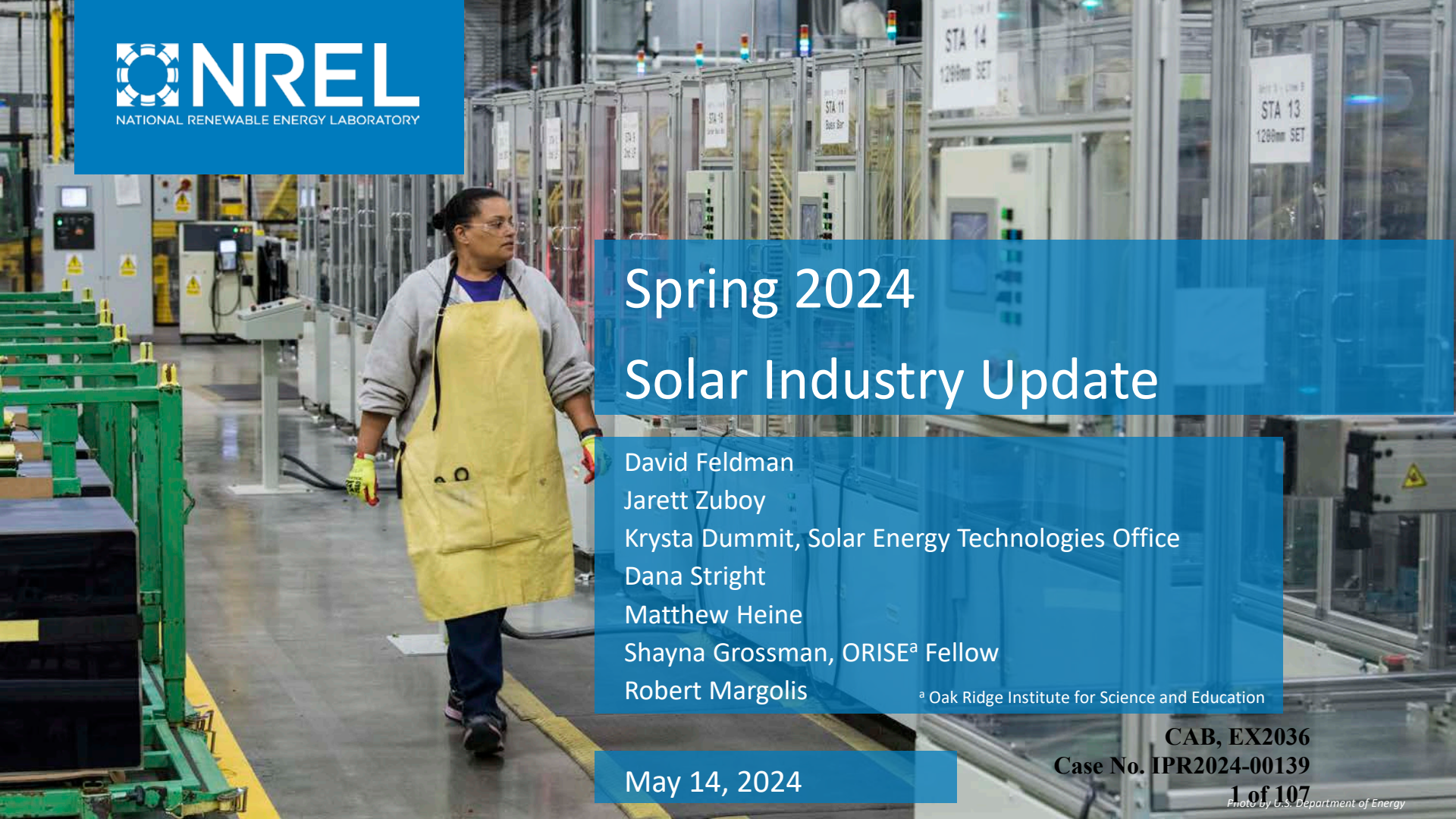

Spring 2024 Solar Industry Update

David Feldman
Jarett Zuboy
Krysta Dummit, Solar Energy Technologies Office
Dana Stright
Matthew Heine
Shayna Grossman, ORISE[a] Fellow
Robert Margolis

[a] Oak Ridge Institute for Science and Education

May 14, 2024

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Photo by U.S. Department of Energy

Agenda

1. Global Solar Deployment
2. U.S. PV Deployment
3. PV System Pricing
4. Global Manufacturing
5. Component Pricing
6. Market and Policy
7. U.S. PV Imports

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Executive Summary

Global Solar Deployment

- IEA reported that in 2023, 407–446 GW_{dc} of PV was installed globally, bringing cumulative PV installs to 1.6 TW_{dc}.
  - China continues to dominate the global market, representing ~60% of 2023 installs, up 120% y/y. The rest of the world was up 30% y/y.
  - The U.S. was the second-largest market in terms of cumulative and annual installations.
- Analysts project that cumulative global PV installations will reach 2 TW_{dc} – 5 TW_{dc} by 2030 and 4 TW_{dc} – 15 TW_{dc} by 2050.

U.S. PV Deployment

- In 2023, PV represented approximately 54% of new U.S. electric generation capacity, compared to 6% in 2010.
- Solar still represented only 11.2% of net summer capacity and 5.6% of annual generation in 2023.
- However, 22 states generated more than 5% of their electricity from solar, with California leading the way at 28.2%.
- EIA reported that the United States installed 26.3 GW_{ac} (~32 GW_{dc}) of PV in 2023, ending the year with 137.5 GW_{ac} of cumulative PV installations.
- SEIA, which has different definitions of "placed-in-service," reported 40.3 GW_{dc} of PV installed in 2023, 186.5 GW_{dc} cumulative.
- The United States installed approximately 26.0 GWh / 8.8 GW_{ac} of energy storage onto the electric grid in 2023, up 34% y/y.

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

PV System and Component Pricing

- The median system price of large-scale utility-owned PV systems in 2023 was \$1.27/W_{ac}—relatively flat since 2018.
- The median price for residential PV systems reported by EnergySage increased 6.3% y/y to \$2.8/W_{dc}—in-line with mid-2020 price levels.
- Global polysilicon spot prices fell 22% from mid-January (\$8.70/kg) to late April (\$6.76/kg), approaching the lowest nominal price seen over the past decade.
- The recent plunge in global module prices leveled off, staying around \$0.11/W_{dc} in Q1 2024.
- In Q4 2023, the average U.S. module price (\$0.31/W_{dc}) was down 5% q/q and down 22% y/y, but at a 140% premium over the global spot pricing.

Global Manufacturing

- In 2023, global PV shipments were approximately 564 GW—an increase of 100% from 2022.
- In 2023, 98% of PV shipments were mono c-Si technology, compared to 35% in 2015.
- N-type mono c-Si grew to 63% of global PV shipments—up from 51% in 2022 (and 5% in 2019).
- In 2023, the United States produced about 7 GW of PV modules.

U.S. PV Imports

- According to U.S. Census data, 55.6 GW_{dc} of modules and 3.7 GW_{dc} of cells were imported in 2023, an increase of 87% y/y and 46% y/y, respectively.
- In Q1 2024, PV module imports held relatively steady for the third straight quarter at 15.2 GW_{dc}.

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- **IEA reported that in 2023, 407–446 GW_{dc} of PV was installed globally, bringing cumulative PV installs to 1.6 TW_{dc}.**
  - **China continues to dominate the global market, representing ~60% of 2023 installs, up 120% y/y. The rest of the world was up 30% y/y.**
  - **The United States was the second-largest market in terms of cumulative and annual installations.**
- **Analysts project that cumulative global PV installations will reach 2 TW_{dc} – 5 TW_{dc} by 2030 and 4 TW_{dc} – 15 TW_{dc} by 2050.**

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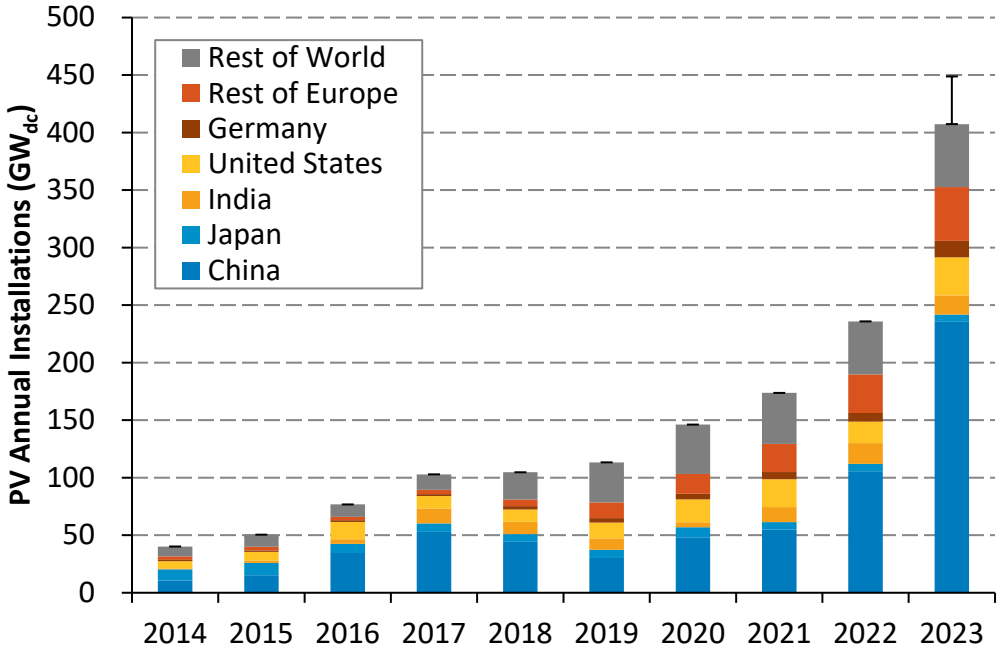
Global Annual PV Capacity Additions by Country



- From 2014 to 2023, global PV capacity additions grew from 40 GW_{dc} to between 407 GW_{dc} and 446 GW_{dc}.
  - The spread in estimated global installations is due to uncertainty in Chinese reporting.
  - In 2023, global PV installs increased 73%–91% y/y.
- The total cumulative installed capacity for PV at the end of 2023 reached 1.6 TW_{dc}.
- At least 29 countries installed more than 1 GW_{dc} in 2023, and 19 countries have a cumulative capacity above 10 GW_{dc}.
- China continues to dominate the global market, representing ~60% of 2023 installs, up 120% y/y. The rest of the world was up 30% y/y.
  - China was the last country to represent over half the global solar market, in 2017 (51%).

Note: China's National Energy Administration reports values in W_{ac}. Therefore, there is uncertainty in W_{dc} capacity due to differing assumptions on inverter loading ratio. The "upside" reflects a higher inverter loading ratio.

Sources: IEA, Snapshot of Global PV Markets: 2024; Trends in Photovoltaic Applications 2023.

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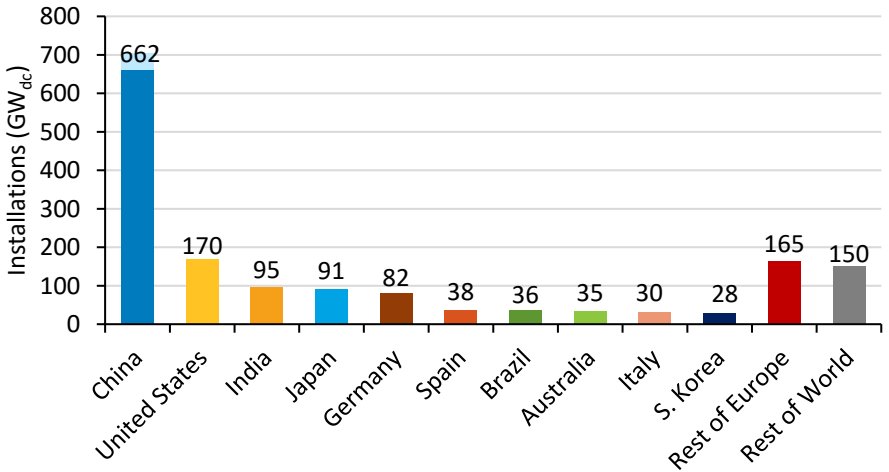
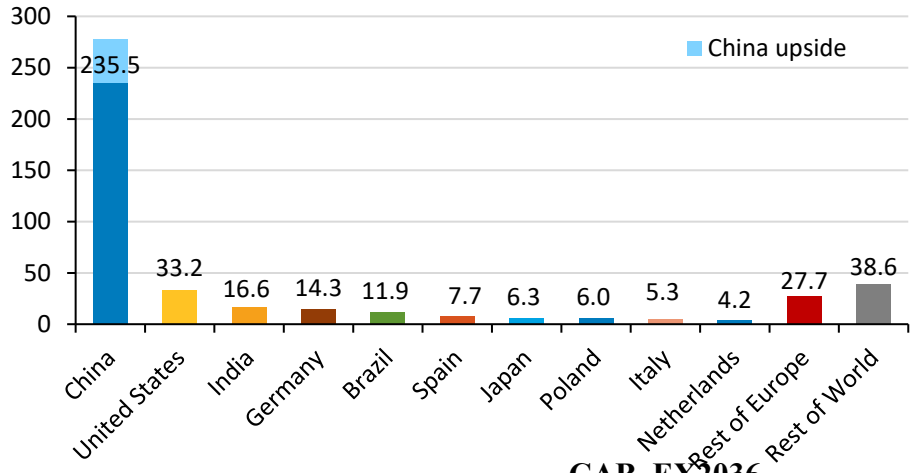
Top PV Markets

- In 2023, several countries had very large growth years, with China, Germany, and Italy roughly doubling 2022 installations.
- IEA reports that the large stockpile of PV modules increased further in 2023 to 150 GW_{dc}. China has tried to absorb some of the overcapacity (thus the large installation year). However, the large increase in manufacturing capacity, the switch from PERC to TOPCon, and insufficient demand have exacerbated the situation.

Cumulative PV Deployment, 2023 (1.6 TW_{dc})



Annual PV Deployment, 2023 (407 GW_{dc} to 446 GW_{dc})



Note: China's National Energy Administration reports values in W_{ac}. Therefore, there is uncertainty in W_{dc} capacity due to differing assumptions on inverter loading ratio. The "upside" reflects a higher inverter loading ratio.

Sources: IEA, Snapshot of Global PV Markets: 2024; Trends in Photovoltaic Applications 2023.

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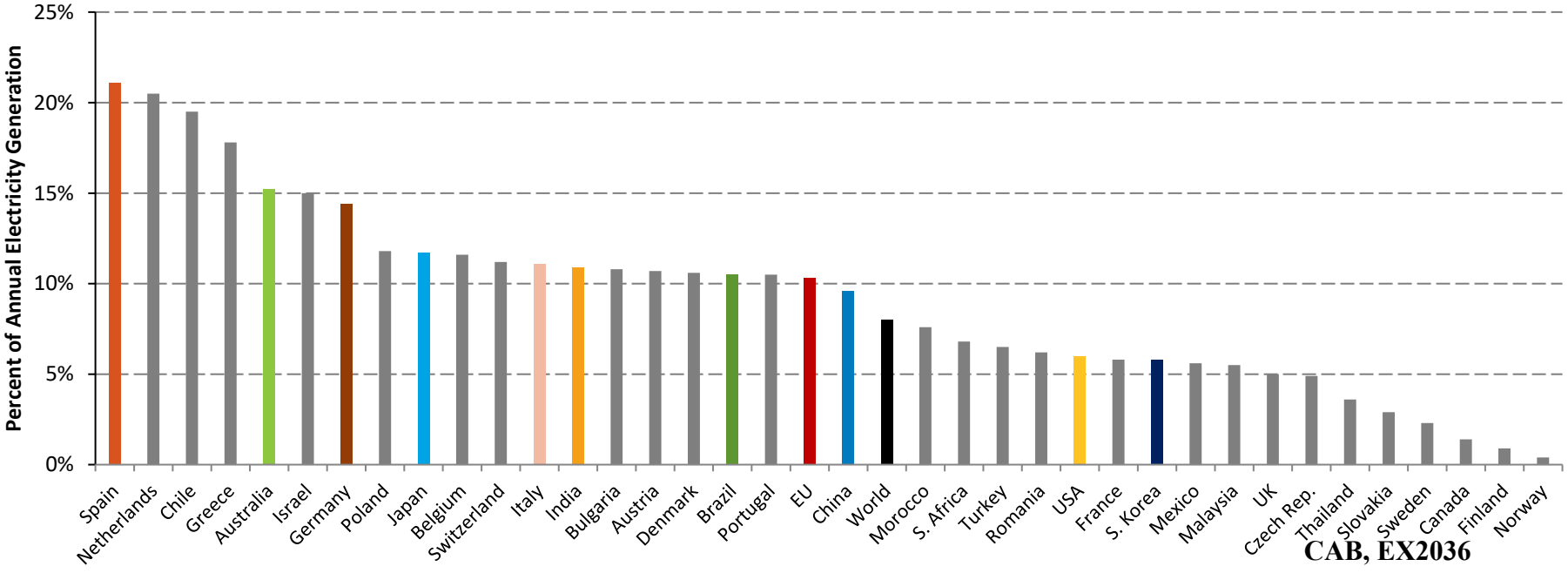
Global PV Penetration

- IEA estimates that in 2023, 6% of global electricity generation came from PV.

- The United States, despite being a leading PV market, is below the global average and other leading markets in terms of PV generation as a percentage of total country electricity generation, with 6%.
  - If California were a country, its PV contribution (28%) would be the highest.



Source: IEA, Snapshot of Global PV Markets: 2024.

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Long-term Global Projections

As of 2022, cumulative global PV capacity was about 1,200 GW_{dc}. Analysts project that cumulative global PV installations will reach 2 TW_{dc} – 5 TW_{dc} by 2030 and 4 TW_{dc} – 15 TW_{dc} by 2050. Their results differ largely due to discrepancies in the projections of China's future capacity.

EIA's Reference Case assumes current energy trends, existing laws and regulations, and select economic/technological changes. This is the most conservative estimate of those analyzed.

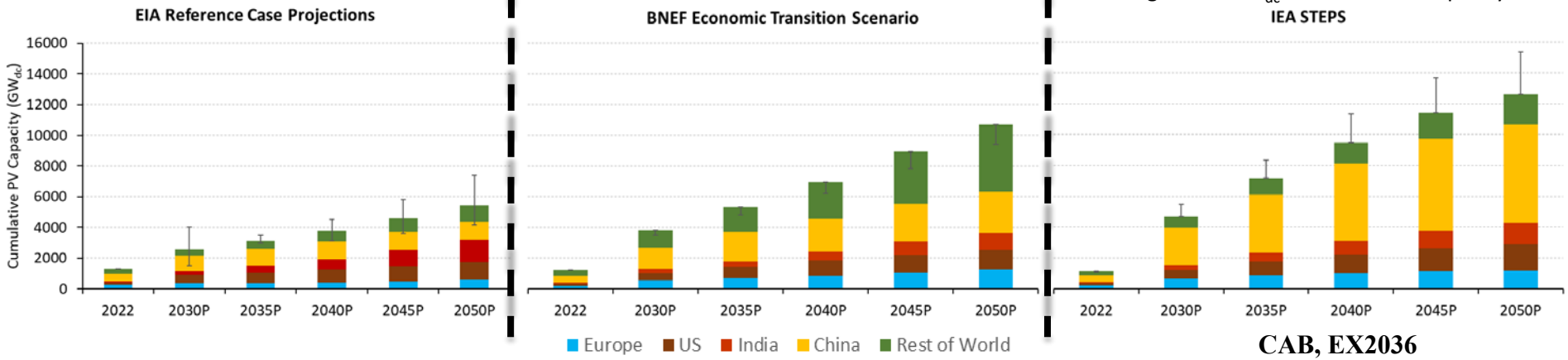
- EIA reference case projects over 5 TW_{dc} of PV capacity by 2050 with the United States, China, and India each having over 1 TW_{dc} of cumulative capacity.

BNEF's Economic Transition Scenario (ETS) is BNEF's baseline scenario of how the energy transition might evolve as a result of cost-based technological changes.

- BNEF ETS projects over 10 TW_{dc} of PV capacity by 2050, with the U.S., China, India, and Europe each having over 1,000 GW_{dc} of cumulative capacity.

IEA's Stated Policies Scenario (STEPS) uses assumptions based on the latest policy settings, including energy, climate, and industrial policies.

- IEA STEPS projects over 12.5 GW_{dc} of PV capacity by 2050, with the United States, Europe, China, and India each having over 1 TW_{dc} of cumulative capacity and China having over 6 TW_{dc} of cumulative capacity.



Notes: P = projection. Colored bars represent base case projections for region/country-level estimates. Error bars represent high and low global projections. Not all sources have data for all categories. EIA reports in GW_{ac} while BNEF and IEA report in GW_{dc}. An ILR value of 1.25 was used to convert between GW_{ac} and GW_{dc}.

Sources: EIA, International Energy Outlook 2023 ; BNEF, New Energy Outlook 2023 ; IEA, World Energy Outlook 2023

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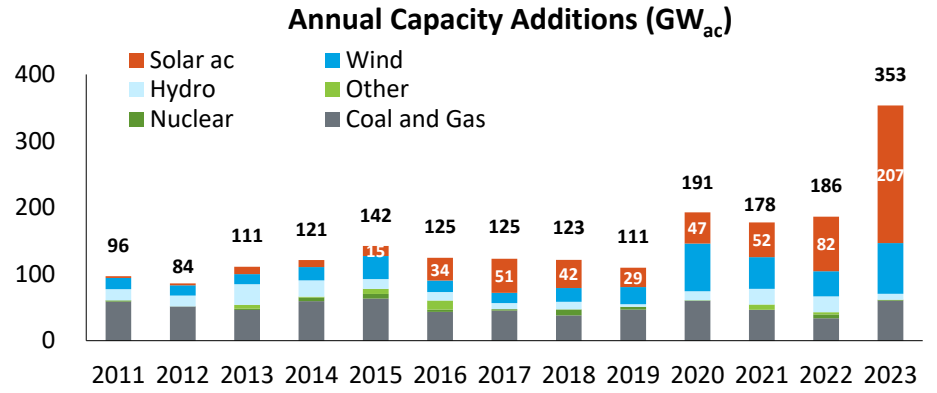
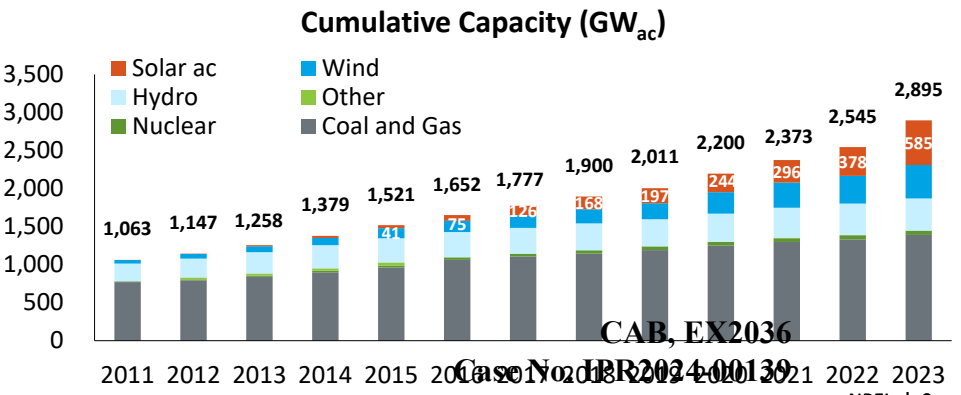
Chinese Generation Capacity Additions by Source

Note: Annual and cumulative solar values assume that China's National Energy Administration (NEA) reports distributed PV in direct-current terms and utility-scale PV in alternating-current terms. NEA reported 120 GW of utility-scale PV and 96 GW of distributed PV for 2023. On this slide, ac/dc conversions assume a dc-to-ac ratio of 1.1 for distributed PV. We use IEA-reported total capacity for W_{dc}.

