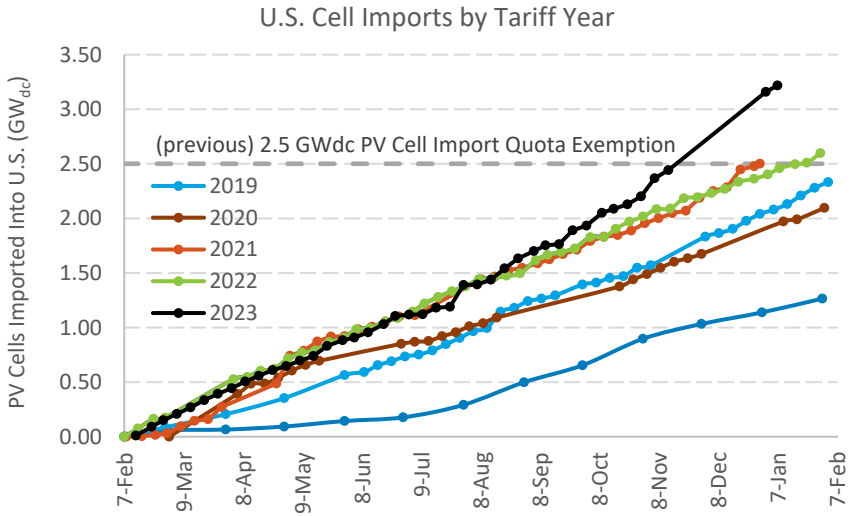
Sources: Imports by HTS code: 8541460015(2018-2021)/8541430010(2022-) and 8541460035(2018-2021)/8541430080(2022-), Second Quantity (watts) from the U.S. International Trade Commission DataWeb as well as the U.S. Census Bureau USA Trade Online tool and corrections page as of 1/10/24. Manual corrections were made to imports from India due to suspected data entry errors.

c-Si Cell Import Data

- According to U.S. Census data, 875 MW_{dc} of cells were imported in Q3 2023 (2.4 GW in Q1–Q3 2023, +31% y/y), setting a record for imports in a single quarter. However, that record has already been broken by the first 2 months of imports in Q4.
  - This was mainly the result of increased imports from South Korea in Q3 (+228 MW_{dc} q/q) and again the first 2 months of Q4 (+225 MW_{dc} q/q), although there was also a noticeable increase in imports from Cambodia (+84 MW_{dc}) in Q4, after having been responsible for less 4 MW total imports prior to Q2 2023.



- According to CBP Commodity Status Reports, starting in mid-September of 2023, there was a noticeable uptick in the import of cells relative to prior years. In mid-November, imports exceeded the previous 2.5 GW_{dc} PV cell import quota level, which was significantly earlier than in any prior year.
- As of early January, cell imports had exceeded 3 GW_{dc} for the first time, although it would be unlikely for imports to hit the new 5.0 GW_{dc} quota before it resets on February 7.



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 1/10/24; U.S. Customs and Border Protection Commodity Status Reports Feb 2019–Jan 2024.