Sources: China NEA (1/26/24, 2/28/24, 4/29/24); IEA, National Survey Report of PV Power Applications in China, 2021.

- In 2023, solar contributed 59% of new generation capacity in China (235 GW_{dc} to 277 GW_{dc}/207 GW_{ac}) and 20% of cumulative capacity (662 GW_{dc} to 704 GW_{dc}/585 GW_{ac}).
  - The record for annual solar installed was broken for the third year in a row.
  - In 2023, 42% of new PV was distributed, 58% was utility scale.
  - Wind and solar accounted for 80% of capacity installed in 2023, and together they have constituted the most capacity installed for 8 years running.
  - Annual coal and gas additions rose 78% in 2023.
  - In Q1 2024, China added 43.6 GW_{ac} of PV (21.9 GW_{ac} utility scale, 21.6 GW_{ac} distributed).
- Renewable sources continue to capture a larger share of China's growing electric capacity.
  - In 2011, renewables made up 26% of 1.1 TW_{ac} of total capacity.
  - In 2023, renewables made up 50% of 2.9 TW_{ac} of total capacity.





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Chinese Market Update

Note: See slide 9 for installed capacity assumptions.

Sources: BNEF, China Market Outlook 1H 2024: Renewables Rise in Headwinds, 3/7/24; BNEF, China's New RPS Targets Wind and Solar Deployment, 9/15/23; China NEA (1/26/24, 2/28/24); PVTech (04/22/24).

- China installed 120 GW_{ac} of utility-scale PV in 2023, a 275% increase from 32 GW_{ac} installed in 2022.
  - Reasons for the surge included declining module prices and increasing construction of renewable energy "megabases"—gigawatt-scale wind and solar projects sited in remote areas.
  - Provincial Renewable Portfolio Standard (RPS) targets were another driver.
    - For most provinces, the target non-hydro electricity share was raised 1.2 percentage points for 2023 and 1.7 percentage points for 2024, which has spurred measures promoting wind and solar deployment in some provinces.
    - For example, in 2023 Yunnan closed some of its RPS gap by increasing renewable energy compensation rates and facilitating land approval and interconnection for utility-scale projects.
- The 87 GW_{ac} of distributed PV installed in 2023 was 74% higher than the 50 GW_{ac} installed in 2022.
  - Declining PV equipment prices and high power prices drove demand.
  - The rapid deployment has exposed potential constraints including grid-interconnection capacity and increasing curtailment.
- China deployed 20 GW_{ac} of energy storage in 2023, reaching a cumulative 31 GW_{ac} and achieving its 30-GW_{ac} goal 2 years early.
  - The growth has primarily been driven by provincial mandates.
  - As of January 2024, 26 provinces mandated storage with PV projects, with an average storage capacity requirement equivalent to 12% of the PV capacity.
- In Q1 2024, China installed 46 GW_{ac} of new PV—a 36% increase from Q1 2023.

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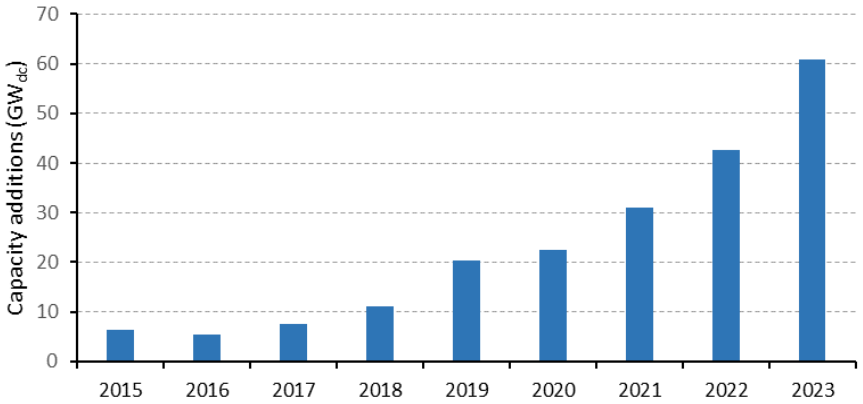
European Market

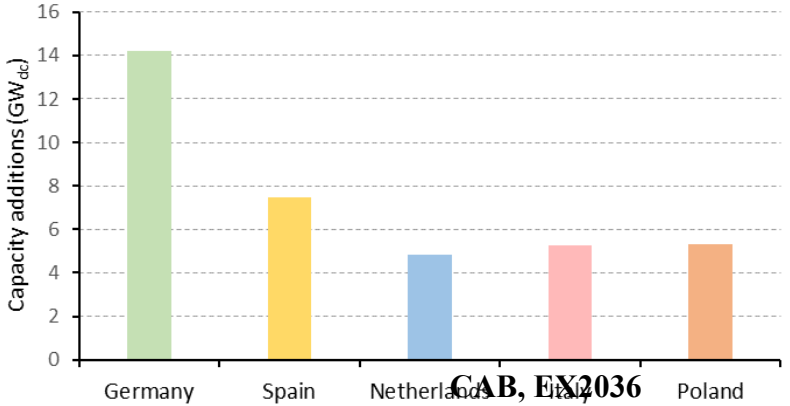
- Europe's annual PV additions reached a record of nearly 61 GW_{dc} in 2023, up 41% from 2022.
  - In the EU, utility-scale PV made up 34% of new additions (down 6% from 2022), commercial and industrial PV made up 33% of new additions (up 4% from 2022), and residential PV made up 33% of new additions (up 2% from 2022).

- IEA reports that the war in Ukraine and resulting reduced gas acquisitions increased the price of electricity, making PV more competitive.
- A large extent of growth in the EU residential sector stems from delayed 2022 projects. Slower growth in this sector is anticipated in 2024.
- UPV deployment declined in 2023 due to delayed auctions, higher grid fees, inflation, and permitting/grid-connection issues.

Europe's Annual PV Capacity Additions (GW_{dc})



2023 Annual PV Capacity Additions by Country (GW_{dc})



Sources: : IEA, Snapshot of Global PV Markets: 2024; Trends in Photovoltaic Applications 2023.; BNEF, 1Q 2024 Global PV Market Outlook, 2/19/24; EU Market Outlook for Solar Power 2023–2027 - SolarPower Europe

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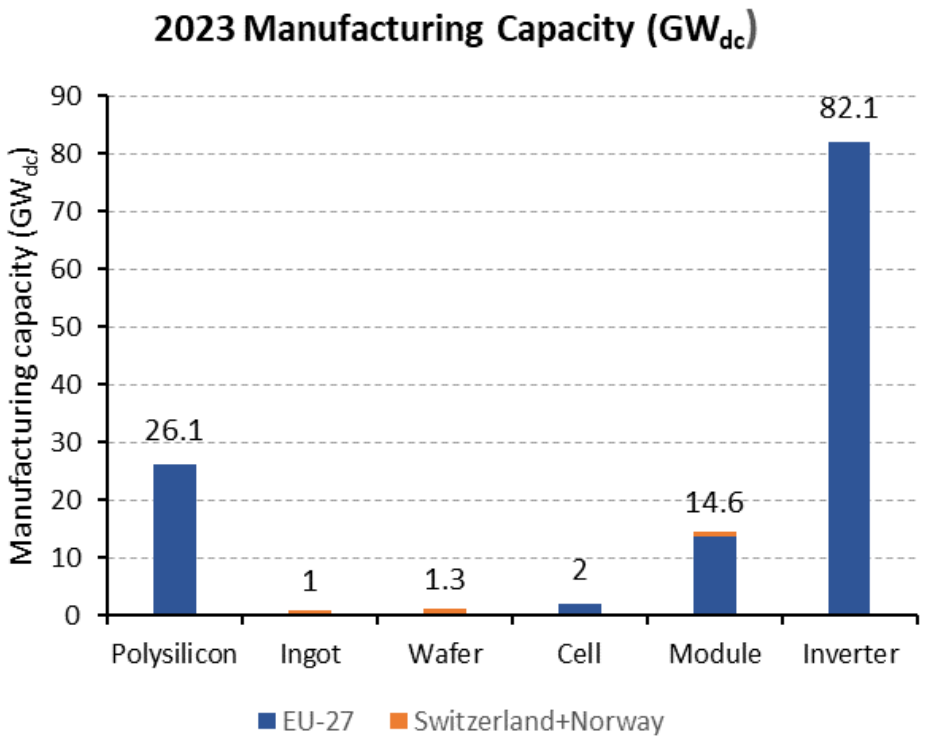
EU Manufacturing Market



- In the EU, polysilicon production decreased by 12% from 2022, cell production increased by 42%, module production increased by 59%, and inverter production increased by 14%.
- This year, REC Solar Norway shut down their operations. The only polysilicon manufacturer left in Europe is Wacker Chemie. They produce 60,000 MT/yr in Germany.
- Norwegian Crystals announced its bankruptcy in August 2023, leaving NorSun as the only ingot/wafer producer in Europe. NorSun temporarily suspended its operations in September 2023.
- Solar cell manufacturing in the EU has grown 0.6 GW from 2022, with 7 active companies in this segment.
- There are 57 active module manufacturers in the EU.
- The EU recently adopted a ban on products made with forced labor (which may impact the EU solar supply chain by limiting imports from China). Member states will have to begin applying the regulation in 2027.

Sources: BNEF, 1Q 2024 Global PV Market Outlook, 2/19/24; EU Market Outlook for Solar Power 2023-2027, Solar Power Europe ; About Us, RECOM Technologies, accessed 5/21/24 ; EU to support solar manufacturing in face of "very fragile situation", PV Tech, 3/4/24 ; European Parliament passes forced labour ban , PV Tech, 4/24/24.

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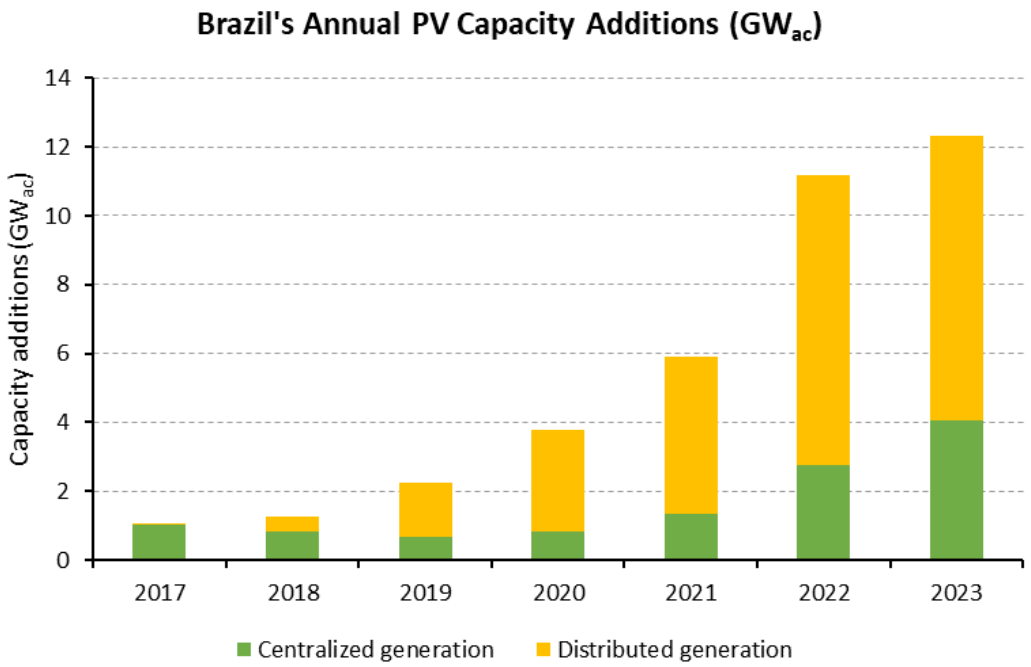
Brazil Market Update



- ABSOLAR reported that Brazil installed around 12 GW_{ac} (17 GW_{dc}) of PV this year (IEA reported 12 GW_{dc}). This is more than Brazil's entire cumulative capacity in 2020.
- Growth in deployment was driven by sub-5 MW solar systems, which are eligible for net-metering benefits.
- Small-scale solar faces headwinds from rising transmission tariffs (due to new 2022 net metering regulations), difficulty getting permits, competition with wholesale market, and import taxes on modules.
- In 2023, Brazil ended its import tax exemption for modules. The country now operates under a tariff rate quota (TRQ) system where the first 30 GW of imported modules are exempt and additional imports face tariffs.
- BNEF expects another 17–19 GW_{dc} of solar installations in 2024, with a possibility of a slowdown in the distributed sector due to the government's efforts to slow this market.

Sources: BNEF, 1Q 2024 Global PV Market Outlook, 2/19/24; BNEF, Trend Newsletter, 3/7/24 ; ABSOLAR - Brazilian Association of Photovoltaic Solar Energy

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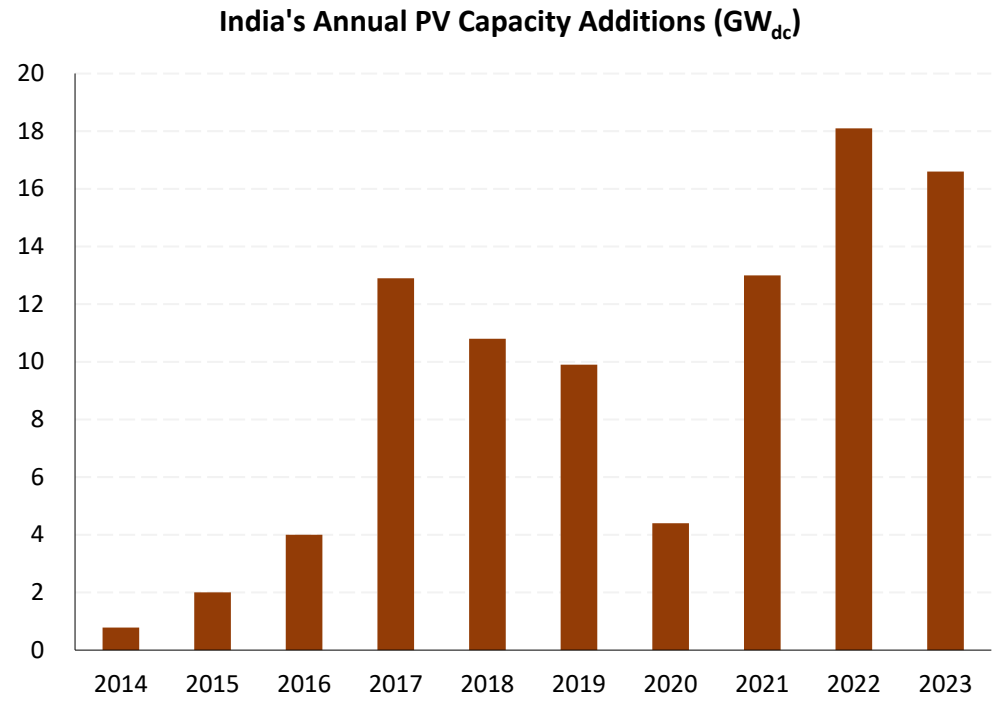
Indian Market Update



Sources: BNEF, 1Q 2024 Global PV Market Outlook, 2/19/24; BNEF, 1H 2024 India Renewables Market Outlook, 2/29/24; Mercom India Research, Q4 & Annual 2023 India Solar Market Update, 12/23; Mercom Q1 2024 India Solar Market Update; Mercom (3/12/24); PV Magazine (2/15/24) ; IEA, Snapshot of Global PV Markets: 2024; Trends in Photovoltaic Applications 2023.

- IEA reported that India added 16.6 GW_{dc} of PV in 2023, down 11% from the record 18.6 GW_{dc} installed in 2022.
  - Most PV installs were centralized systems.
  - BNEF reported that small-scale project deployment (mostly rooftop PV but also off-grid and agricultural PV) rose 35% from 2022 and made up about a third of new 2023 PV capacity.
  - BNEF also reported that PV constituted 49% of total capacity added in 2023 and 17% of India's cumulative capacity.
- BNEF reported that large project costs fell 27% between Q4 2022 and Q4 2023.
  - Driven primarily by plummeting module prices, Q4 2023 saw India's lowest-ever average project cost.
  - Analysts expect the lower costs to spur increased deployment in 2024.
  - At year end, 105 GW_{ac} (~140 GW_{dc}) of large projects were in the development pipeline.
- A new PV subsidy program may boost deployment of residential rooftop installations going forward.

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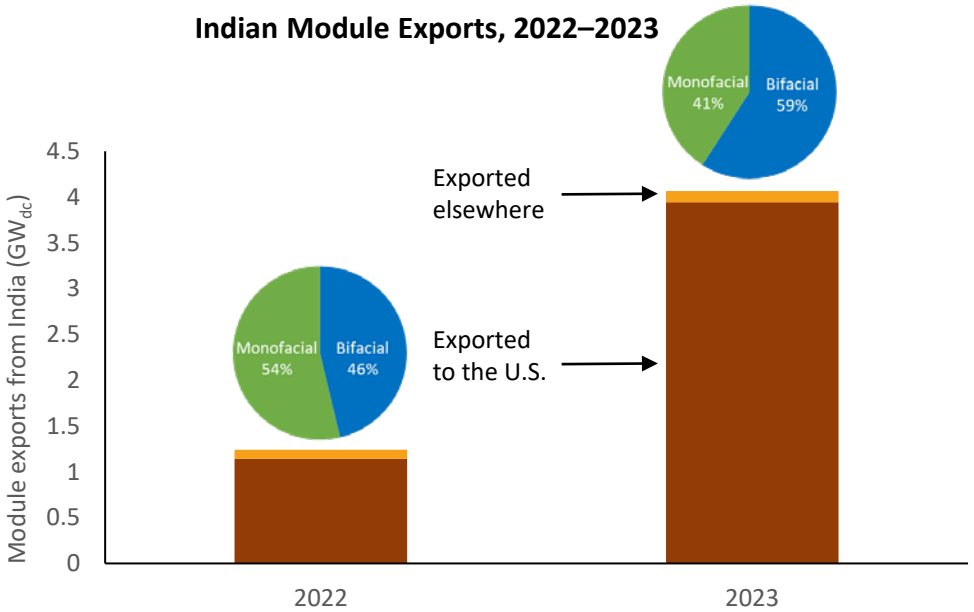
Indian Market Update

- Indian module exports grew 230%, from 1.2 GW_{dc} in 2022 to 4.1 GW_{dc} in 2023.
- About 97% of 2023 exports went to the United States.

Indian Module Exports, 2022–2023



Sources: BNEF, 1H 2024 India Renewables Market Outlook, 2/29/24; Mercom Clean Energy Insights (3/14/23, 2/26/24); Mercom India Research, State of Solar PV Market in India 2024, Spring 2024; TaiyangNews (2/12/24); : PVTech Research. PV Manufacturing & Technology Quarterly Report - Release 32 - February 2024.

  - U.S. trade policies, such as the Uyghur Forced Labor Prevention Act, favor Indian module imports.
  - The U.S. market provides Indian manufacturers with higher profit margins compared with the Indian market.
  - A Q4 2023 slowdown in exports may be linked to reduced U.S. demand and/or concerns from U.S. buyers about the quality of Indian modules.
  - The bifacial share of exported modules rose.
- Mercom estimates India's module/cell manufacturing capacity reached 64.5/5.8 GW_{dc} in 2023, and Mercom projects 150+/75+ GW_{dc} by 2026—far exceeding actual and projected domestic module deployment.
  - PVTech estimates there was 29/5.4 GW_{dc} of Indian module/cell capacity at the end of 2023, producing a total of 12/1 GW_{dc} of modules/cells in 2023.
- Indian module imports grew 41%, from 11.6 GW_{dc} in 2022 to 16.3 GW_{dc} in 2023.
  - Most imports were from China as record-low prices made Chinese modules attractive despite a 40% tariff.
  - India's effort to balance domestic PV manufacturing with domestic deployment has produced a confusing array of trade barriers and exemptions, which remain in flux as of early 2024.

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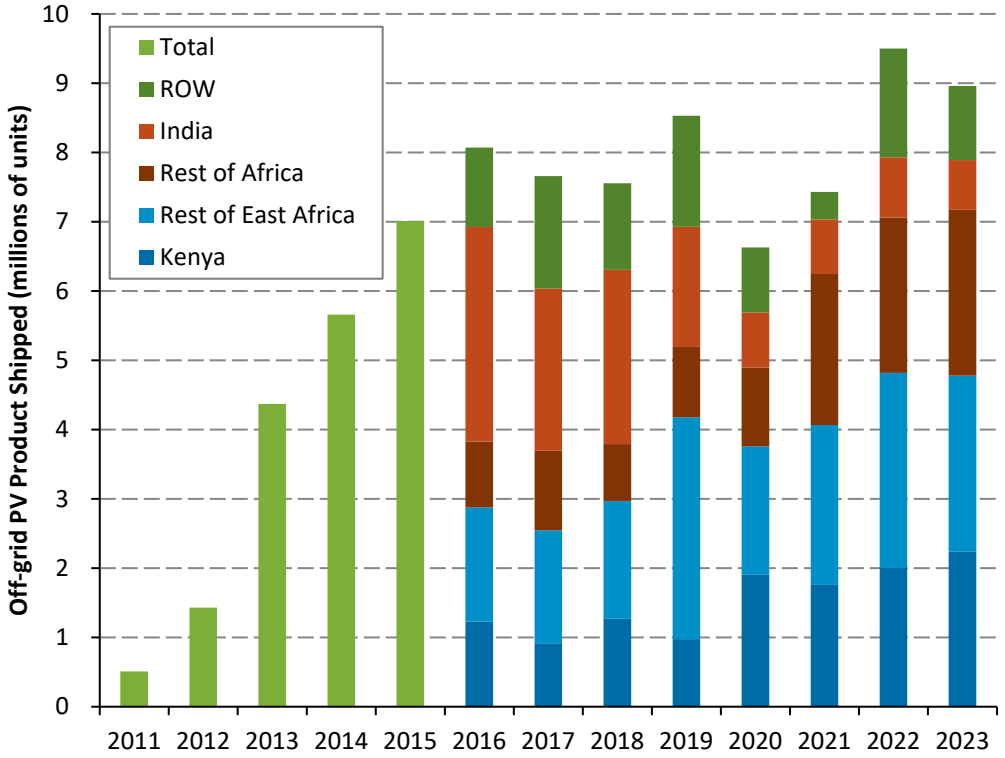
Global Off-Grid Solar Market



- Global sales of solar energy kits reached their second highest level ever, though they fell from historical high sales in 2022.
  - Most products were portable lanterns. However, there were also over 1 million solar home systems sold in 2023, and solar power appliances, such as fans, TVs, refrigerators, water pumps, and radios.
- An estimated 116 million people currently benefit from improved access to energy through off-grid solar energy products.

Source: Global Off-Grid Lighting Association, "Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data."

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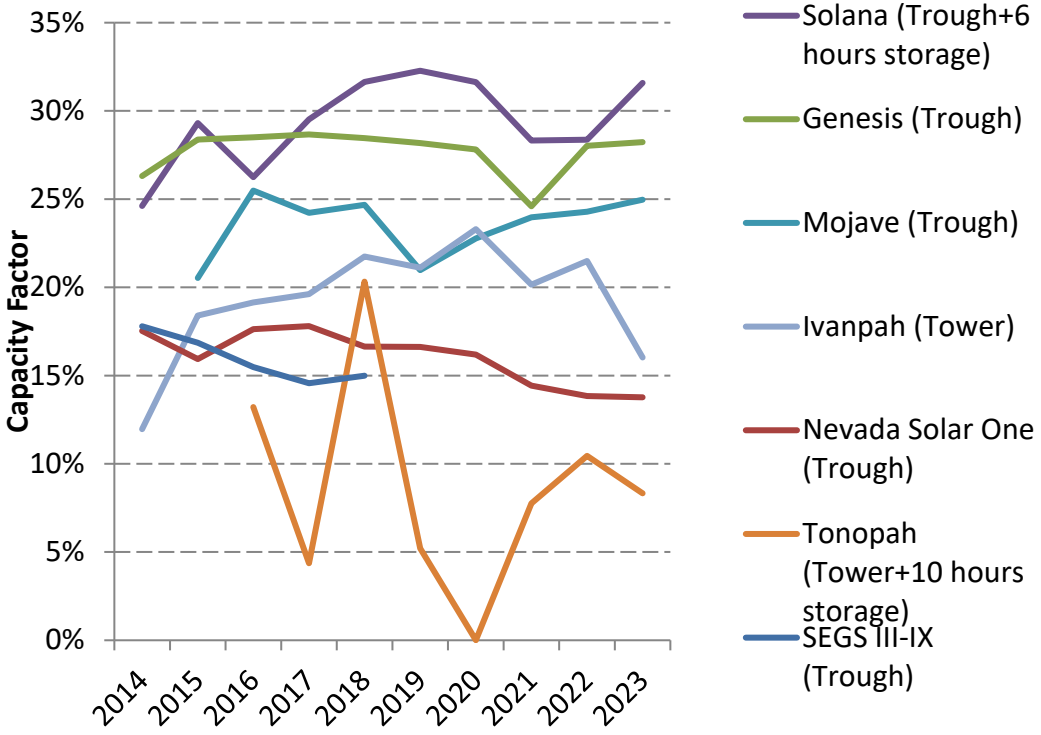
U.S. CSP Project Generation Performance, 2014–2023



Source: EIA, Form 923.

- Over the past decade since the LPO-funded CSP plants came on-line, performance has generally been more consistent for the trough plants than those using tower technologies, particularly in 2023.
  - Tonopah produced no electricity from March to July, and two of the three Ivanpah towers produced no/little electricity for two to three months in the first half of 2023.
  - Annual weather variation also caused some of the differences in annual production
- Absolute capacity factor is not necessarily the best metric for performance as plants can be designed and operated differently.
  - Tonopah now operates to sell power at night (though that would not explain producing no power during the sunniest part of the year).

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- **In 2023, PV represented approximately 54% of new U.S. electric generation capacity, compared to 6% in 2010.**
  - In 2023, over 40 GW_{ac} of new installed capacity was either from non-carbon emission sources or battery technologies—3 GW_{ac} above the previous record level achieved in 2021.
- **Solar still represented only 11.2% of net summer capacity and 5.6% of annual generation in 2023.**
  - However, 22 states generated more than 5% of their electricity from solar, with California leading the way at 28.2%.
- **EIA reported that the United States installed 26.3 GW_{ac} (~32 GW_{dc}) of PV in 2023, ending the year with 137.5 GW_{ac} of cumulative PV installations.**
  - SEIA, which has different definitions of "placed-in-service," reported 40.3 GW_{dc} of PV installed in 2023 and 186.5 GW_{dc} cumulative.
- **The United States installed approximately 26.0 GWh / 8.8 GW_{ac} of energy storage onto the electric grid in 2023, up 34% y/y.**

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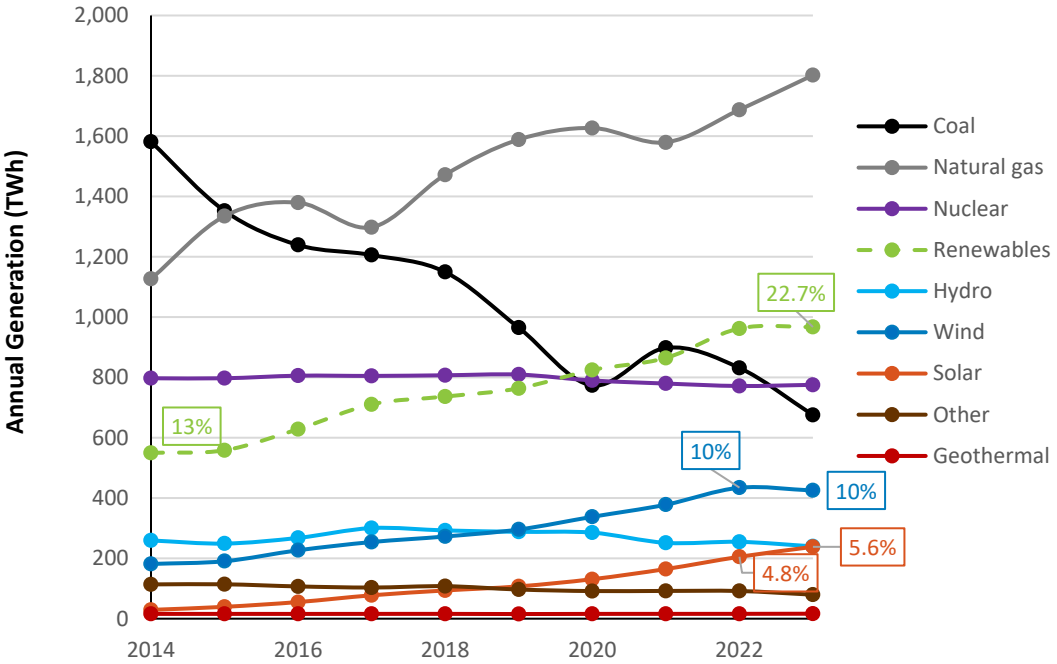
U.S. Generation, 2014–2023



- In 2023, the United States generated 4,250 terawatt-hours (or 4.3 petawatt-hours) of electric power.
- Energy generation from renewables continued its steady upward trend, as a result of increases in solar generation (and despite a drop in wind and hydro generation).
  - Solar and wind generation together accounted for almost as much power as coal generation.
  - Solar was on par with hydropower.
- The percentage of electricity generated by fossil fuels in the United States dropped from 67% in 2014 to 59% in 2023, while the percentage of electricity generated by renewable energy sources increased from 13% to 23% over the same period.
- In 2023, renewable energy facilities continued to produce more electricity than both nuclear and coal sources, though utility-scale renewable energy generation fell y/y.
  - Despite an increase in U.S. wind generation capacity, analysts attributed the drop in wind production to slow wind speeds in the mid-west in warm months. Hydropower production dropped due to low water levels caused by drought.

Sources: U.S. Energy Information Administration (EIA), "Electricity Data Browser." Accessed March 10, 2024; and an Insight Climate News article (February 27, 2024).

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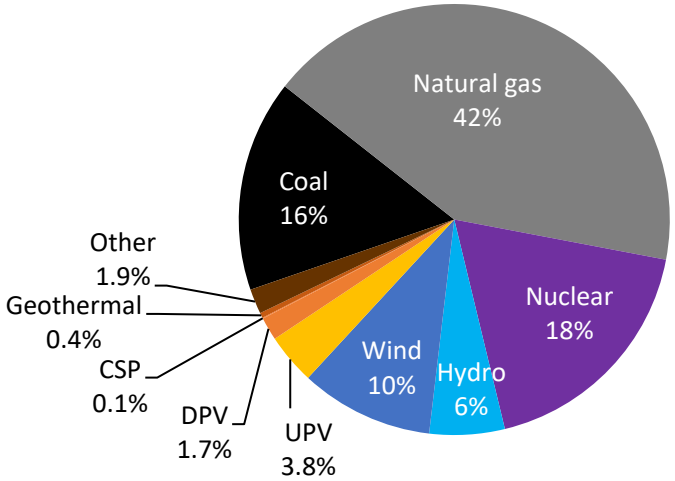
2023 U.S. Generation and Capacity

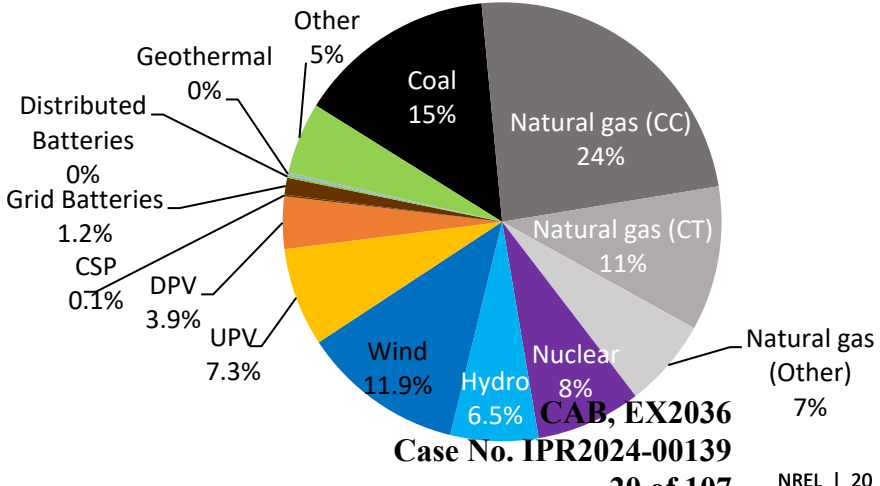
- Renewables are becoming an increasingly large part of the U.S. electric generation mix, representing 31% of capacity and 23% of generation in 2023.
  - All non-carbon energy sources—including solar, wind, nuclear, hydropower, and geothermal—-represented 39% of capacity and 41% of generation in 2023.

- Solar still represents a small but growing percentage of the U.S. electric generation mix.
  - In 2023, solar represented 11.2% of net summer capacity and 5.6% of annual generation.
- Capacity is not proportional to generation, as certain technologies (e.g., natural gas) have lower capacity factors than others (e.g., nuclear).

2023 U.S. Generation (Total 4,252 TWh)



2023 U.S. Generation Capacity (Total 1.2 TW)



Sources: EIA, "Electric Power Monthly" Tables 6.1, 6.1A, February 2024, "Electricity Data Browser," March 10, 2024.

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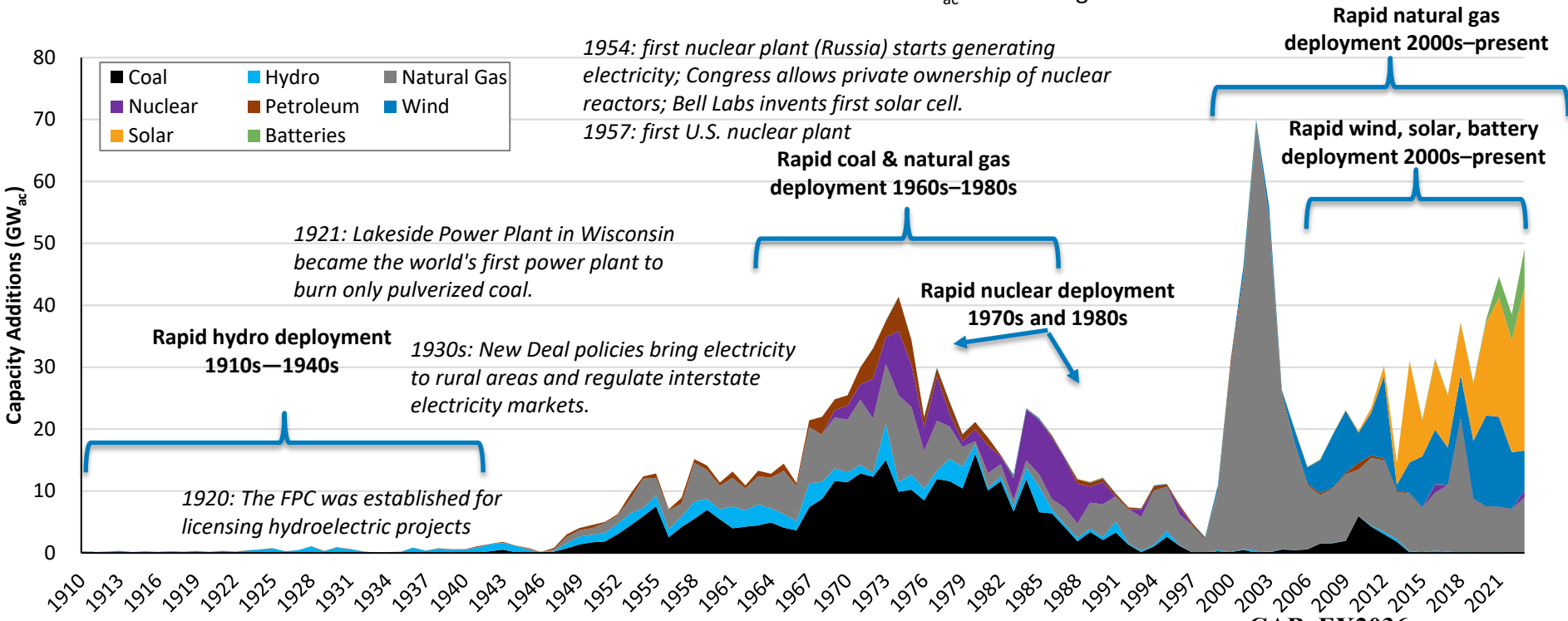
Solar at Historic Level of Deployment

2023 had the third highest level of new electricity generation on record, with solar, batteries, and wind leading the way. According to EIA, planned capacity in 2024 and 2025 would be the highest on record, though solar would still not exceed the 64 GW_{ac} of natural gas installed in 2002.



Sources: EIA.U.S installed capacity, Form 860. & Electric Power Monthly (March 2024). EIA, Energy Kids.

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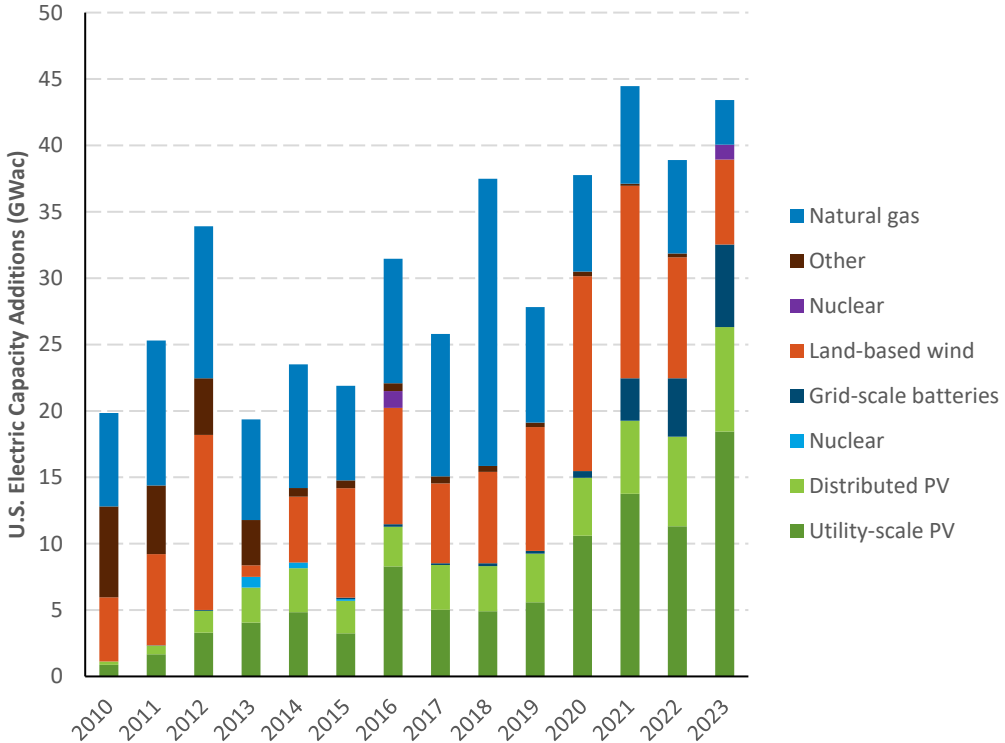
New U.S. Capacity Additions, 2014–2023



- In 2023, PV represented approximately 53.5% of new U.S. electric generation capacity (37.5% UPV, 16.0% DPV), compared to 6% in 2010.
  - Wind represented 13% of added capacity and grid-scale batteries an additional 13%, for a total of 79% of capacity additions from those three technologies.
- Over 40 GW_{ac} of new installed capacity was either from non-carbon emission sources or battery technologies in 2023—3 GW_{ac} above the previous record level achieved in 2021.
  - 2023 wind installations were half their record-level achieved in 2020, though still the third-leading technology installed.

Note: "Other" includes coal, geothermal, landfill gas, biomass, and petroleum.
Sources: EIA, "Electric Power Monthly" Tables 6.1, 6.2B, 1.1, 1.1A; Forms 860M & 861M. April 2024.

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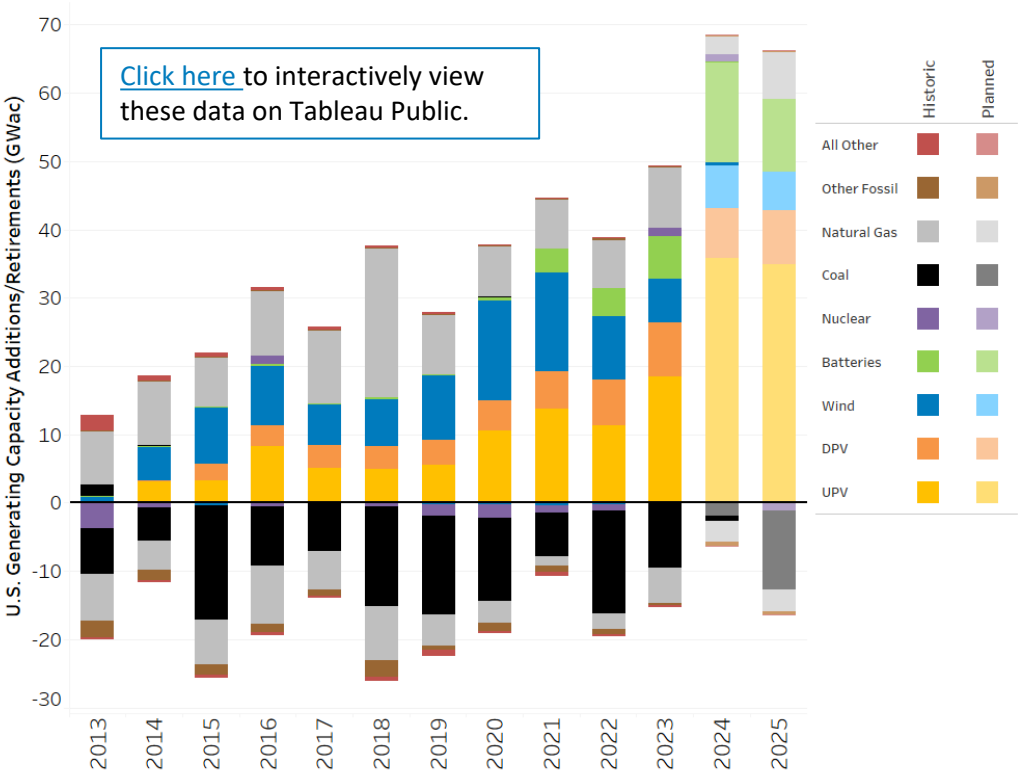
U.S. Generation Capacity Additions and Retirements by Source: 2013–2023 and Planned 2024–2025



- EIA projects that the percentage of U.S. electric capacity additions from solar will grow from 54% in 2023 (31 GW_{ac}) to 63% in 2024 (43 GW_{ac}) and 65% in 2025 (42 GW_{ac}).
  - Natural gas accounted for 18% of new capacity in 2023, though only 7% when subtracting retirements from additions. In 2024, there are projected to be more natural gas retirements than additions, rebounding slightly in 2025.
  - 2024 will mark the first time in a decade that simple-cycle, natural gas turbines additions will exceed combined-cycle capacity, due in part to natural gas switching from baseload generation to peak support because of the growing presence of renewables on the grid.
- In the next two years, EIA projects that PV, storage, and wind will add 124 GW_{ac} of capacity in the United States, or 92% of additions.
  - In contrast, EIA is projecting nearly 20 GW of retirements from coal, natural gas, and other fossil fuels in that time, or 89% of retirements.
  - Since 2013, a nearly equal volume of coal has been retired as solar (UPV + DPV) has been added to the grid.

Sources: EIA Form 860M/Preliminary Monthly Electric Generator Inventory ("Planned" and "Operating") and EIA Short-Term Energy Outlook Table 7e, downloaded March 2024.

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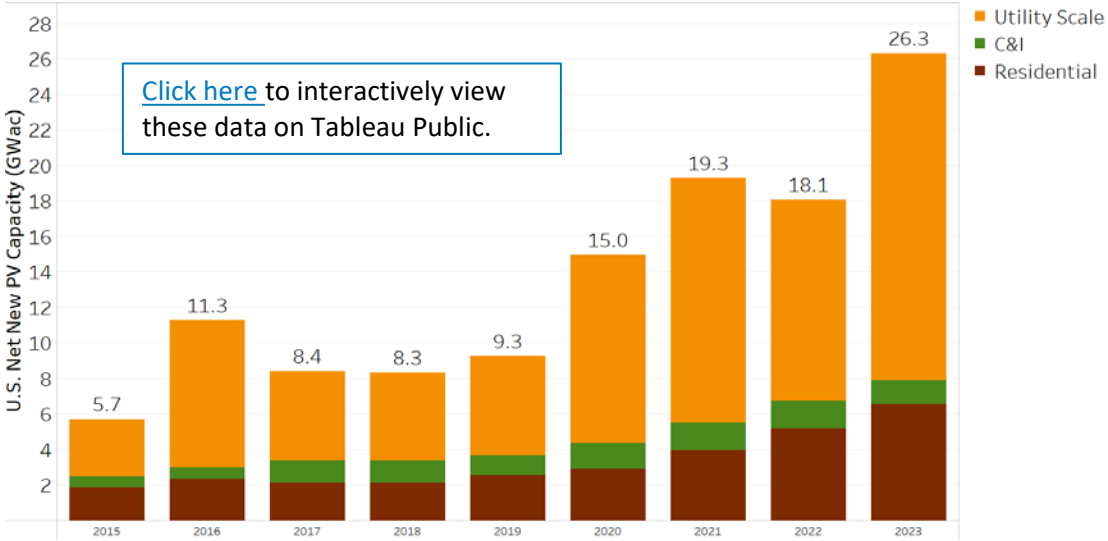
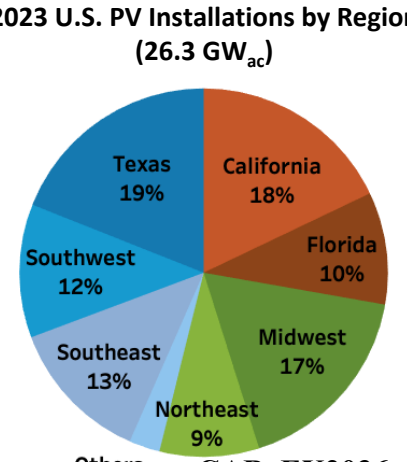
U.S. Installation Breakdown Annual: EIA (GW_{ac})

- The United States installed 26.3 GW_{ac} of PV in 2023—up 46% y/y.
  - In 2023, utility-scale (18.4 GW_{ac}) and residential (6.6 GW_{ac}) PV were up 34% and 27%, respectively, while C&I (1.3 GW_{ac}) PV was down 16%.