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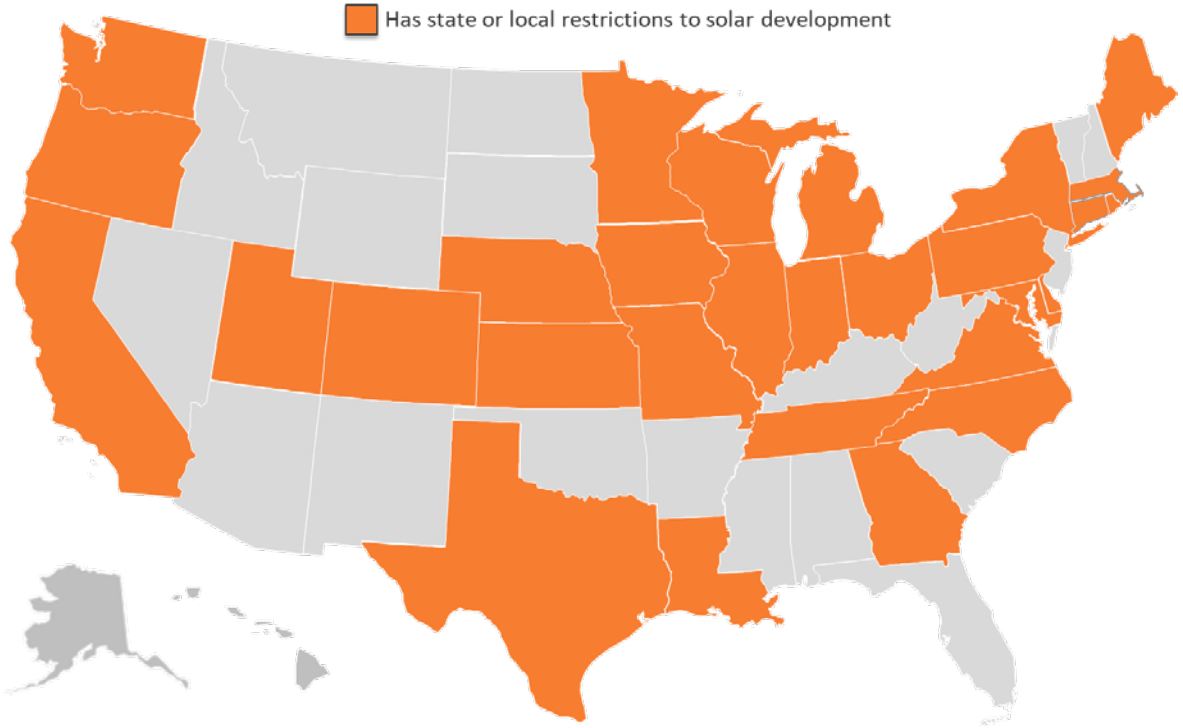
State and Local Restrictions on PV Development



Opposition to PV development is increasing:

- Between 2022 and 2023, the number of renewable energy projects facing organized opposition increased 39%.
- At least one restriction on PV development exists in 29 states.

The fate of PV modules at the end of their lives as well as module toxicity are among multiple reasons given for opposing PV projects, for example:

- "County Council members also raised concerns about decommissioning and whether landfills would accept solar panels."
- "A local group … claimed that the solar array would pose risks to the health of area residents due to toxic chemicals in the panels."

Source: Sabin Center for Climate Change Law. Opposition to Renewable Energy Facilities in the United States: May 2023 Edition.

Media Coverage of PV Waste and Toxicity

Media coverage about waste and toxicity has appeared as U.S. and global PV deployment has grown.