- Approximately 47% of U.S. PV capacity installed in 2023 was in Texas, Florida, and California.
- Despite a concentration of PV installations in the top three markets, diversification of growth continues across the United States.
  - 34 states installed more than 100 MW_{ac} in 2023 and 16 states installed more than 500 MW_{ac}.



Click here to interactively view these data on Tableau Public.



Note: EIA reports values in Wac which is standard for utilities. The solar industry has traditionally reported in Wdc.
Sources: EIA, "Electric Power Monthly," forms EIA-023, EIA-826, and EIA-861 (March 2023, April 2022, February 2021, February 2019).

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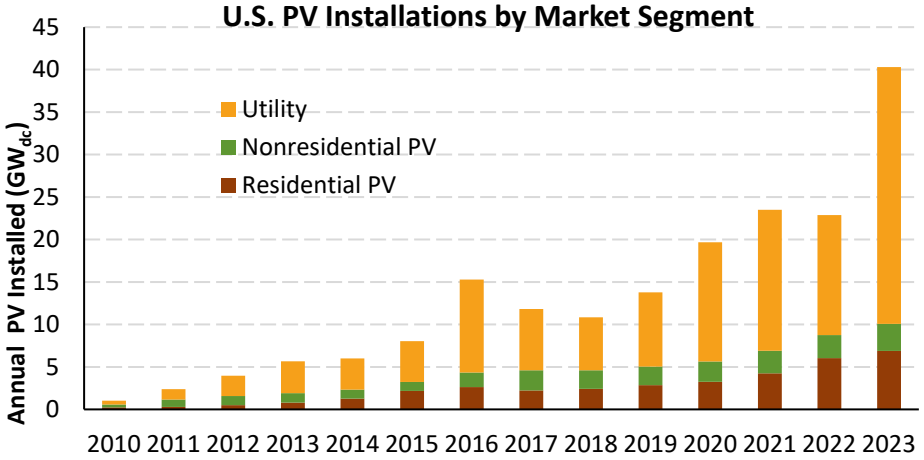
U.S. Installation Breakdown Annual: SEIA (GW_{dc})

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

- SEIA reports that the United States installed 40.3 GW_{dc}* of PV in 2023 (186.5 GW_{dc} cumulative)—an annual increase of 76% y/y.
  - 30.2 GW_{dc} UPV (+114% y/y), 3.2 GW_{dc} non-residential (+17% y/y), and 6.9 GW_{dc} residential (+14% y/y).
- Q4 2023 installations totaled 19.6 GW_{dc}.



* Wood Mackenzie/SEIA differ from EIA in what is considered an "operational" project.

Sources: Wood Mackenzie/SEIA: U.S. Solar Market Insight: Q2 2024.

- In 2023, 56% of installed capacity occurred in California, Texas, and Florida. However, 37 states and Puerto Rico, installed more than 100 MW.
  - Texas produced more electricity from solar than coal in 2023.
- The reasons for overall 2023 growth varied by market segment:
  - A huge surge in residential California installations in the first half of the year to take advantage of the expiring NEM 2.0 offset lower installation in H2 as well as declines in other states due to higher interest rates.
  - Installations of larger, non-residential California projects continued to grow in H2 2023 from NEM 2.0 due to the longer development cycle. Community solar projects continued to face interconnection delays, but also expanded into new markets.
  - Utility-scale PV installations grew in large part due to stabilization of module supply chains and the subsequent installations of delayed projects.

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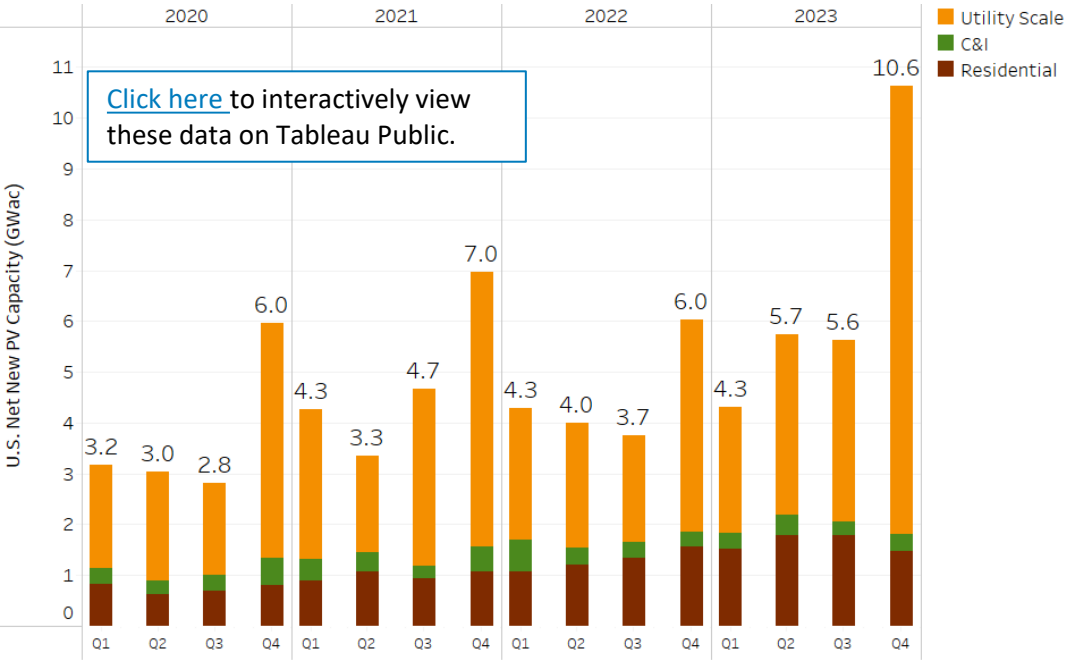
U.S. Installation Breakdown Quarterly: EIA (GW_{ac})



- In Q4 2023, the United Stated installed over 10 GW_{ac} of solar capacity—a first.
- According to EIA data, 40% of 2023 installed U.S. solar capacity occurred in Q4—relatively consistent with previous years, though much greater in absolute terms.
  - Utility-scale PV represented 83% of Q4 2023 solar installations—its highest percentage ever.
- Residential installs fell in the second half of 2023—the first time since 2017.

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).

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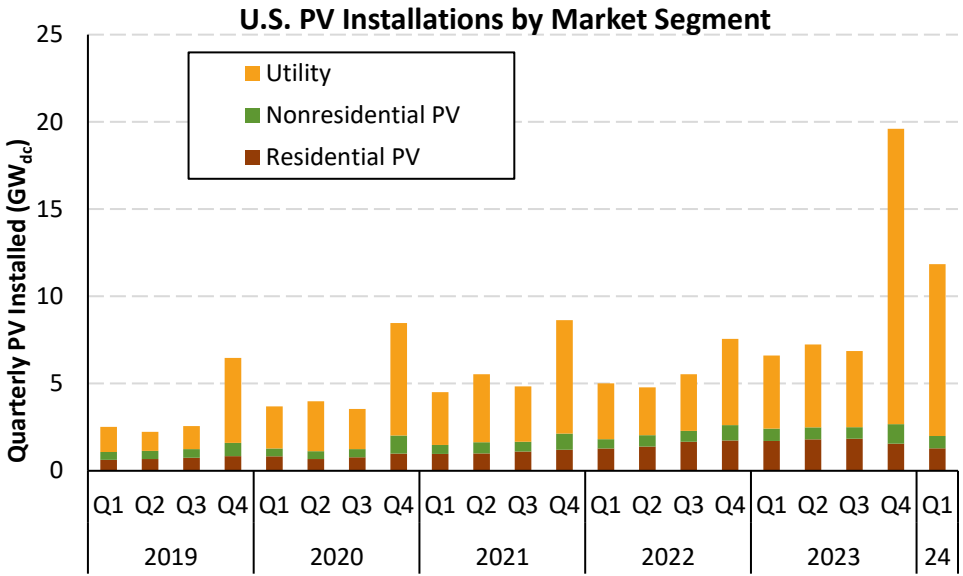
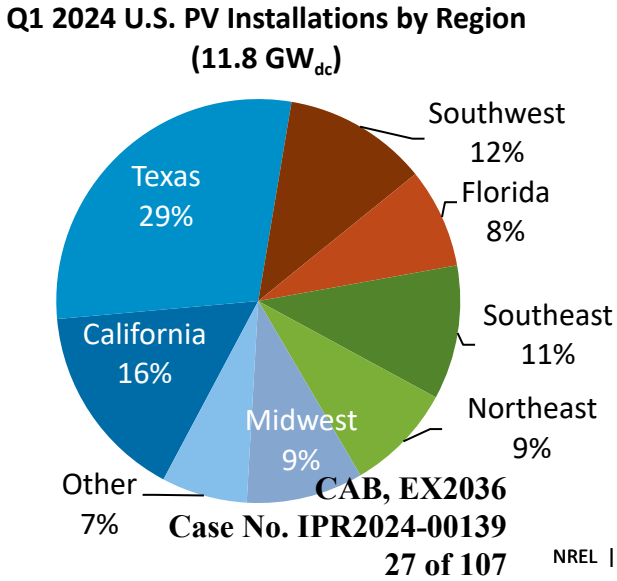
U.S. Installation Breakdown Quarterly: SEIA (GW_{dc})

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

- Wood Mackenzie/SEIA reports a record 19.6 GW_{dc} of PV installations in Q4 2023 and 11.8 GW_{dc} in Q1 2024—an increase of 159% and 79% y/y, respectively.
  - In Q1 2024, utility-scale installations were up 135% while residential PV was down 25% y/y. Nonresidential was flat.
- Florida, Texas, and California represented 57% of Q1 installations, despite their residential PV installations being down 21%–51%.





Sources: Wood Mackenzie/SEIA: U.S. Solar Market Insight: Q2 2024.

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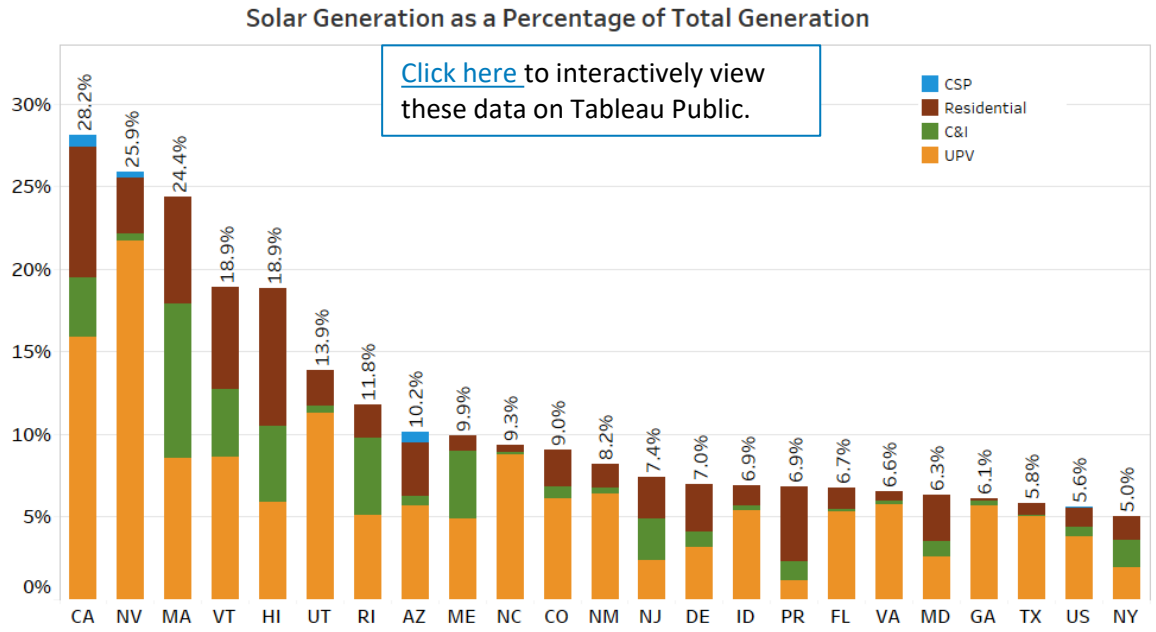
Solar Generation as a Percentage of Total Generation, 2023



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. Generation reported to EIA is net of station service, which EIA refers to as "net 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 March 2024.

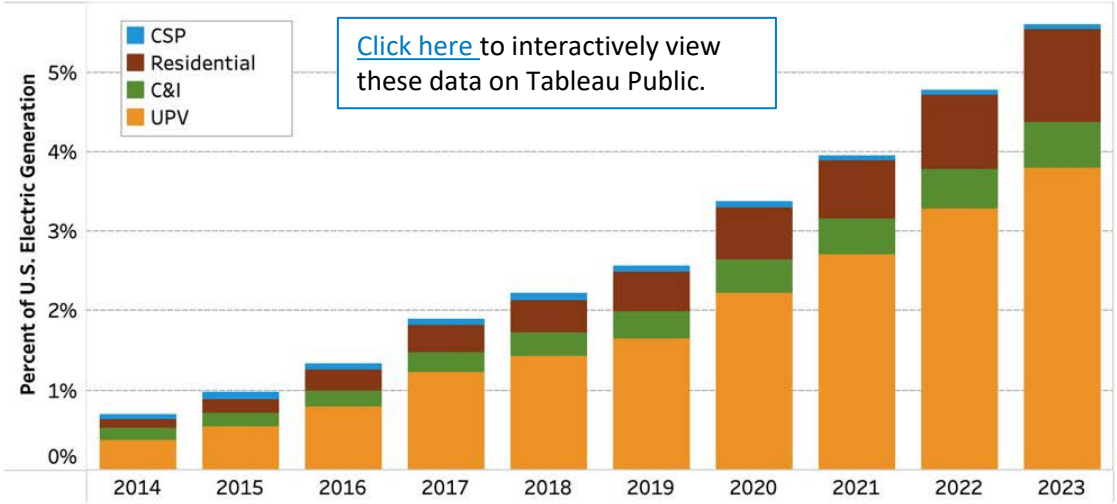
In 2023, 22 states generated more than 5% of their electricity from solar, with California leading the way at 28.2%.

- Five states (California, Nevada, Massachusetts, Vermont, and Hawaii) 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.

Nationally, 5.6% of electricity was generated from solar in 2023—up from 4.8% in 2022.

The roles of utility-scale 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.

Solar Generation as a Percentage of Total Generation, 2014–2023



- In 2014, solar produced approximately 0.7% of total U.S. electric generation.
- By 2023, solar grew to about 5.6% of electric generation.
  - 3.8% from utility-scale PV (UPV), a nearly 10-fold increase
  - 1.8% from distributed PV (DPV), a 7-fold increase
  - 0.1% from concentrating solar power (CSP)
- 2023 is the first year that solar has accounted for more than 5% of U.S. electricity generation.

Note: EIA monthly data for 2023 are not final. Additionally, smaller utilities report information to EIA on a yearly basis. Therefore, a certain amount of solar data has not yet been reported.
Source: U.S. Energy Information Administration, "Electricity Data Browser." Accessed March 12, 2024.

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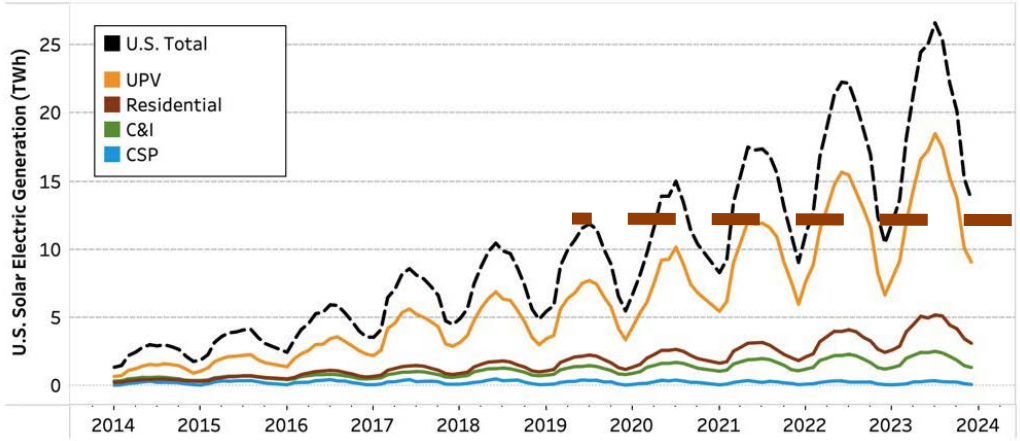
Monthly U.S. Solar Generation, 2014–2023

Click here to interactively view these data on Tableau Public.



- Total peak monthly U.S. solar generation increased by a factor of 8.8 from 2014 to 2023.
  - U.S. electric generation in December 2023 (during the low seasonal period of electric generation) was above the peak solar production in 2019 (brown dashed line).
  - In May 2023, solar produced 7.5% of all U.S. electricity production, and solar produced over 5% of all U.S. electricity production from March through October of 2023.
- Utility-scale solar electricity production (including PV and CSP technologies) dropped by 51% from its summer peak (July 2023) to its winter low (December 2023), and DPV systems dropped 42%.
  - The drop in production would likely be greater without continued solar deployment throughout the year.

Note: EIA monthly data for 2023 are not final. Additionally, smaller utilities report information to EIA on a yearly basis. Therefore, a certain amount of solar data have not yet been reported. "U.S. Total" includes DPV generation.
Sources: U.S. Energy Information Administration, "Monthly and annual electric power operations by state, sector, and energy source." Accessed March 12, 2024.

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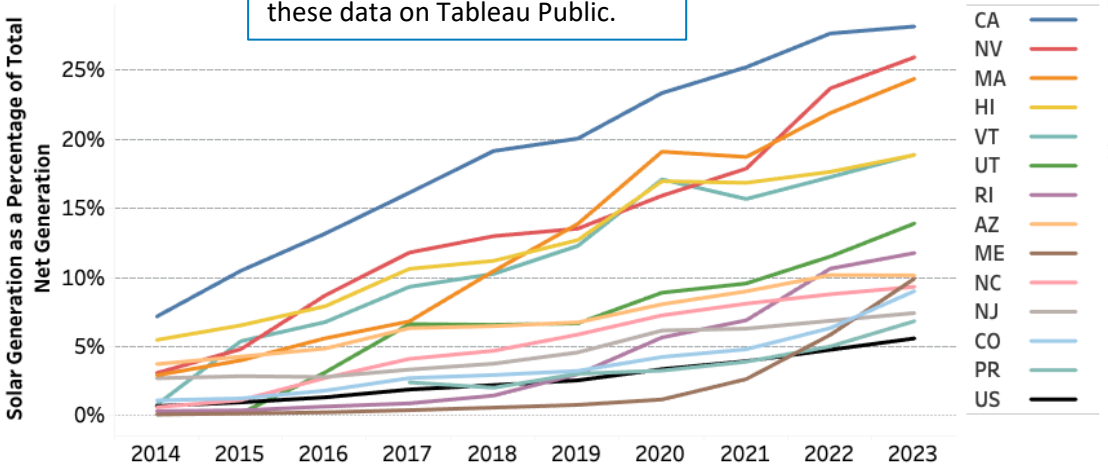
Solar Generation as a Percentage of Total Generation, 2014–2023

Click here to interactively view these data on Tableau Public.



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 DPV generation. Net generation does not include imports and exports to and from each state. Therefore, the percentage of solar consumed in each state may vary from its percentage of net generation.
Source: U.S. Energy Information Administration (EIA), "Monthly and annual electric power operations by state, sector, and energy source." Accessed March 12, 2024.

- From 2014 to 2023, leading solar deployment states greatly increased solar electricity penetration.
  - Rhode Island and Maine (purple and brown respectively) have seen substantial growth since 2019.
- In the past 5 years, 5 states (MA, VT, UT, AZ, and RI) shifted over 10% of their electricity generation to solar sources.
  - Some of the increase in Massachusetts' percentage is due to a significant reduction in total electricity production in the state.
- The United States, as a whole, has a much lower level (5.6%) of solar generation, but it has still increased solar generation by about 723% since 2014.

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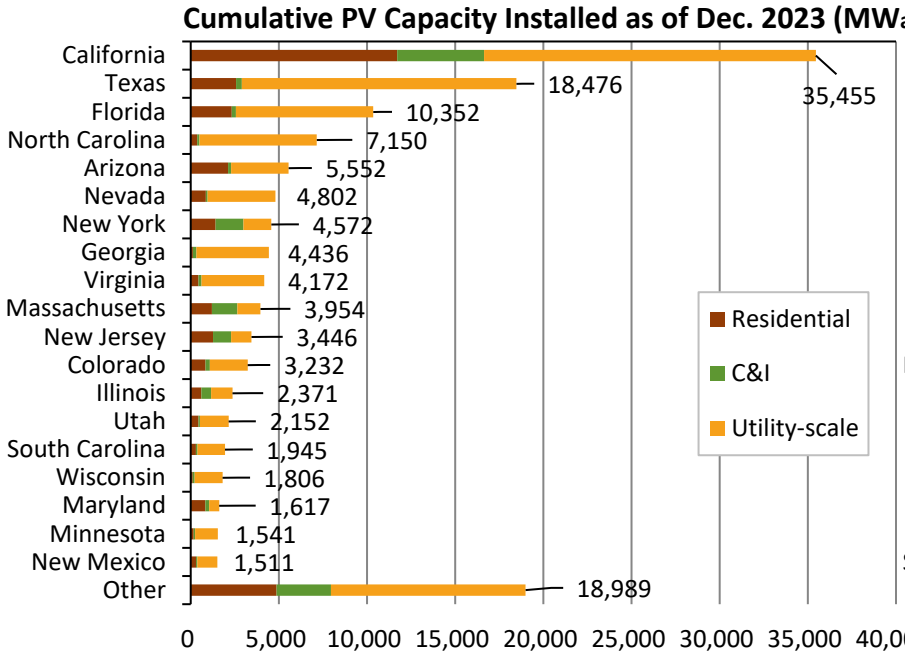
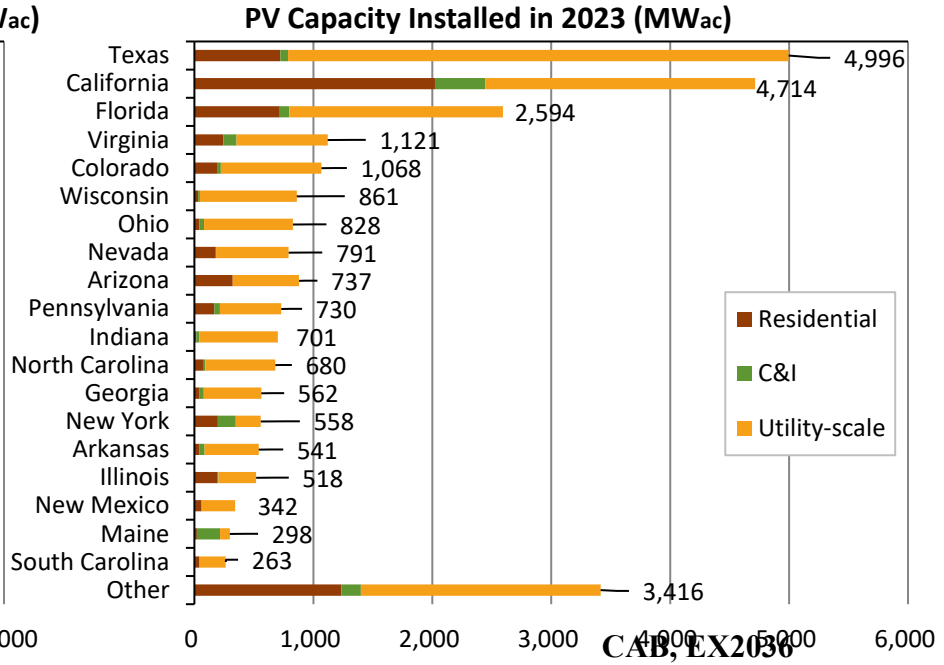
U.S. Installation Breakdown by State

- In 2023, 5 states installed >1 GW_{ac} (Texas, California, Florida, Virginia, and Colorado), and 7 installed >1 GW_{dc} (+Ohio, Wisconsin).
  - In comparison, 29 countries installed >1 GW_{dc} in 2023, according to IEA data, as noted on slide 5.

At the end of 2023, there were 137.5 GW_{ac} of solar PV systems in the United States, of which 89.8 GW_{ac} were utility-scale PV, 32.9 GW_{ac} were residential PV, and 14.8 GW_{ac} were C&I PV.





Note: EIA monthly data for 2023 are not final. Additionally, smaller utilities report information to EIA on a yearly basis. Therefore, a certain amount of solar PV capacity may not have been reported. Arizona's C&I installations in 2023 were net negative.

Sources: EIA, "Electric Power Monthly," forms EIA-023, EIA-826, and EIA-861 (February 2024, February 2023).

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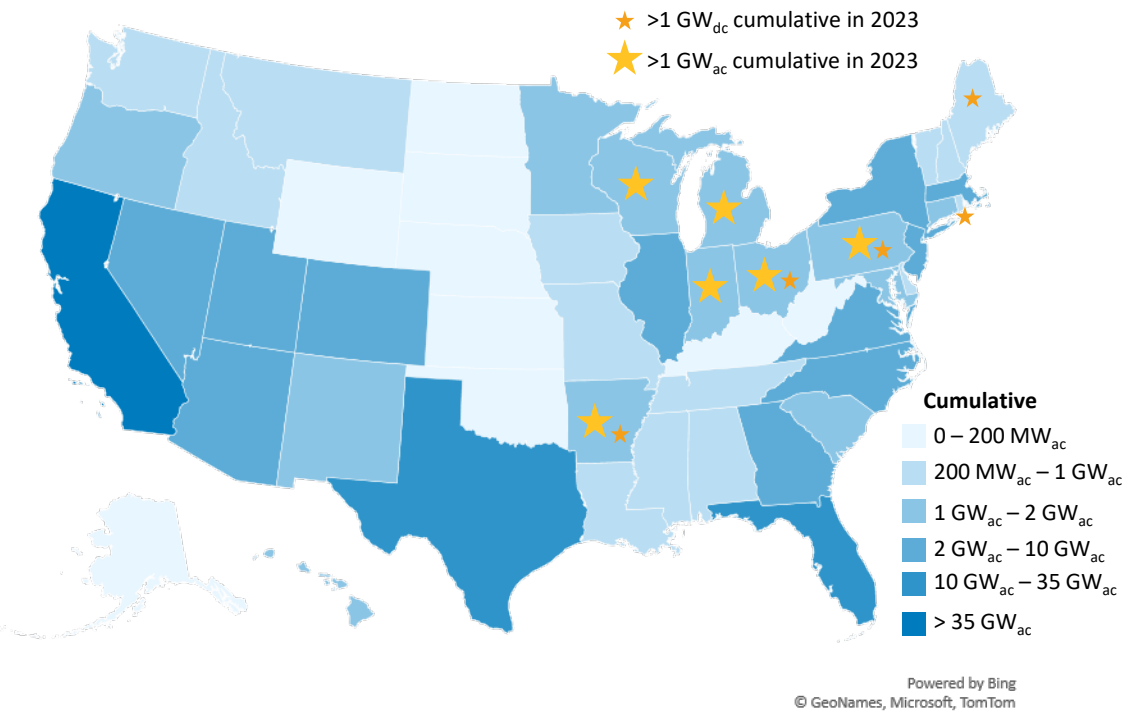
Cumulative U.S. Installation Breakdown by State



At the end of 2023, the United States surpassed half of states (27) having >1 GW_{ac} installed cumulatively, with Indiana, Michigan, Ohio, Wisconsin, Arkansas, and Pennsylvania joining the ranks since 2022.

- The tally rises to 29 states, when looking at those which have achieved the >1 GW_{dc} distinction, with Maine, Rhode Island, Pennsylvania, Arkansas, and Ohio just crossing that threshold in 2023.

Note: EIA monthly data for 2023 are not final. Additionally, smaller utilities report information to EIA on a yearly basis. Therefore, a certain amount of solar capacity has yet to be reported.
Sources: EIA, "Electric Power Monthly," forms EIA-023, EIA-826, and EIA-861 (February 2024, February 2023).

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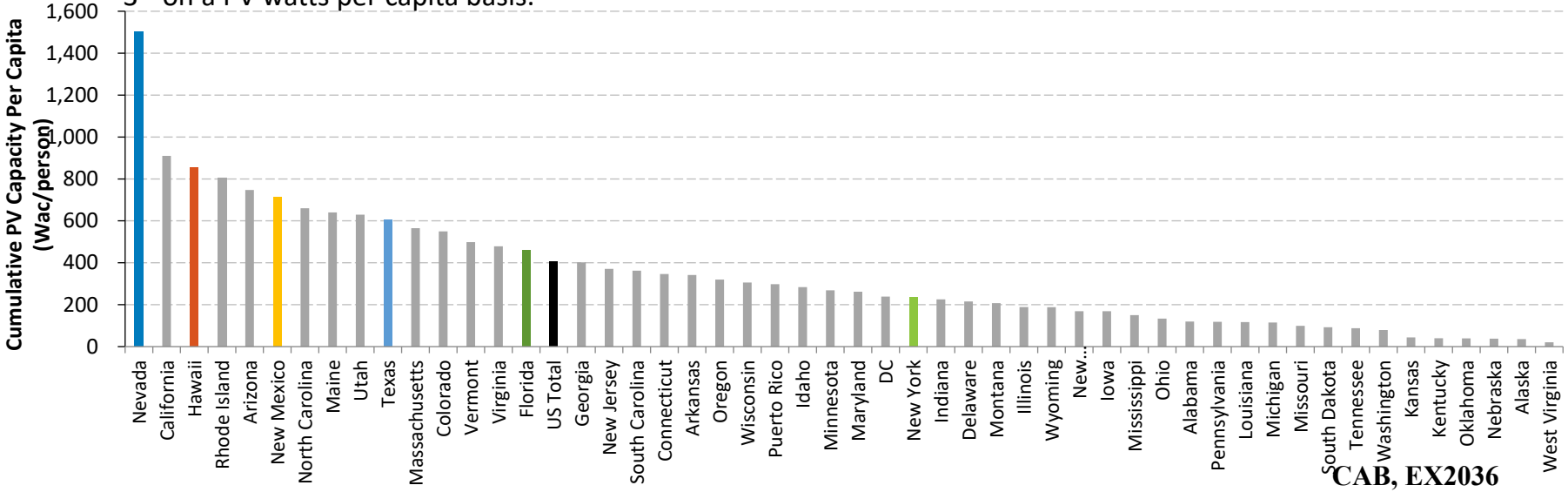
Cumulative U.S. PV Capacity Per Capita (2023)

- Some large states that ranked high in total cumulative capacity at the end of 2023, such as Texas (#2), Florida (#3) and New York (#6), are relatively lower in rankings when looking on a watts per capita basis. Texas drops to #10, Florida to #15, and New York to #28.
  - Conversely, New Mexico, Nevada, and Hawaii, which ranked 22nd, 25th and 30th in cumulative PV capacity, are 6th, 1st and 3rd on a PV watts per capita basis.



Note: EIA monthly data for 2023 are not final. Additionally, smaller utilities report information to EIA on a yearly basis. Therefore, a certain amount of solar PV capacity may not have been reported.

Sources: EIA, "Electric Power Monthly," forms EIA-023, EIA-826, and EIA-861 (February 2024); United States Census Bureau (2024).

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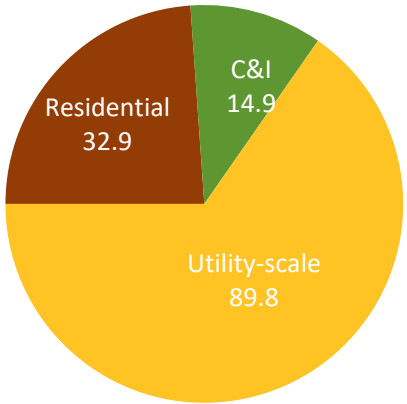
U.S. PV Installation Breakdown Annual: EIA (GW_{ac})

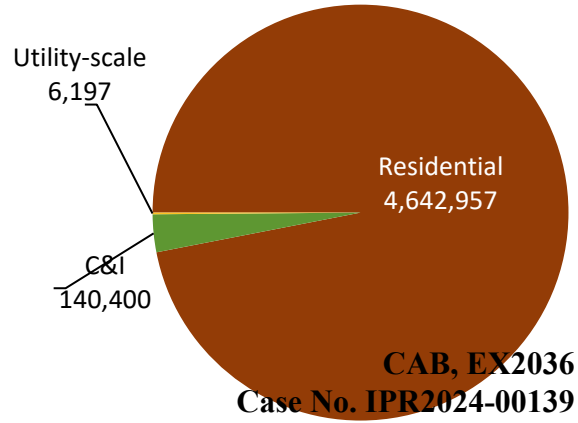
- At the end of 2023, there were 137.5 GW_{ac} of cumulative PV installations.
- EIA reports that at the end of 2023, 65% of U.S. installed PV capacity was from utility-scale PV systems.

- Despite representing only 24% of installed U.S. PV capacity at the end of 2023, 97% of PV systems—over 4.4 million systems—were residential applications.
  - In 2023, the United States installed 893,000 PV systems, of which 880,000 were residential, 13,000 were C&I, and 399 were utility-scale.

Cumulative U.S. PV Installations as of December 2023 (137.5 GW_{ac})



Cumulative U.S. PV Installations as of December 2023 (4.8 million systems)



Sources: EIA, "Electric Power Monthly," forms EIA-023, EIA-826, EIA-860, and EIA-861 (April 2023).

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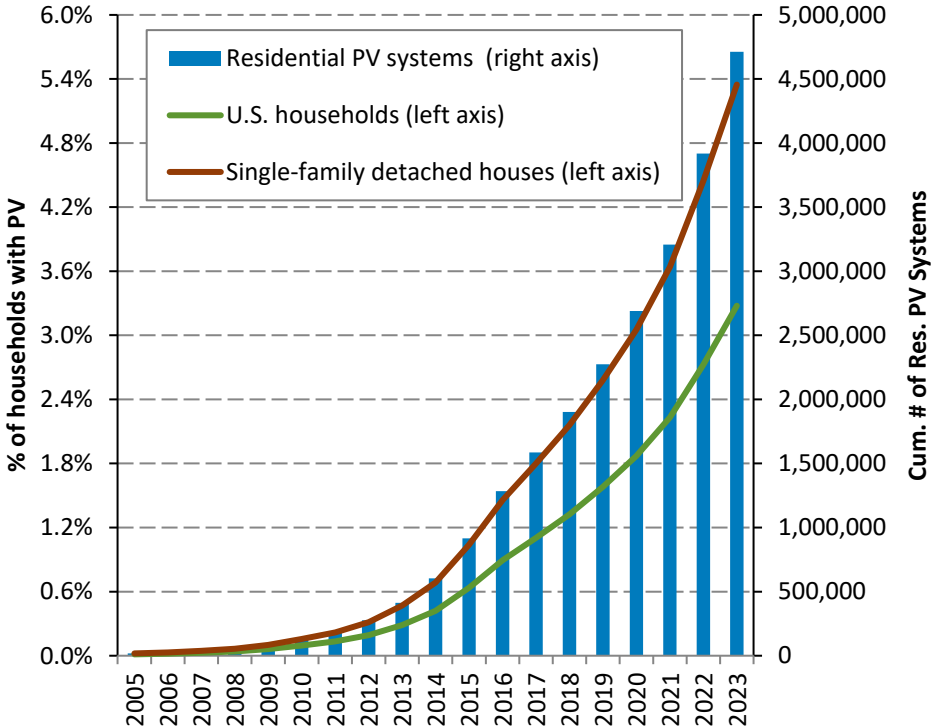
U.S. Residential PV Penetration



- Since 2005 when Congress passed the investment tax credit, the number of annually installed residential PV systems has grown by approximately 36% per year, or over 250X.
- At the end of 2023, SEIA estimates there were approximately 4.7 million residential PV systems in the United States.
  - Still, only 3.3% of households own or lease a PV system (or 5.3% of households living in single-family detached structures).
  - However, solar penetration varies by location. Hawaii, California, and Arizona have residential systems on an estimated 35%, 23%, and 14% of households, respectively, living in single-family detached structures.

Sources: Res. PV Installations: 2000-2009, IREC 2010 Solar Market Trends Report; 2010-2022, SEIA/Wood Mackenzie Solar Market Insight 2023 Year-in-Review; U.S. Households from U.S. Census Bureau.

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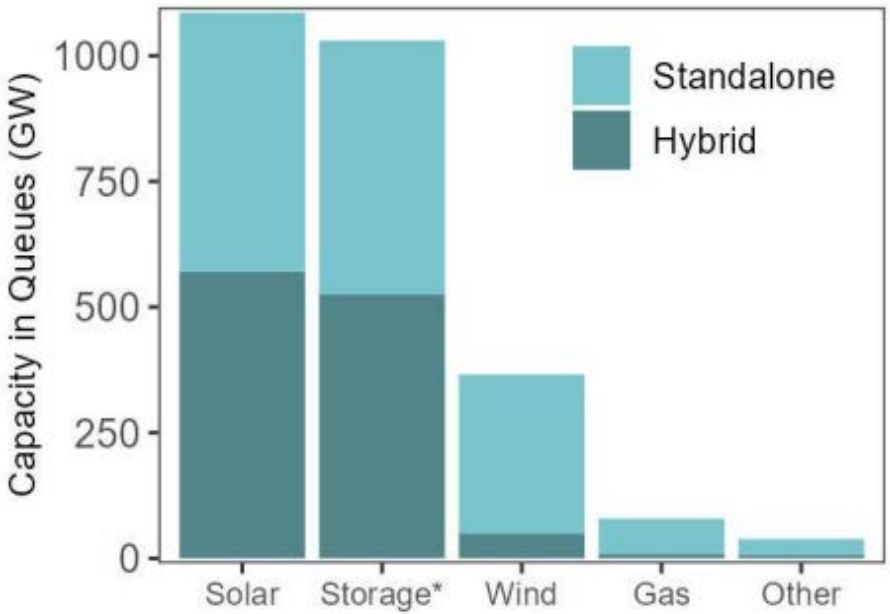
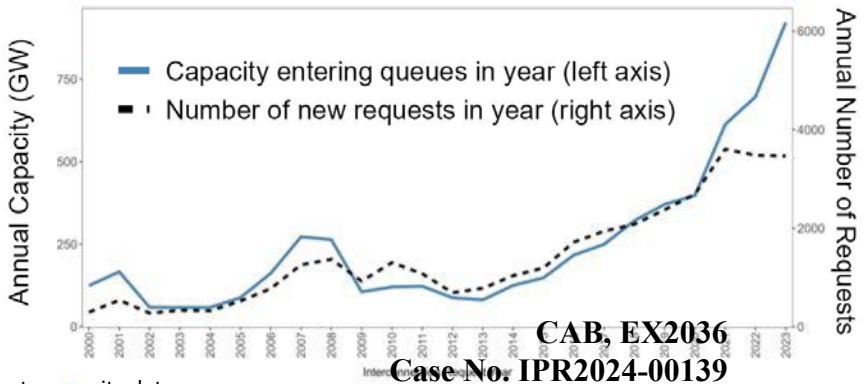
U.S. Transmission Interconnection Queues

- LBNL reports that substantial solar and storage capacity have been proposed in most regions of the United States.
  - Over 12,000 large-scale projects representing 1.57 TW_{ac} of generator capacity (1.48 TW of which is zero-carbon and 1.09 TW is solar) and 1.03 TW_{ac} of storage are seeking interconnection.
- Annual interconnection requests have increased dramatically—in terms of both number and capacity—since 2013; over 900 GW_{ac} was added in 2023 alone. Over half of solar and storage capacity in the queue is from hybrid projects.
- Only 13% of proposed solar projects (and 10% of solar+battery projects) entering queues from 2000 to 2018 have reached commercial operations (compared to 19% for all technologies).
- The average time spent in queues has increased over time. The typical projects completed in 2022-2023 took 5 years from interconnection request to commercial operation. This compares to 3 years in 2015 and less than 2 years in 2008.

Proposed Interconnections by Technology



Interconnection Requests by Year



*Hybrid storage capacity is estimated using storage: generator ratios from projects that provide separate capacity data

Source: LBNL, Queued Up: Characteristics of Power Plants Seeking Transmission Interconnection, 2024.

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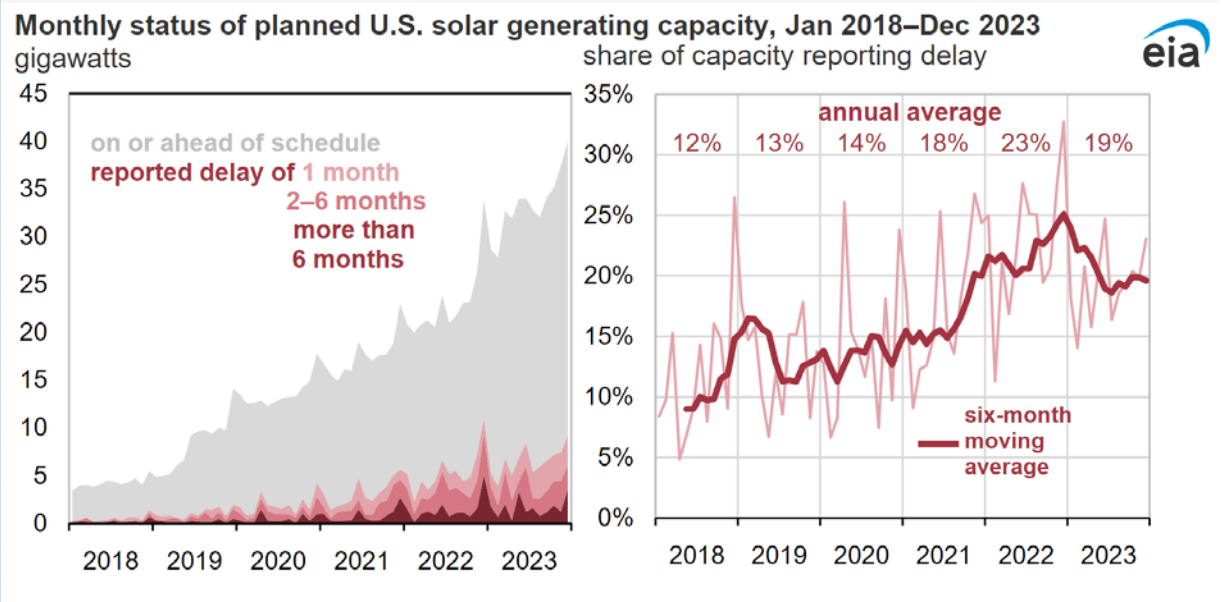
EIA Reports Fewer Delays



- EIA reports that in 2023 developers delayed 19% of planned solar capacity—a reduction from the high of 23% in 2022, though still above historical averages.
- According to EIA data, the percentage of total solar planned capacity with a postponed operational date increased from 2021 to 2022, peaking in December 2022 at 33%.
- The rapid rise in delays between mid-2021 and late 2022 corresponded with constrained importation of PV modules into the United States, related to issues including policies that targeted China's alleged use of forced labor (WRO on Hoshine, UFLPA), the AD/CVD circumvention investigation, and COVID-related supply chain disruptions. The impact of such issues eased by 2023, corresponding with increased module imports and reduced delays.

Source: EIA "Today In Energy" (May 8, 2024)

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FERC Issues Long-term Transmission Planning Rules

FERC issued final rule for Order #1920, two years in the making, which establishes a new long-term planning process to better anticipate and address regional grid needs and to encourage cooperation with states.

- Requires transmission providers to plan ahead at least 20 years, update regional transmission needs at least every 5 years, and determine how to pay for them.

The level of transmission investment has not been adequate to handle large changes to the grid, with transmission providers more focused on short-term needs.

- Order gives transmission providers opportunity to select cheaper, more efficient, long-term regional transmission facilities.
- Requires transmission providers to consider several alternative transmission technologies (e.g., dynamic line ratings, advanced power flow control devices, advanced conductors, and transmission switching).

Transmission projects which require multiple-state approval have had difficulties due to varying goals of, and benefits to, states (e.g., different levels of use of projects, different renewable energy goals).

- Order permits but does not require transmission providers to use a State Agreement process, providing states a role in the process.
- FERC also issued Order #1977, which gives FERC authority to issue permits to construct a national corridor if states deny siting application (so long as they have made good faith effort to engage with landowners early and developed environmental justice plans). States are encouraged to work together because if they do not FERC and transmission owners can move ahead without state permission.

Analysts believe that more efforts are needed to properly build out transmission infrastructure, including low-cost access to loans (e.g., loan guarantees, revolving loan funds). The final rule also does not establish renewable energy zones by transmission planners (as discussed in the NOPR) or mandate grid-enhancing technologies.

The order will also likely be challenged in court.

Sources: Holland & Knight (05/15/24); Morgan Lewis (05/14/24); NYTimes (05/13/24); UtilityDive (05/15/24)

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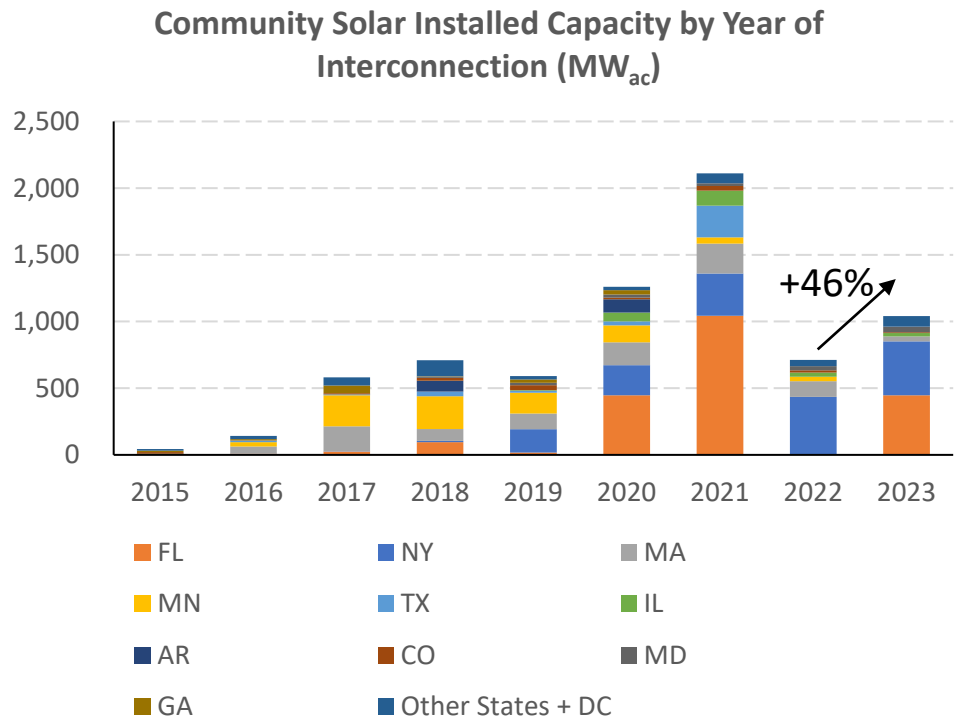
Community Solar



- Cumulative community solar capacity topped 7.2 GW_{ac} in 2023 with 9 states adding a total of 1.04 GW_{ac} of new interconnected capacity.
- The majority of new installations in 2023 were in Florida (447 MW_{ac}) and New York (404 MW_{ac}).
  - Florida Power & Light's SolarTogether program is the largest community solar program in the United States with 26 current utility-owned projects on-line and 18 planned projects (1341 MW_{ac} of planned community solar).
  - New York's additions dropped by 7% from 2022. Wood Mackenzie projects that market saturation and interconnection issues will challenge community solar projects' long-term market viability.
- Wood Mackenzie projects 1–2 GW of growth through 2025 and an approximate doubling of cumulative community solar capacity over the next five years.