- Frequently lacks context and/or introduces inaccurate information

2017

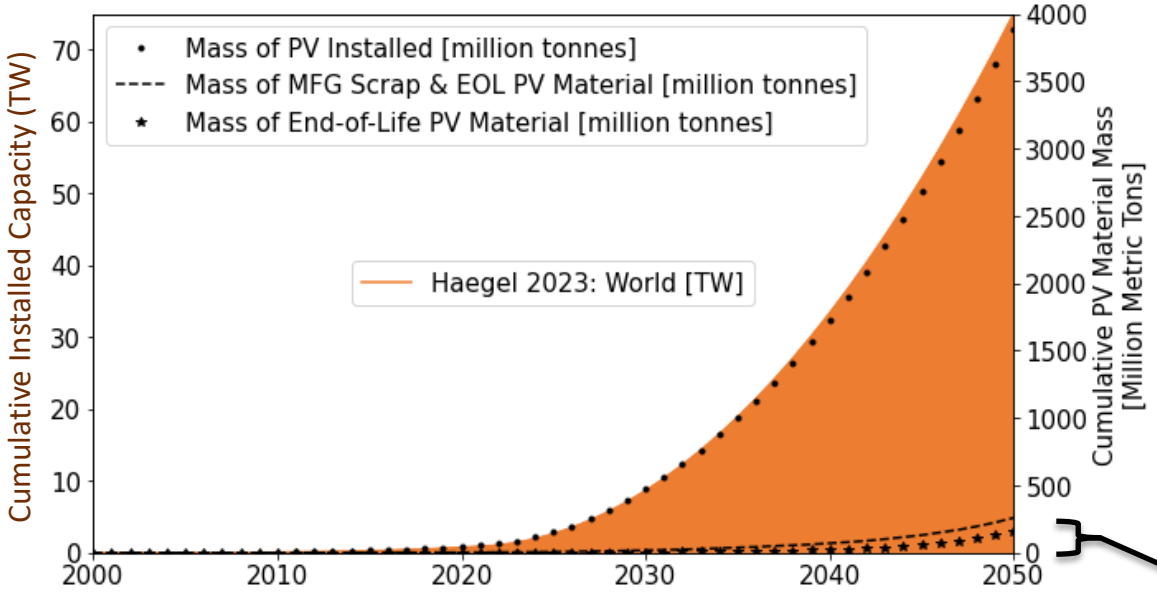
2020

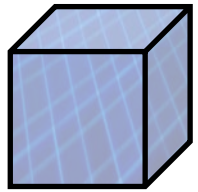
2021

2023

Source: CBS News (5/1/23); Environmental Progress (6/21/17); Harvard Business Review (6/1821); Wired (8/22/20).

Global PV Module Deployment and Waste Projections





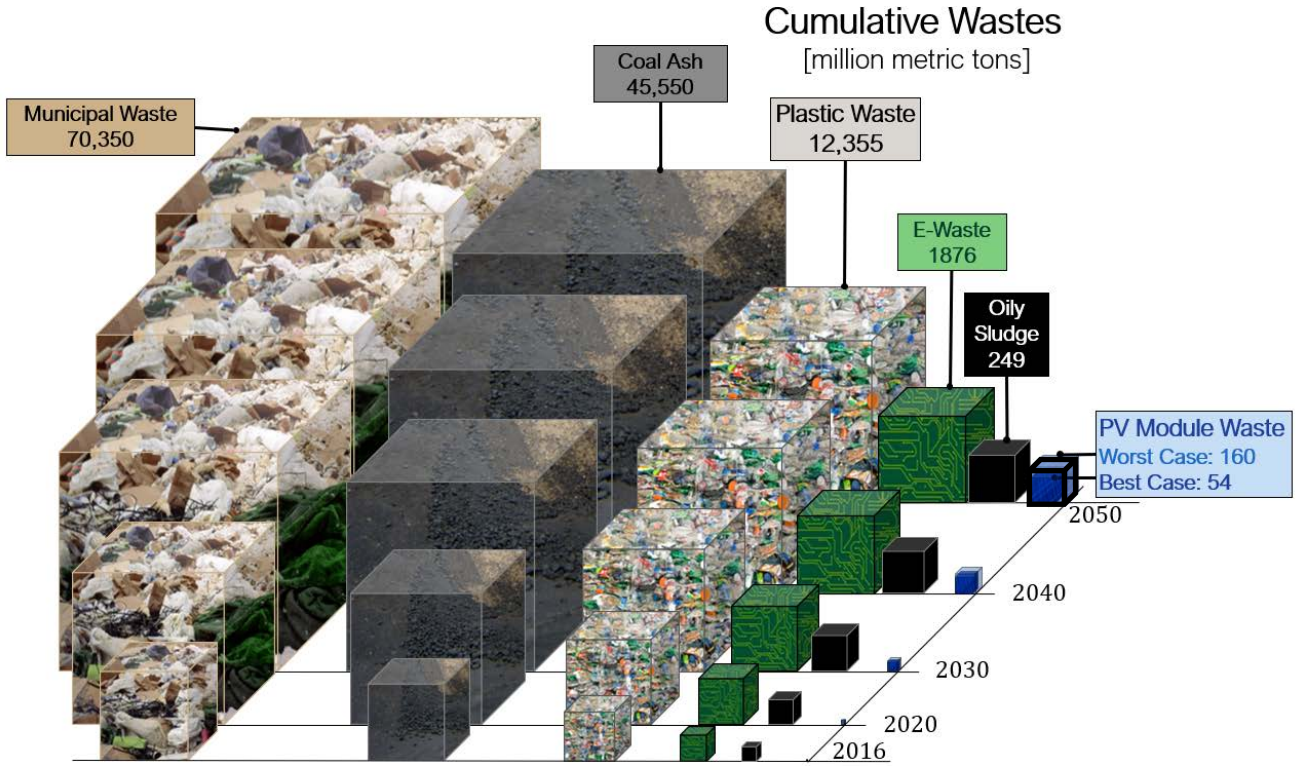
Globally, about 75 TW_{dc} of PV must be deployed by 2050 to achieve decarbonization goals.