Note: Community solar refers to any solar project or purchasing program, within a geographic area, in which the benefits flow to multiple customers such as individuals, businesses, nonprofits, and other groups. In most cases, customers benefit from energy generated by solar panels at an off-site array.
Source: Wood Mackenzie, Community Solar Outlook H1 2024 (February 2024). NREL Sharing the Sun Project List, accessed 4/22/24. SolarTogether, Florida Power & Light, accessed 5/7/24.

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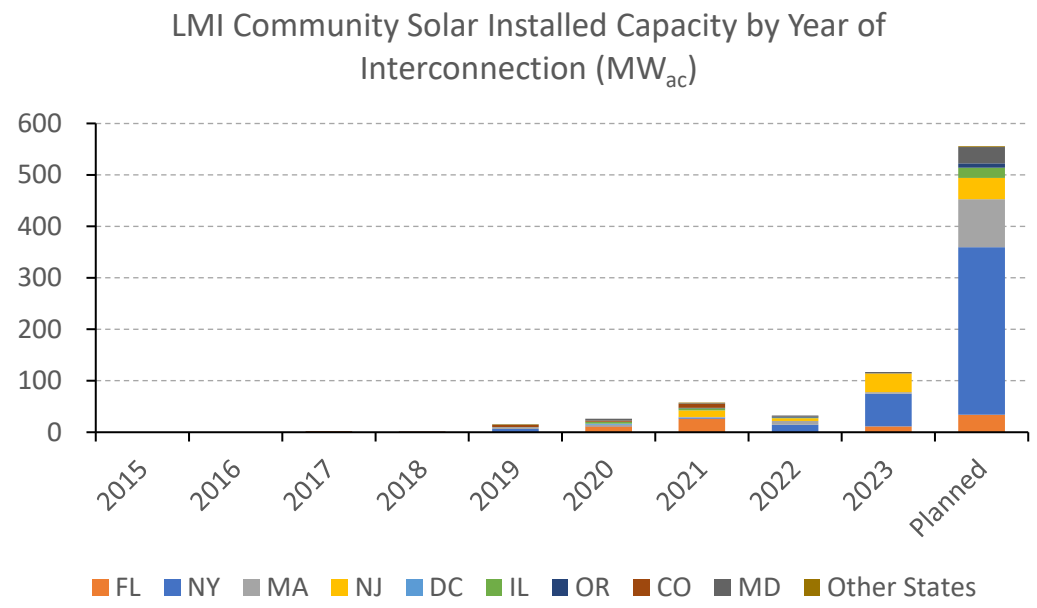
NREL-Tracked LMI Community Solar



- NREL tracked 253 MW_{ac} of LMI community solar installations, 116 MW_{ac} of which was installed in 2023.
  - 75% the projects were located in New York, New Jersey, and Florida.
- There are another 555 MW_{ac} of planned LMI community solar projects in the dataset, most of which are located in New York.
- The IRS announced in that in 2023 and 2024 it intends to allocate a combined ~800 MW_{dc} per year of Low-Income Communities Bonus Credits to Low-Income Benefit Projects (which in general meet the definition of a LMI Community Solar project)
  - These annual allocations go through at least 2032.

Note: Community solar refers to any solar project or purchasing program, within a geographic area, in which the benefits flow to multiple customers such as individuals, businesses, nonprofits, and other groups. In most cases, customers benefit from energy generated by solar panels at an off-site array.
Note: Complete LMI community solar projects are energized projects, and pending projects are awarded or under construction. Projects that are wait-listed, under review, or withdrawn are not considered to be pending. Unless documented from the subscription and procurement reports like Colorado and District of Columbia, the remaining LMI capacity refers to a conservative calculation based on the community solar LMI carve-out rate by program.
Source: Wood Mackenzie, Community Solar Outlook H1 2024 (February 2024). NREL Sharing the Sun Project List, accessed 4/22/24. Sharing the Sun: Community Solar Deployment and Subscriptions (as of June 2023), NREL. SolarTogether, Florida Power & Light, accessed 5/7/24.

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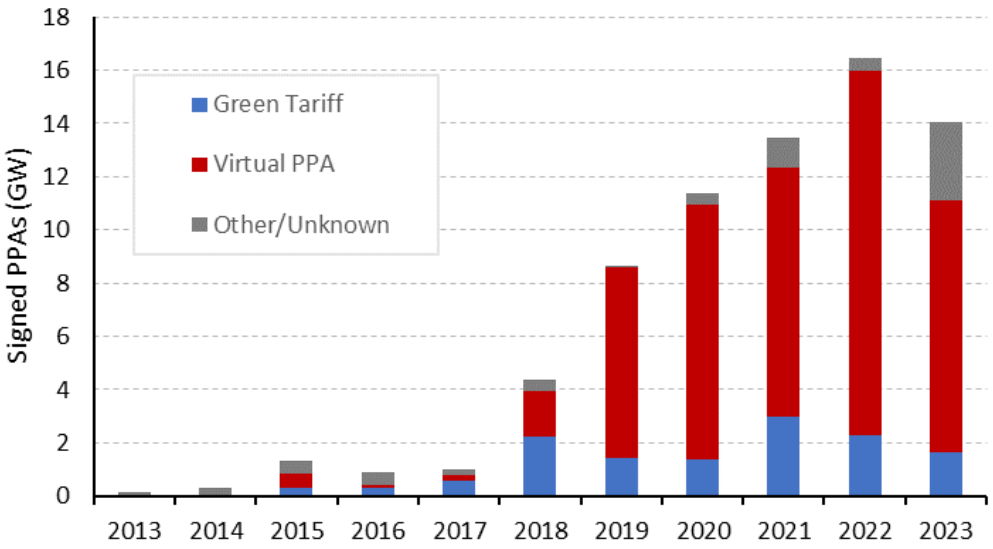
U.S. Off-Site Corporate Solar PPAs



- U.S. corporate solar contracts were down 14.5% in 2023 y/y, though the contracted capacity was 3.3 times larger than it was 5 years ago.
  - The United States represented approximately 49% of the global off-site corporate solar market in 2023, followed by Spain (9%) and India (6%).
  - 67% of the 2023 U.S. solar contracts were in the form of virtual PPAs, with the remainder coming mostly from green tariffs (12%).
  - In addition to the 14.1 GW of U.S. solar PPAs in 2023, companies signed 3.2 GW of U.S. wind PPAs.
- Through 2023, the leading five U.S. offsite corporate solar offtakers were Amazon, Meta, Microsoft, Google, and Verizon, with a collective 40 GW of PPAs.
  - In 2023 alone, Amazon signed 4.0 GW and Meta signed 2.8 GW of off-site U.S. solar PPAs.
  - In May 2024, Microsoft signed the largest ever corporate PPA for more than 10.5 GW of renewable energy (largely solar) in the United States and Europe.

Sources: BloombergNEF, "Corporate PPA Deal Tracker," as of April 29, 2024. Microsoft announces largest-ever corporate procurement of renewable energy, PV Magazine, 5/1/24.

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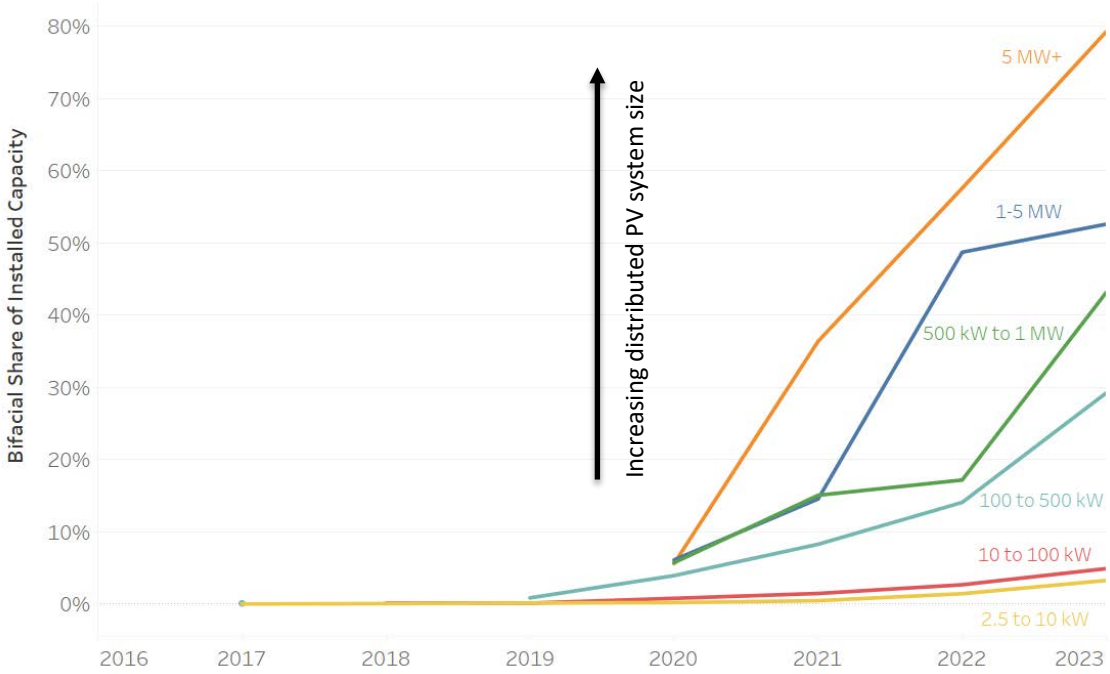
Bifacial Module Surge in Large Distributed PV Systems



- The share of bifacial modules grew rapidly in California and New York's large distributed PV systems between 2020 and 2023.
  - From 4% of capacity in 2020 to 29% of capacity in 2023 for systems 100–500 kW_{dc}.
  - 6% to 43% for systems 500 kW_{dc} to 1 MW_{dc}.
  - 6% to 53% for systems 1–5 MW_{dc}.
  - 6% to 79% for systems 5+ MW_{dc}.
- The bifacial module share remained at 5% or less for systems 2.5–100 kW_{dc}.
- Ground-mount and flat-roof nonresidential PV installations can provide bifacial energy gain, but typical sloped residential rooftop installations do not provide bifacial gain.
- Installers may use bifacial modules to avoid tariff-related module costs. Bifacial modules were exempted from Section 201 tariffs starting in June 2019.
- These distributed generation data do not include utility-scale PV projects, which are the primary application for bifacial modules.

Note: Bifacial modules are defined as having the term "bifacial" in the description field in the California Energy Commission's PV Module List.
Sources: CA NEM database (3/31/24); Solar Electric Programs Reported by NYSERDA (3/31/24); Solar Power World (11/16/21); DOE, Solar Futures Study.

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

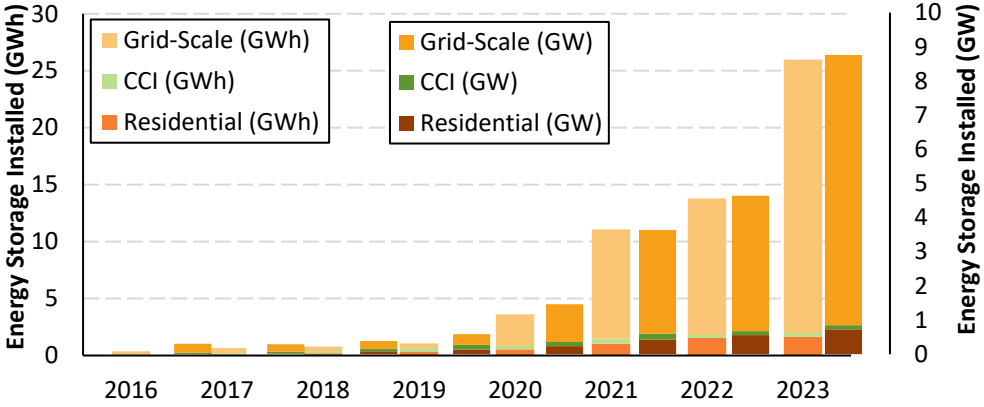
The United States installed approximately 26.0 GWh (8.8 GW_{ac}) of energy storage onto the electric grid in 2023, +34% (+30%) y/y, as a result of high levels of residential deployment and grid-scale deployment.

- Half of all 2023 grid-scale deployment occurred in Q4.
- At the end of 2023, Wood Mackenzie reported 57.7 GWh (20.5 GW_{ac}) of U.S. energy storage.

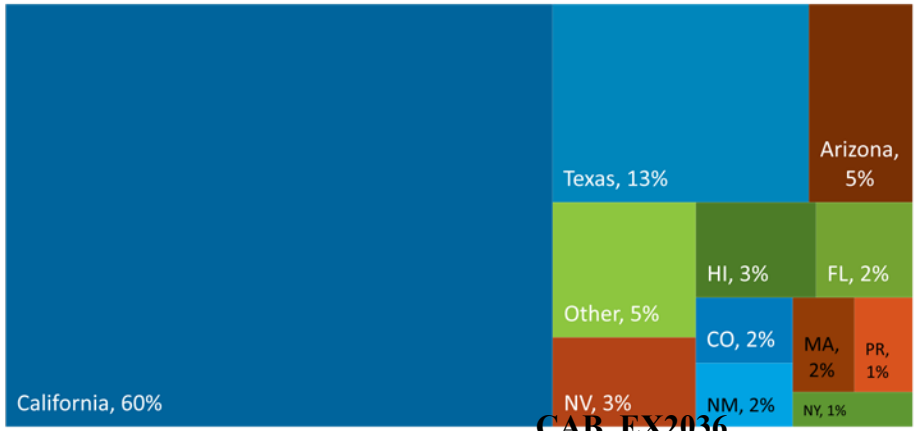
California represented over half of all 2023 battery installed capacity, with the top nine states representing approximately 97% of the market.

- 7 states installed more than 800 MWh of storage in 2023.

U.S. Energy Storage Installations by Market Segment



Cumulative U.S. Energy Storage Installs by Region (57.6 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: Q1 2024.

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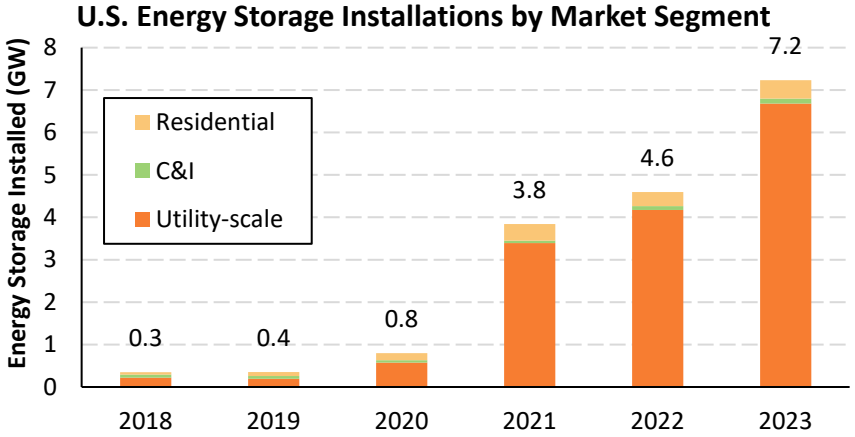
U.S. Energy Storage Installations by Market Segment (EIA)

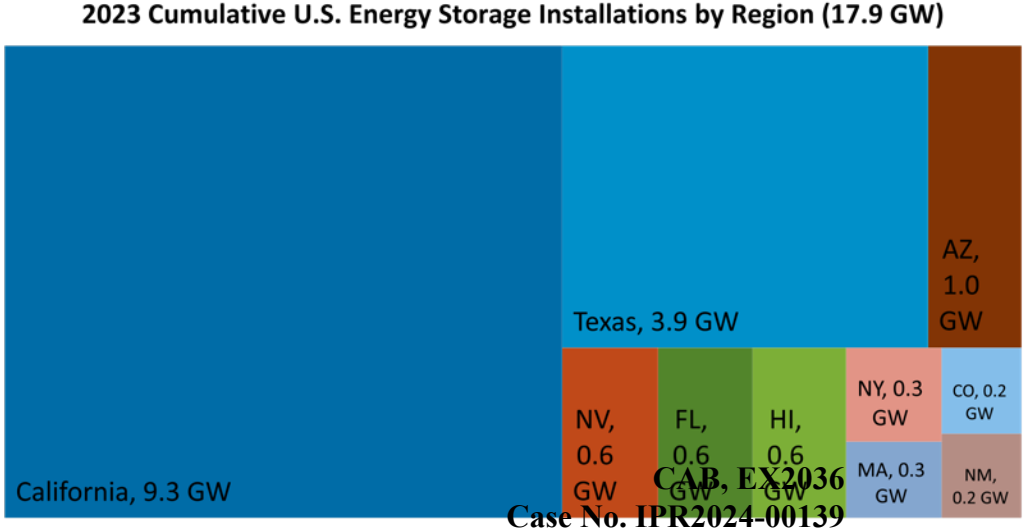
EIA reports that the United States installed approximately 7.2 GW_{ac} of energy storage onto the electric grid in 2023—up 57% y/y as a result of high levels of deployment in all sectors.

– EIA reported a 23% increase in utility-scale, 29% increase for C&I, and 30% increase for residential storage installations in 2023, y/y.

At the end of 2023, California represented 52% of cumulative installed battery storage capacity, followed by Texas (22%).

– The top ten markets represented 95% of installed energy storage capacity.





Note: EIA reports no storage from Puerto Rico.

Sources: EIA Form 860M.

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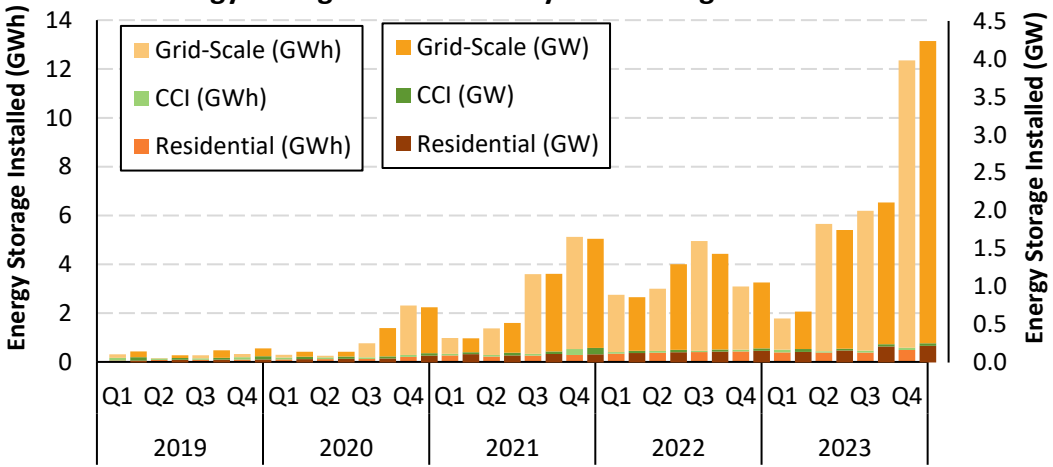
U.S. Energy Storage Installations by Market Segment

- The United States installed approximately 12.4 GWh (4.2 GW_{ac}) of energy storage onto the electric grid in Q4 2023—its largest quarter on record by more than 6 GWh (2 GW_{ac})—as a result of record growth in the grid-scale and residential sectors.
  - Long-duration storage is beginning to take off; Form Energy has a contract in California for a 5 MW/500 MWh system and in Washington and Minnesota for 10 MW/1,000 MWh iron-air battery pilot systems. Dominion is also partnering with Enervenue for a 10-hour nickel-hydrogen chemistry non-lithium-ion storage system.

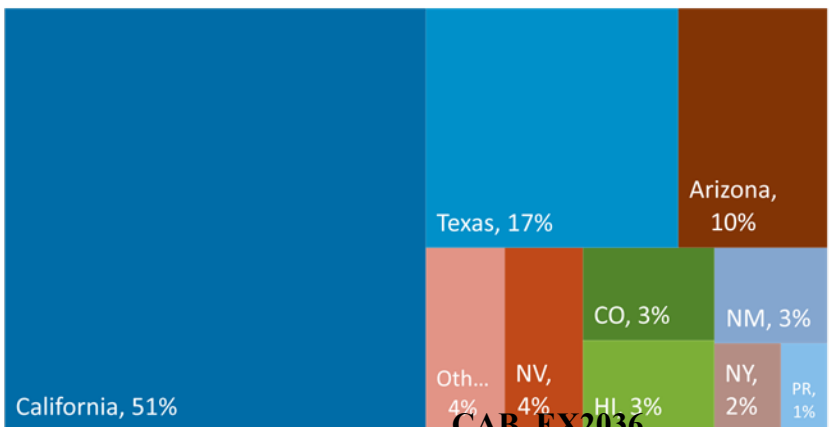
U.S. Energy Storage Installations by Market Segment



California represented over half of all 2023 battery installed capacity, with the top nine states representing approximately 97% of the market.

- 7 states installed more than 800 MWh of storage in 2023.
- California led in all market sectors in 2023, though Texas and Arizona installed large levels of grid-scale storage, New York and Massachusetts installed large levels of CCI, and Puerto Rico far outpaced every state, except California, in residential installs.
- Puerto Rico's Solar Access Program opened in February. It will provide up to 30,000 low-income households with free solar and storage.
- Hawaii began its successor program to its Battery Bonus program; the incentives are significantly below previous levels.

2023 U.S. Energy Storage Installs by Region (26.0 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: Q1 2024.

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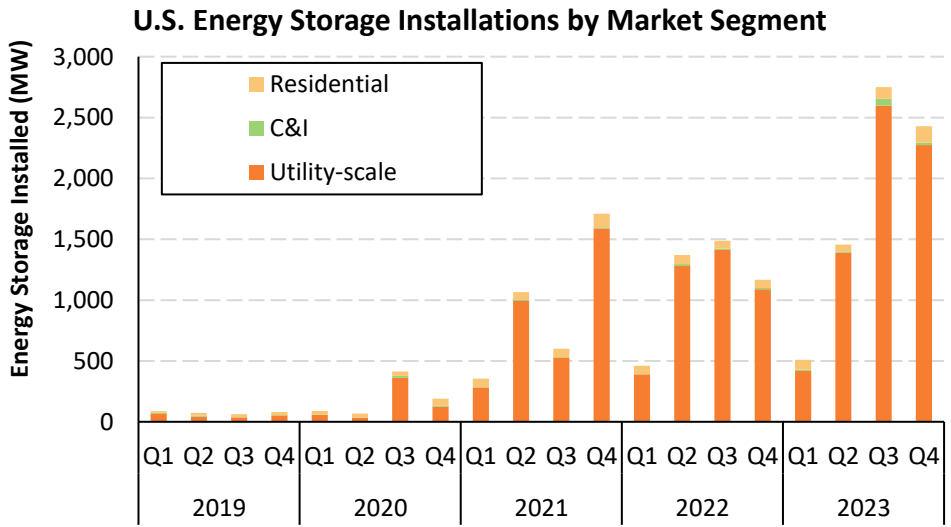
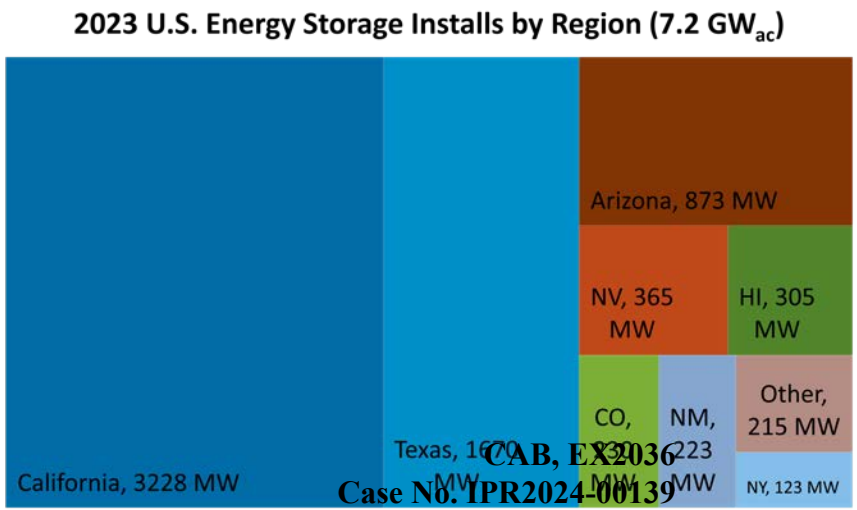
U.S. Energy Storage Installations by Market Segment (EIA)

- EIA reports that the United States installed approximately 2.5 GW_{ac} of energy storage onto the electric grid in Q4 of 2023—up 107% y/y, but down 11% q/q.

- California represented 45% of battery installations in 2023, followed by Texas (23%) and Arizona (12%).
- 8 states installed more than 100 MW of storage in 2023.





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

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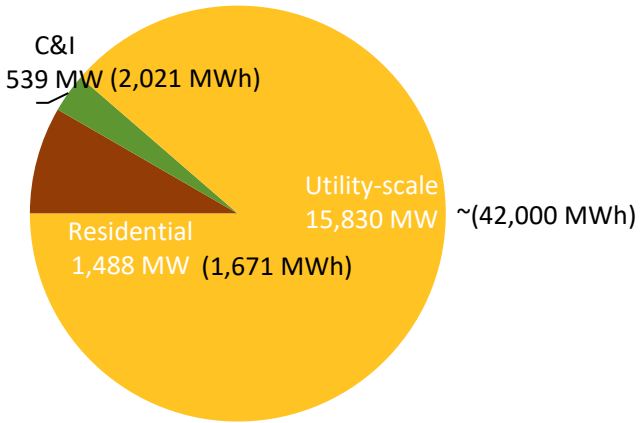
U.S. BESS Installation Breakdown Annual: EIA (GW_{ac})

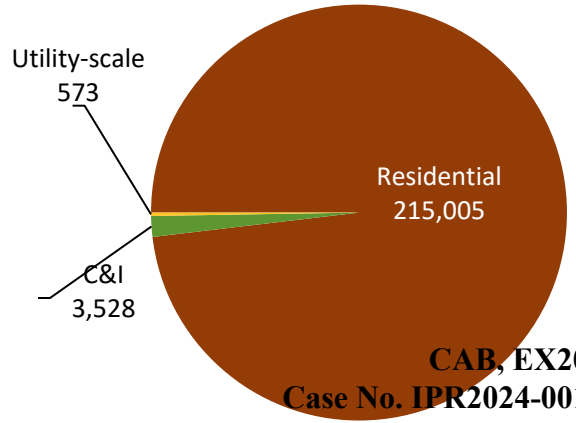
- At the end of 2023, EIA reports that there were 17.9 GW_{ac} (~46 GWh) of cumulative U.S. battery energy storage installations.
- EIA reports that at the end of 2023, 88% of U.S. installed battery energy storage capacity was from utility-scale PV systems.

Cumulative U.S. BESS Installations as of December 2023 (17.9 GWac / ~44 GWh)



- Despite representing only 9% of installed U.S. battery energy storage capacity at the end of 2023, 98% of battery systems—over 215,000 systems—were residential applications.
  - Virtually all distributed BESS and most utility-scale BESS are co-located with PV.
  - In 2023, EIA reports that the U.S. installed 67,700 battery energy storage systems, of which 66,700 were residential, 650 were C&I, and 122 were utility-scale.

Cumulative U.S. BESS Installations as of December 2023 (219,000 systems)



Sources: EIA, "Electric Power Monthly," forms EIA-023, EIA-826, EIA-860, and EIA-861 (April 2024).

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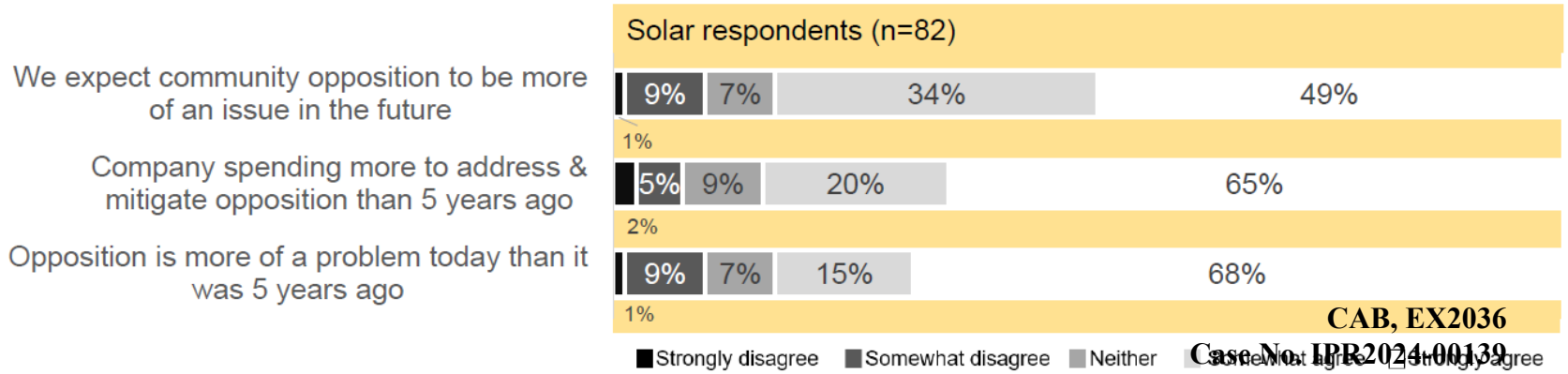
Community Opposition: PV Developer Perspectives

- LBNL conducted a survey of 123 utility-scale wind and solar project developers.
- Local ordinances or zoning, grid interconnection, and community opposition are three leading causes of project cancellations for both wind and solar. Supply chain issues also are a key reason for solar project delays.
- 75% of those surveyed believe that increased community engagement results in fewer project cancellations.

- Opposition to solar and wind has become more prevalent and expensive to deal with than it was 5 years ago. This trend is expected to continue.
- On average, community opposition is expected to delay solar projects by 11 months.
- Those surveyed identified the primary causes of community opposition for solar to be visual concerns, loss of agricultural land, community character, and residential property values.
- 61% of solar developers agreed that if they expect substantial opposition in a given community, they would be unlikely to develop there. Developers also agreed that predicting opposition is difficult.



Source: Wind and Solar Developer Survey, Lawrence Berkeley National Lab, Jan 2024.

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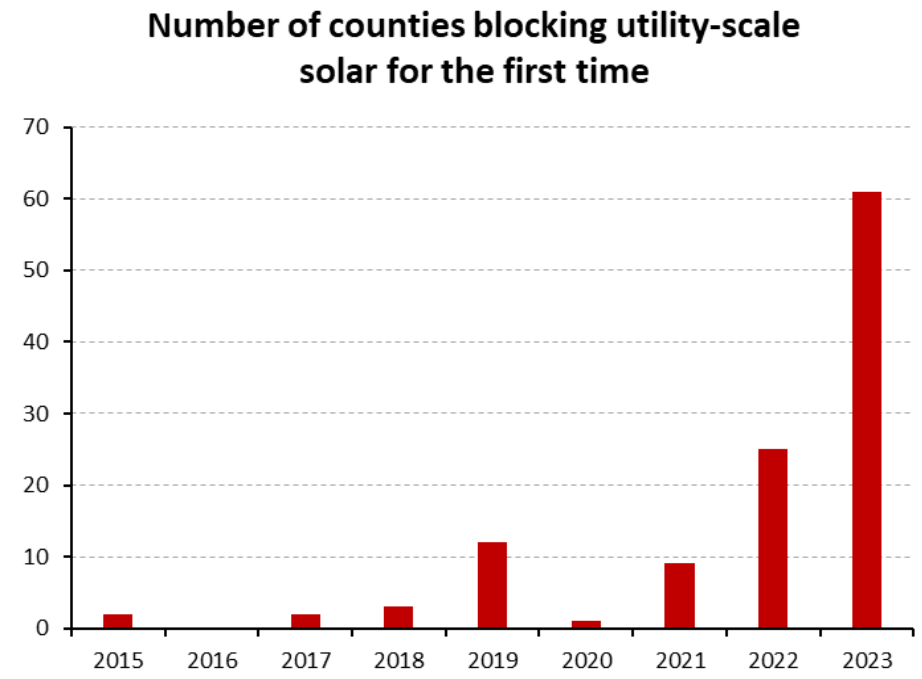
Community Opposition: Quantitative Policy Trends



- 2023 was the first time that the number of counties restricting utility-scale solar projects (61) almost equaled the number of counties adding their first solar farm (62).
- Impediments to clean energy deployment include:
  - Outright bans
  - Moratoriums (counties buying time to write new zoning laws)
  - Height and setback regulations (especially problematic for wind)
  - Noise limits
  - Limits on the amount of agricultural land that can be used for solar
  - Local governments refusing to sign agreements with wind/solar developers
- Large, organized opposition groups (such as Citizens for Responsible Solar and Committee for a Constructive Tomorrow) have initiated local campaigns against solar and have spread misleading claims to bolster opposition.

Sources: Inside how wind and solar energy are being restricted across the US, USA Today, 2/4/24. How we tallied local bans, limits on renewable energy nationwide, USA Today, 2/4/24. How misinformation about solar power hinders the fight against climate change, NPR, 2/18/23. Inside the right-wing conspiracy to thwart the clean energy transition, Canary Media, 3/15/24.

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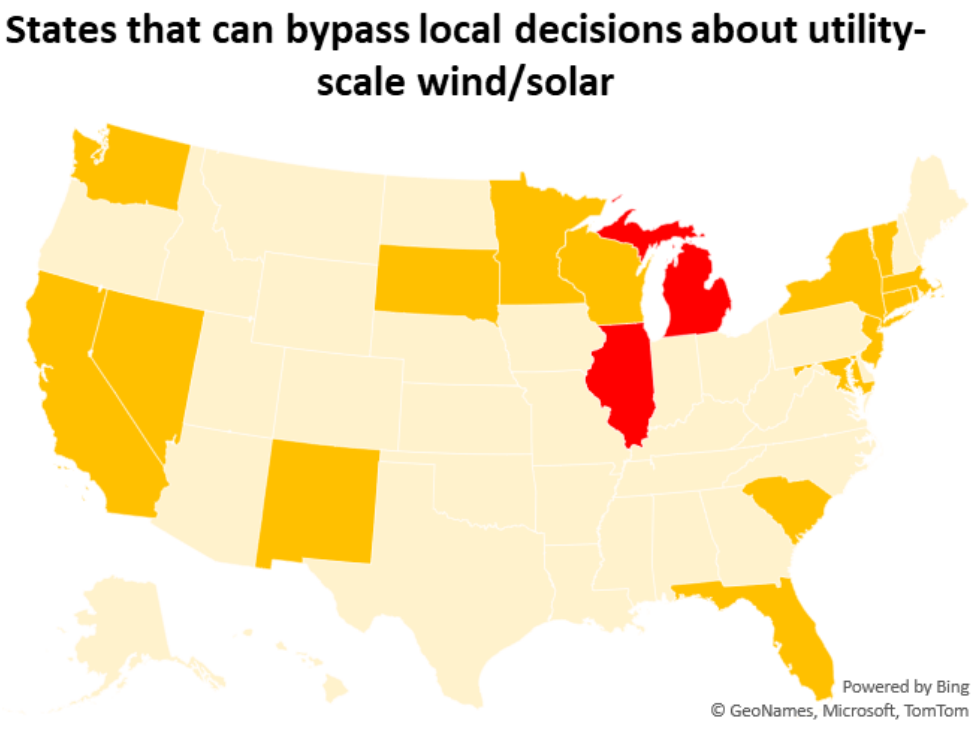
Community Opposition: Counter-Opposition



- Despite vocal opposition groups and restrictive local policies, polls show that most people, regardless of political affiliation, are comfortable living near a wind or solar farm.
  - 75% of those polled by the Washington Post/UMD said they were comfortable living near a field of solar panels.
- Some state governments have laws that can override county-level clean energy bans (dark yellow on the map). Two states enacted override laws in 2023 (red on the map):
  - Illinois enacted a new law blocking any outright ban of wind or solar projects. The law also sets state siting parameters and prohibits counties from adopting more restrictive limits.
  - Michigan passed a clean energy package that gives the state public service commission final say over approval for large-scale wind and solar projects.

Sources: July 13-23, 2023, Washington Post-University of Maryland Climate Poll, The Washington Post, 8/7/23. Some Midwest states look to counter local opposition to wind and solar farm projects, KSUT Public Radio, 3/14/24. "Opposition to Renewable Energy Facilities in the United States", Columbia Law School Sabin Center for Climate Change Law, March 2024.

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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. Market and Policy
7. U.S. PV Imports

- **The median system price of large-scale utility-owned PV systems in 2023 was \$1.27/W_{ac}—relatively flat since 2018.**
- **The median price for residential PV systems reported by EnergySage increased 6.3% y/y to \$2.8/W_{dc}—in-line with mid-2020 price levels.**
- **From H1 2023 to H1 2024, the median reported distributed PV system price across Arizona, California, Massachusetts, and New York:**
  - Decreased 2% to \$4.17/W_{dc} for systems 2.5 to 10 kW
  - Decreased 8% to \$3.46/W_{dc} for systems 10 to 100 kW
  - Increased 4% to \$2.61/W_{dc} for systems 100 to 500 kW
  - Decreased 2% to \$2.23/W_{dc} for systems 500 kW to 1 MW
  - Increased 4% to \$1.65/W_{dc} for systems 1 to 5 MW
  - Decreased 8% to \$1.14/W_{dc} for systems 5 MW to 10 MW

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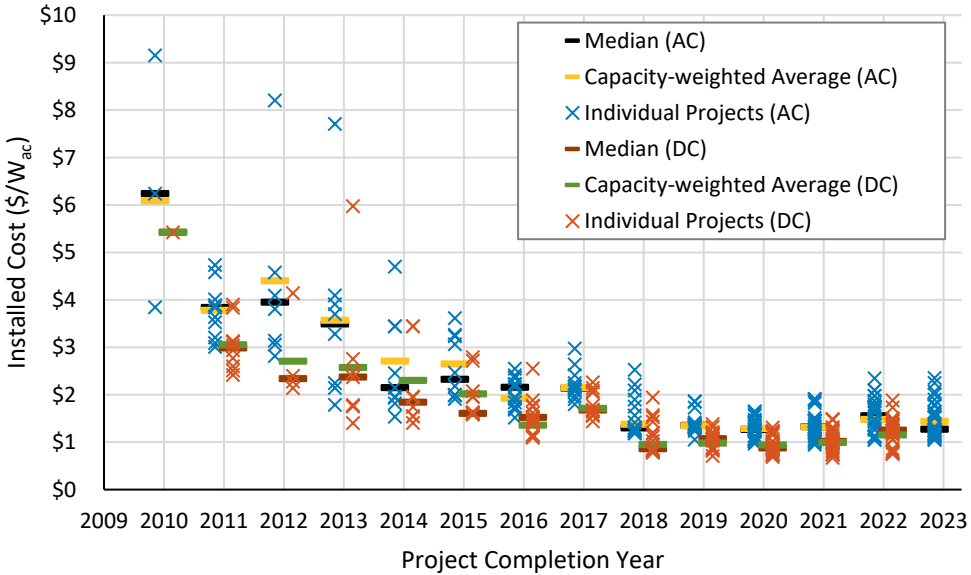
Utility-Owned PV Pricing (>5 MW)



The median system price of large-scale, utility-owned PV systems in 2023 was \$1.27/W_{ac}—relatively flat since 2018.

- The lowest and highest reported prices in 2023 were \$1.05/W_{ac} and \$2.35/W_{ac}, respectively.
- Based on 2022 AC and DC system sizing for this dataset, the \$1.27/W_{ac} would translate into \$0.99/W_{dc}.

Note: Values represent a select dataset of utility-scale PV systems owned by 25 regulated utilities for 233 projects totaling 11.8 GW_{ac} installed from 2010 to 2023.

Sources: FERC Form 1 filings from the following utilities: Alabama Power, Allete, Arizona Public Service, Avangrid, Dominion, DTE, Duke Energy, El Paso Electric, Entergy, Florida Power and Light, Georgia Power, Indiana Michigan Power, Kentucky Utilities, MidAmerican, Nevada Power, Pacific Gas and Electric, Public Service of New Mexico, Southern California Edison, Tampa Electric, Tucson Electric, United Illuminating, Union Electric, UNS Electric, Virginia Electric, and Wisconsin Public Service.

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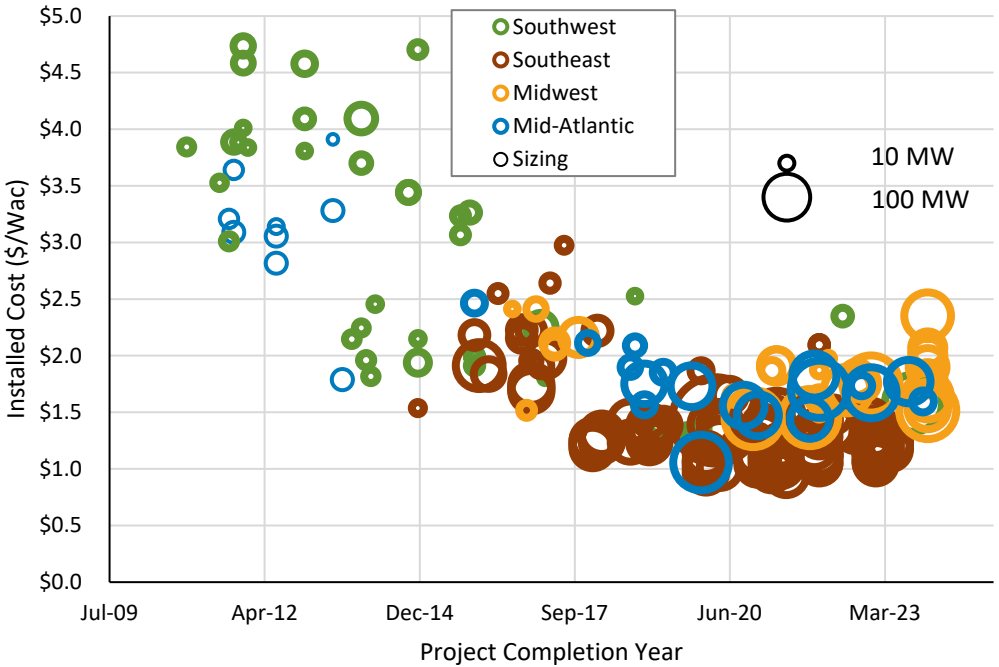
Utility-Owned PV Pricing (>5 MW)



- Project prices in the Southeast were, on average, lower than the rest of the country, with a capacity-weighted average of \$1.2/W_{ac} in 2023, compared to \$1.8/W_{ac} in the Midwest and Mid-Atlantic and \$1.6/W_{ac} in the Southwest.

Note: Values represent a select data set of utility-scale PV systems owned by 25 regulated utilities for 233 projects totaling 11.8 GW_{ac} installed from 2010 to 2023.

Sources: FERC Form 1 filings from the from the following utilities: Alabama Power, Allete, Arizona Public Service, Avangrid, Dominion, DTE, Duke Energy, El Paso Electric, Entergy, Florida Power and Light, Georgia Power, Indiana Michigan Power, Kentucky Utilities, MidAmerican, Nevada Power, Pacific Gas and Electric, Public Service of New Mexico, Southern California Edison, Tampa Electric, Tucson Electric, United Illuminating, Union Electric, UNS Electric, Virginia Electric, and Wisconsin Public Service.

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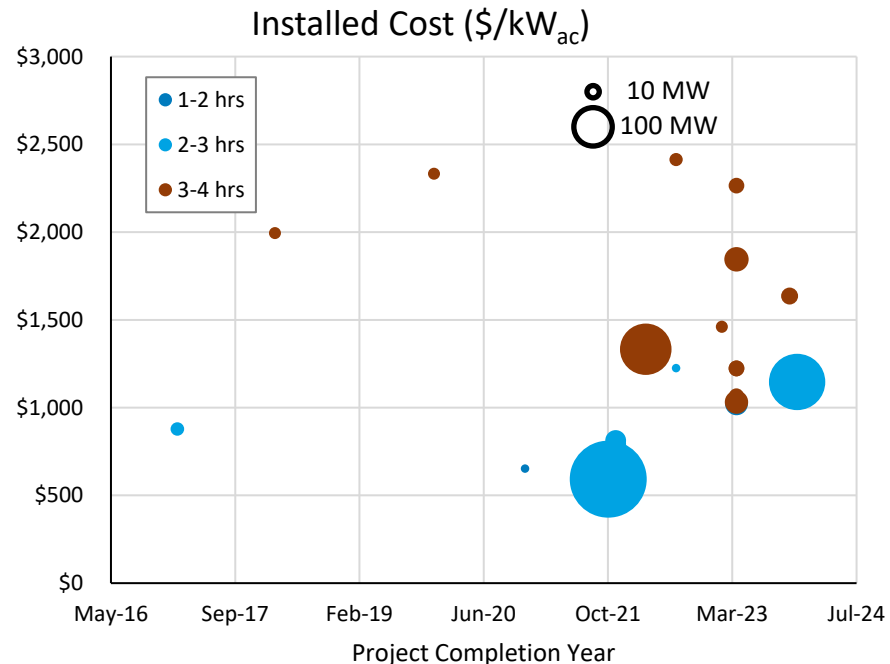
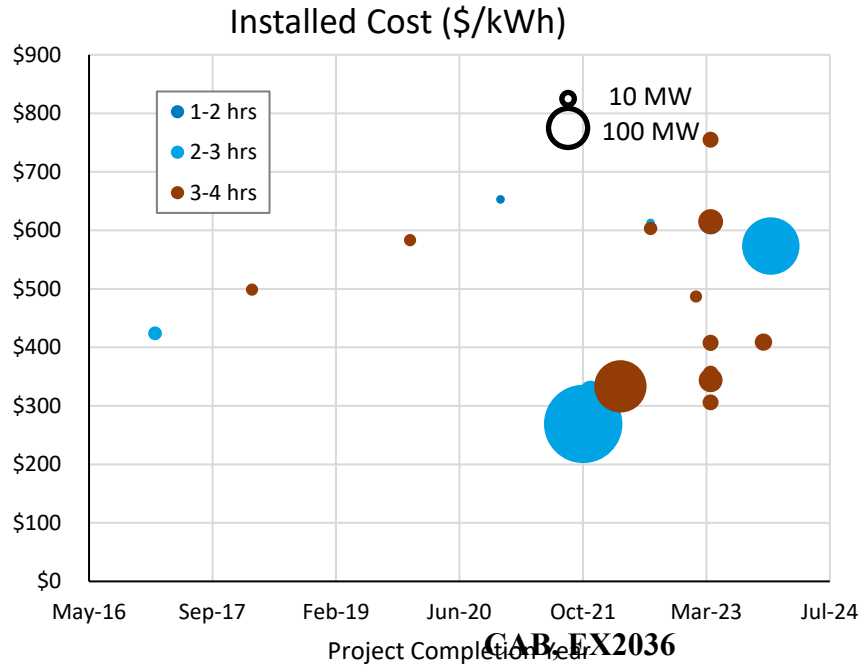
Utility-Owned BESS Pricing (>5 MW)

- There is a wide variety of reported pricing for utility-owned battery storage systems, even accounting for differences in the hours of storage.
- In general, the price of 3–4 hour battery systems fell from $500–600/kWh in 2018–2019 to $400–$500/kWh in 2022–2023.