Timing of end-of-life module material generation depends on module lifetimes.

- A 20-year lifetime results in 160 million metric tons of end-of-life module material by 2050 worldwide.
- A 45-year lifetime results in 54 million metric tons.
- These values assume no module recycling or other circular-economy strategies.

Source: Mirletz et al., "Energy in the Balance: PV Reliability to Power the Energy Transition." PV Reliability Workshop, 2023.

PV Module Waste in Context



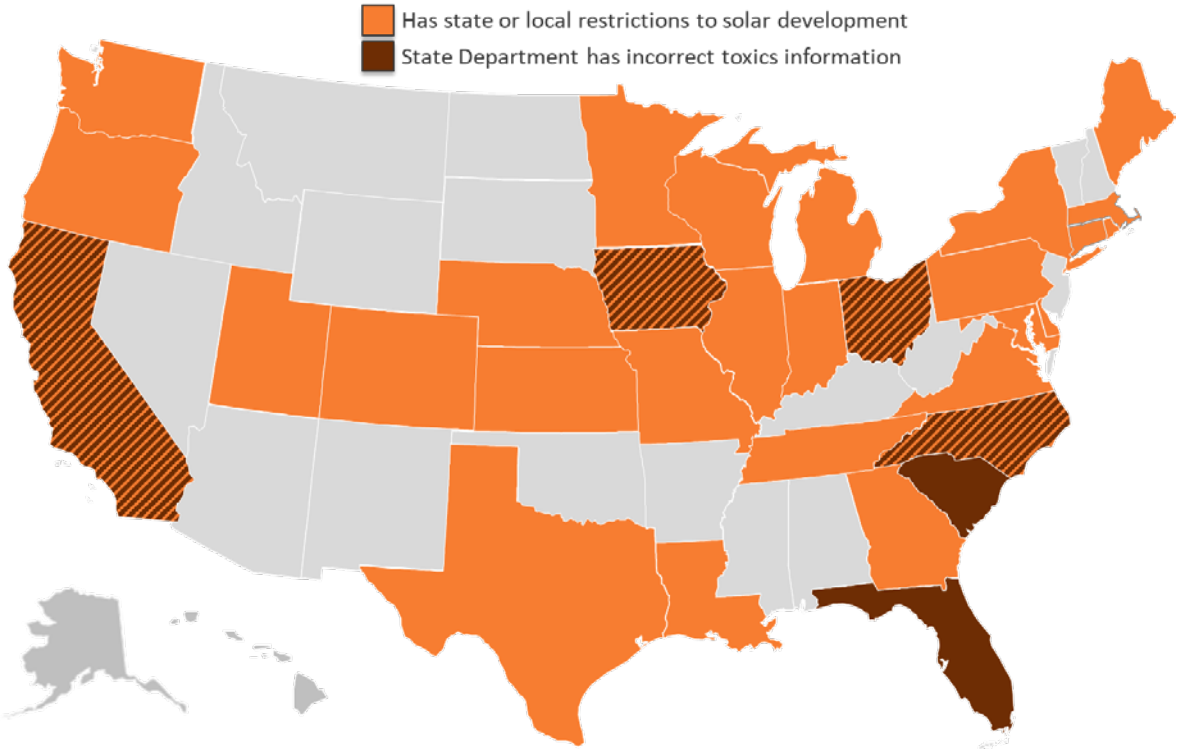
Compared with the amount of PV module material projected through 2050, the projected amounts of other waste categories are much larger, for example:

- Coal ash, 300–800 times larger
- Municipal waste, 440–1,300 times larger.

Circular economy strategies being developed—such as improved module longevity and module recycling—will reduce the generation of end-of-life module material.

Source: Mirletz et al. "Unfounded concerns about photovoltaic module toxicity and waste are slowing decarbonization." Nature Physics, Oct 2023.

Presence of Inaccurate PV Toxicity Information on State Websites



Online resources provided by at least six states—intended to guide the public on end-of-life module treatment—contain inaccurate information about PV module toxicity:

- California
- Florida
- Iowa
- Ohio
- North Carolina
- South Carolina.

Source: California, "Photovoltaic (PV) Modules (Including Solar Panels) Universal Waste Management – FAQs"; Florida, "Managing Unwanted or Broken Solar Panels in Florida"; Iowa, "Solar Panel Recycling and Disposal"; Ohio, "Ohio Department of Health Solar Farm and Photovoltaics Summary and Assessments"; North Carolina, "Solar Panel Recycling and Disposal"; South Carolina, "Shining Some Light on Solar Panels."

Presence of Inaccurate PV Toxicity Information on State Websites

Seven materials are mentioned in the state resources.

Irrelevant to commercial PV applications:

1. Arsenic
2. Gallium*

→ III-V cells for aerospace

3. Germanium → Once used in amorphous silicon PV; not at scale
4. Hexavalent chromium → Not used in PV modules

Managed materials:

5. Cadmium → Used in cadmium telluride PV, closed-loop recycling
6. Lead → Used in solder coating in silicon PV (<0.1% by mass; much lower content than in e-waste)

Alloying/doping materials:

2. Gallium → *Dopant (100 ppb) in p-type silicon PV; reduces light-induced degradation (replacing boron)
7. Selenium → <2% alloy in a stable layer 250x thinner than a human hair of cadmium telluride PV cell; closed-loop recycling. Used in copper indium gallium selenide PV, not at scale.

Sources: Mirletz et al. "Unfounded concerns about photovoltaic module toxicity and waste are slowing decarbonization." Nature Physics, Oct 2023.
Zhi et al. "Ga-doped Czochralski silicon with rear p-type polysilicon passivating contact for high-efficiency p-type solar cell." Solar Energy Materials and Solar Cells, 2021.
Munshi et al. "Polycrystalline CdSeTe/CdTe absorber cells with 28 mA/cm2 short-circuit current." IEEE Journal of Photovoltaics, 2017.
Ablekim et al. "Thin-film solar cells with 19% efficiency by thermal evaporation of CdSe and CdTe." ACS Energy Letters, 2020.

Thank You

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List of Acronyms and Abbreviations

AD: antidumping
ac: alternating current
ASP: average selling price
BBB: U.S. Better Business Bureau
BOS: balance of system
BNEF: Bloomberg New Energy Finance
CAISO: California Independent System Operator
CapEx: capital expenditures
CESA: Clean Energy States Alliance
C&I: commercial and industrial
CBP: U.S. Customs and Border Protection
CdTe: cadmium telluride
CPI: consumer price index
CPUC: California Public Utilities Commission
c-Si: crystalline silicon
CSP: concentrating solar power
CVD: countervailing
dc: direct current
DEWA: Dubai Electricity & Water Authority
DNI: direct normal irradiance
DOE: U.S. Department of Energy
DSCR: debt service coverage ratio
EIA: U.S. Energy Information Administration
ERCOT: Electric Reliability Council of Texas
ETF: exchange traded fund
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
IREC: Interstate Renewable Energy Council
IRS: Internal Revenue Service
ISO: independent system operator
ITC: investment tax credit
kW: kilowatt
kWh: kilowatt-hour
LBNL: Lawrence Berkeley National Laboratory
mono c-Si: monocrystalline
MW: megawatt
MWh: megawatt-hour
NEM: net energy metering
NREL: National Renewable Energy Laboratory
PPA: power purchase agreement
PTC: production tax credit
PV: photovoltaics
Q: quarter
q/q: quarter over quarter
R&D: research and development
SEIA: Solar Energy Industries Association
SREC: solar renewable energy certificate
TAN: Invesco Solar ETF
TOPCon: tunnel oxide passivated contact
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