Note: Values represent a select dataset of utility-scale PV systems owned by 8 regulated utilities for 21 projects totaling 1.2 GW$_{ac}$ installed from 2010 to 2023.

Sources: FERC Form 1 filings from the from the following utilities: Arizona Public Service, Duke Energy-Indiana, Florida Power and Light, Nevada Power, Pacific Gas & Electric, Tampa Electric, Virginia Electric, and Wisconsin Public Service.

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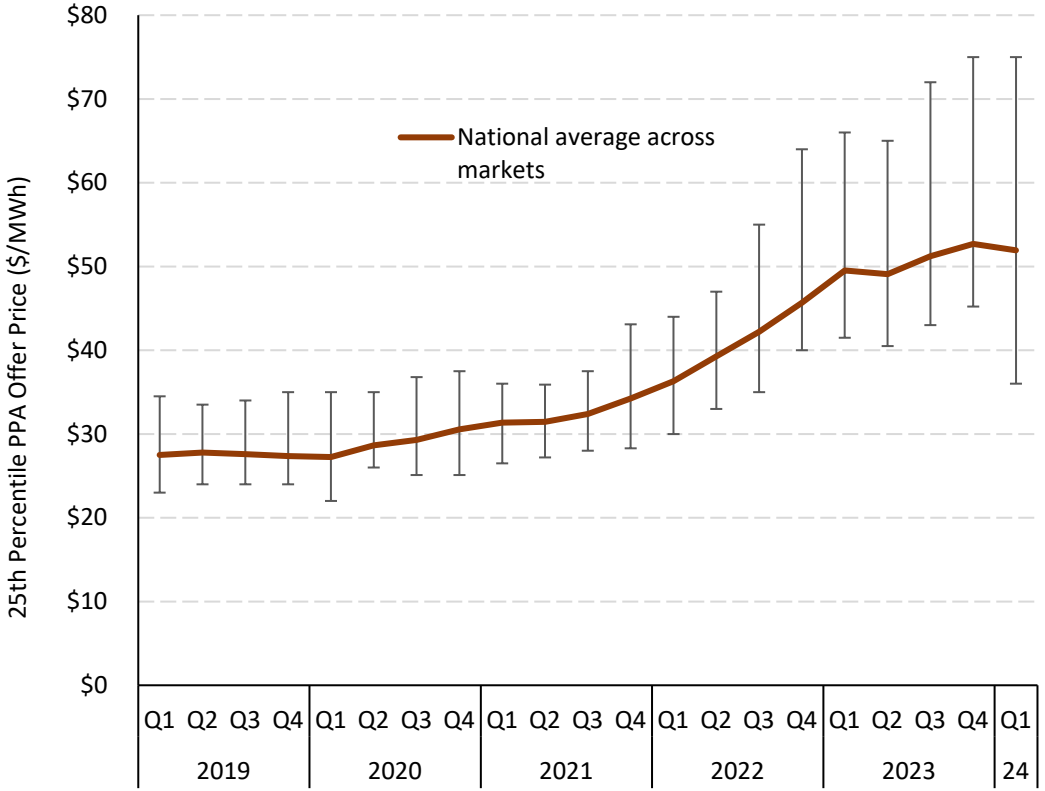
U.S. Solar PPA Pricing (LevelTen)



- LevelTen reports that the U.S. utility-scale PV PPA prices fell approximately 1% q/q, though is still up 5% y/y.
- LevelTen reports that the fall in natural gas prices along with the oversupply of PV panels put downward pressure on PPA prices, allowing developers to reduce pricing.
  - However, they report that lower pricing may be short-term due to continued high inflation rates, a delay in interest rate cuts, and potentially more stringent regulations on U.S. imports.
- LevelTen reported that California ISO was the lowest priced market in Q1 2024, due to several new projects under 50 MW. PJM continued to be one of the more expensive markets, due to higher-priced RECs, interconnection challenges, and ongoing reform in the capacity market.

Source: LevelTen, PPA Price Index.

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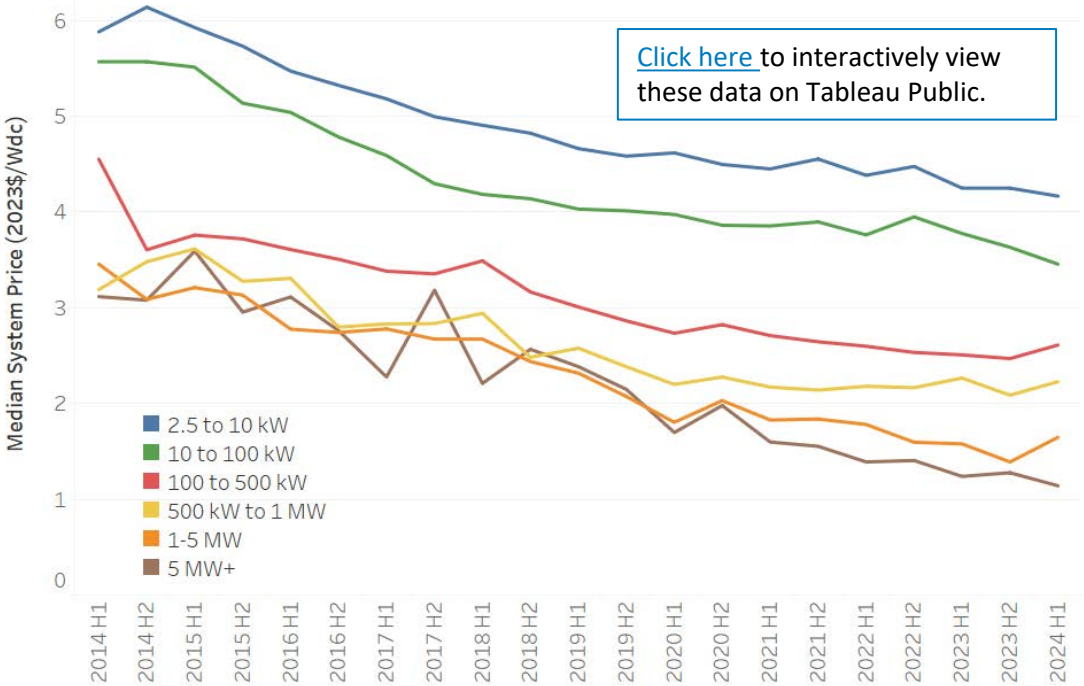
Distributed PV System Pricing from Select States



2024 MW data YTD: Arizona (45.5), California (442), Massachusetts (10.3), New York (137).
Note: System prices above $10/W and below $0.75/W were removed from the dataset. The volatility in median system price among the largest systems is due to the relatively small number of systems deployed each year.
Sources: Arizona Goes Solar (2/1/24); California Distributed Generation (3/31/24); Massachusetts Lists of Qualified Generation Units (2/22/2024); Solar Electric Programs Reported by NYSERDA (4/1/24).

From H1 2023 to H1 2024 (partial), the median reported standalone (no energy storage) distributed PV system price—**in 2023 (inflation-adjusted) dollars**—across Arizona, California, Massachusetts, and New York:

- Decreased 2% to $4.17/$W_{dc}$ for systems 2.5 to 10 kW
- Decreased 8% to $3.46/$W_{dc}$ for systems 10 to 100 kW
- Increased 4% to $2.61/$W_{dc}$ for systems 100 to 500 kW
- Decreased 2% to $2.23/$W_{dc}$ for systems 500 kW to 1 MW
- Increased 4% to $1.65/$W_{dc}$ for systems 1 to 5 MW
- Decreased 8% to $1.14/$W_{dc}$ for systems 5 MW+.

Adjusting for inflation reveals the generally decreasing distributed PV system price trends in real dollars over the past several years of economic volatility.

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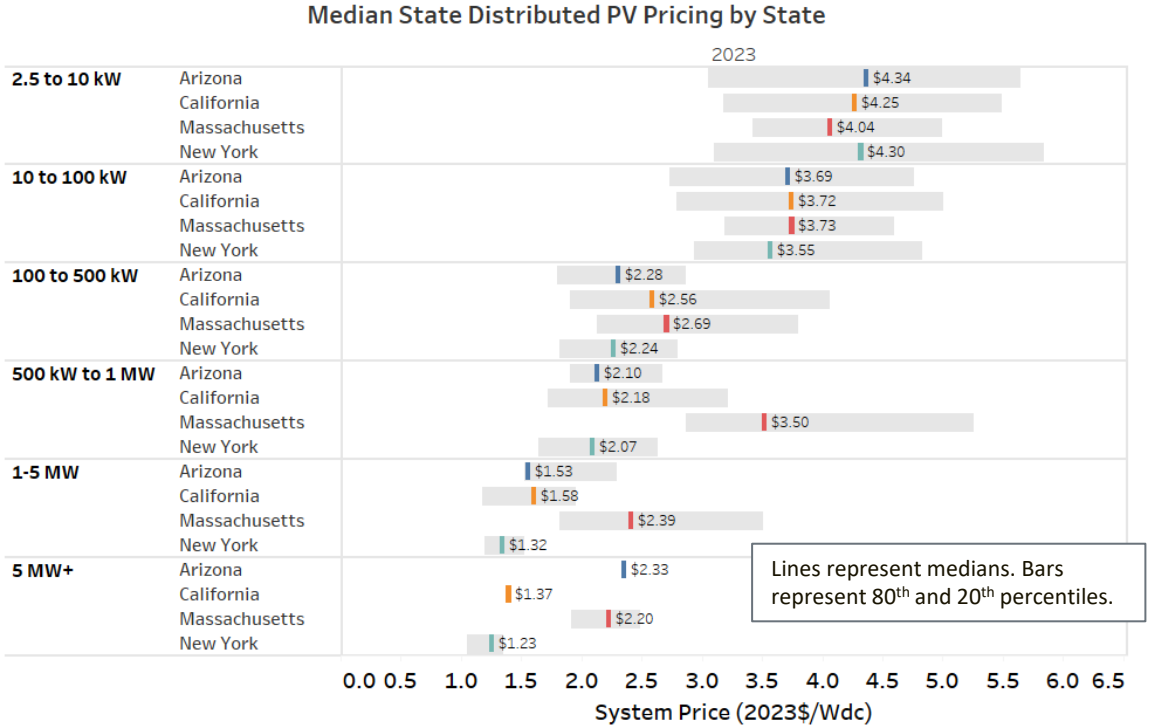
Distributed PV System Pricing from Select States, 2023

Click here to interactively view these data on Tableau Public.



2023 MW data : Arizona (297), California (2,480), Massachusetts (158), New York (748).
Note: System prices above $10/W and below $0.75/W were removed from the dataset.
Sources: Arizona Goes Solar (2/1/24); California Distributed Generation (3/31/24); Massachusetts Lists of Qualified Generation Units (2/22/2024); Solar Electric Programs Reported by NYSERDA (4/1/24).

In addition to price differences based on system size, there is variation in the price of standalone (no energy storage) distributed PV systems between states and within individual markets.

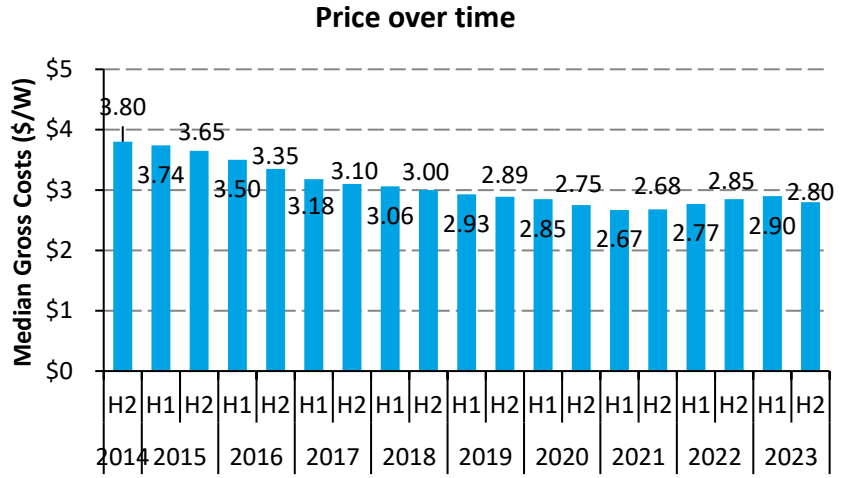
Dollar-per-watt prices generally decrease as system size increases.

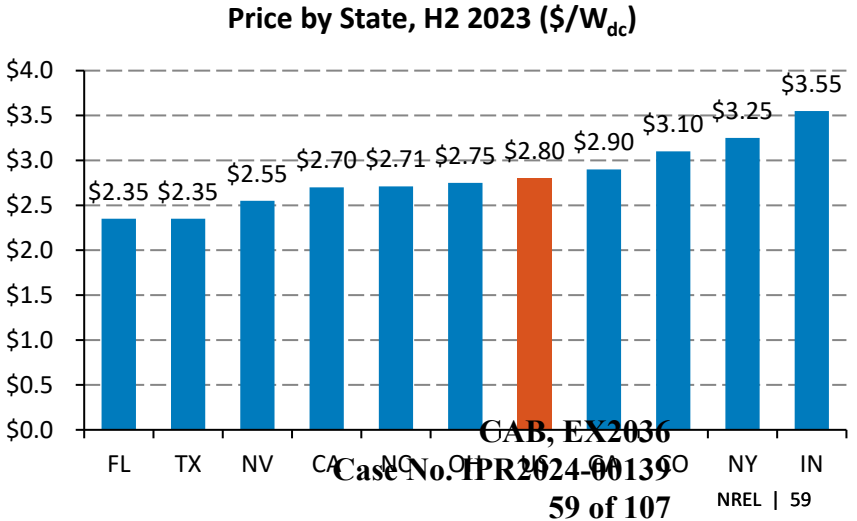
For systems of 2.5–10 kW, median price changes varied between 2022 and 2023:

- -5% in Arizona, -5% in California, -1% in Massachusetts, -1% in New York.

Residential System Price Reported by EnergySage

- The median price for residential PV systems reported by EnergySage fell 1.8% y/y—in-line with mid-2020 price levels.
  - Some of the price decrease may be explained by having the largest average system size on record—11.3 kW_{dc} —allowing project to benefit from economies of scale.
- Residential system price varied by state. In H2 2023, the median price of a residential system in Indiana was 51% higher than the median price of a residential system in Florida.
  - Part of the price disparity between states may be due to differences in average system size (14.3 kW in Florida versus 12 kW in Indiana), though other factors also play a role.
- EnergySage reported that the most popular loan (with a 25-year term and a 3.99% interest rate) cost 47% higher than the cash value of the PV system.





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

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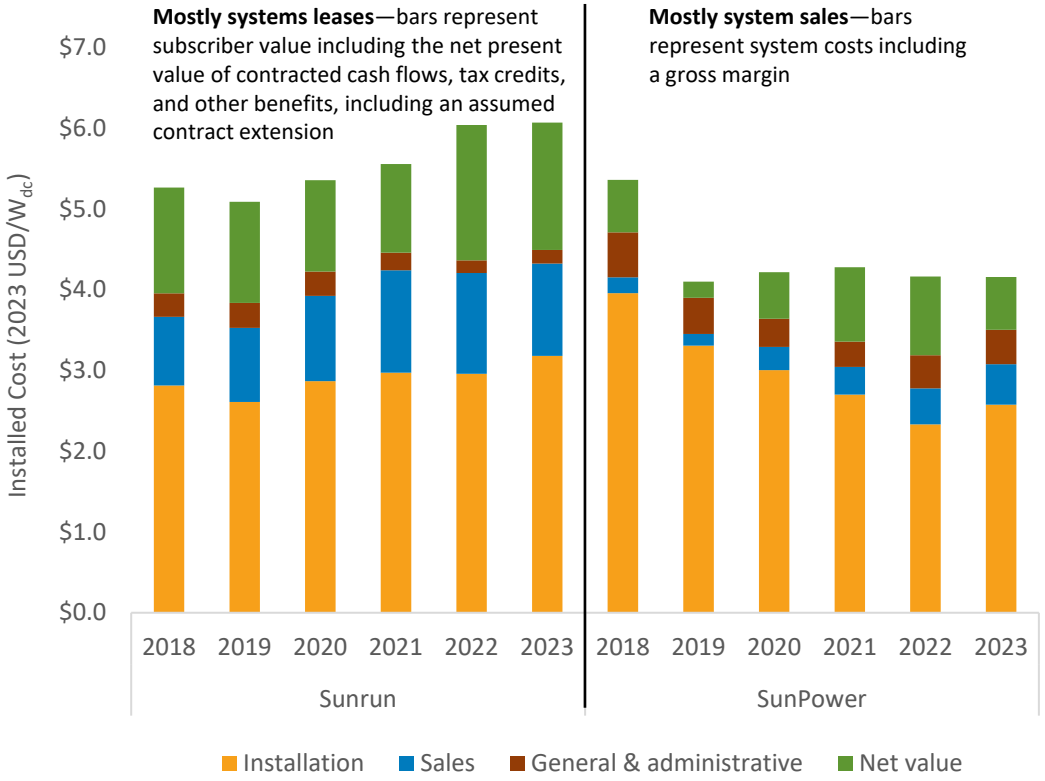
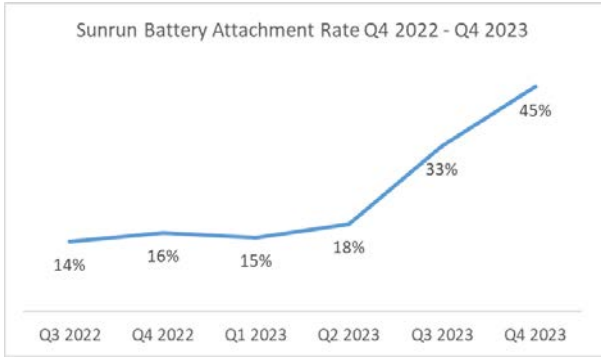
Sunrun and SunPower Cost and Value, 2018–2023



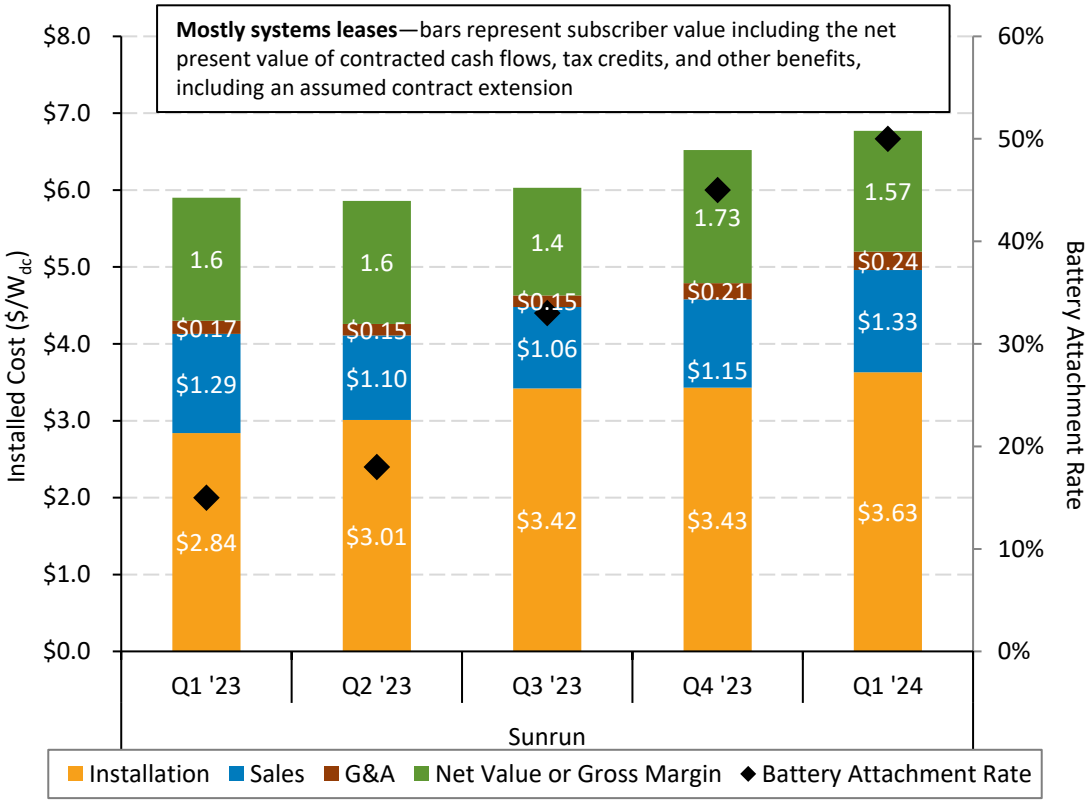
- After falling in 2019, the prices of residential systems installed by national integrators Sunrun and SunPower—adjusted for inflation—rose or stayed relatively flat.
- Recent increases in installation costs are due in part to increasing battery attachment.



- Increases in sales costs also contributed to higher prices.
- General and administrative costs exhibited a generally decreasing trend across companies.

Sources: Corporate filings.

Large Residential Installer Cost and Value, Q1 2024



Sources: Corporate filings.

Large residential installer Sunrun reported a system value change of +15% y/y and +4% q/q in Q1 2024.

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

- Increasing electricity demand and retail rates
- High interest rates
- Increasing battery attachment rates (batteries add cost but can yield higher margins)
- Implementation of virtual power plant programs

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

- Investment Tax Credit adders
- Declining equipment prices
- Increased operating efficiency
- Increased use of SolarAPP+ to reduce time and cost associated with permitting and interconnection

* SunPower results for Q1 2024 were not available as of May 2024.

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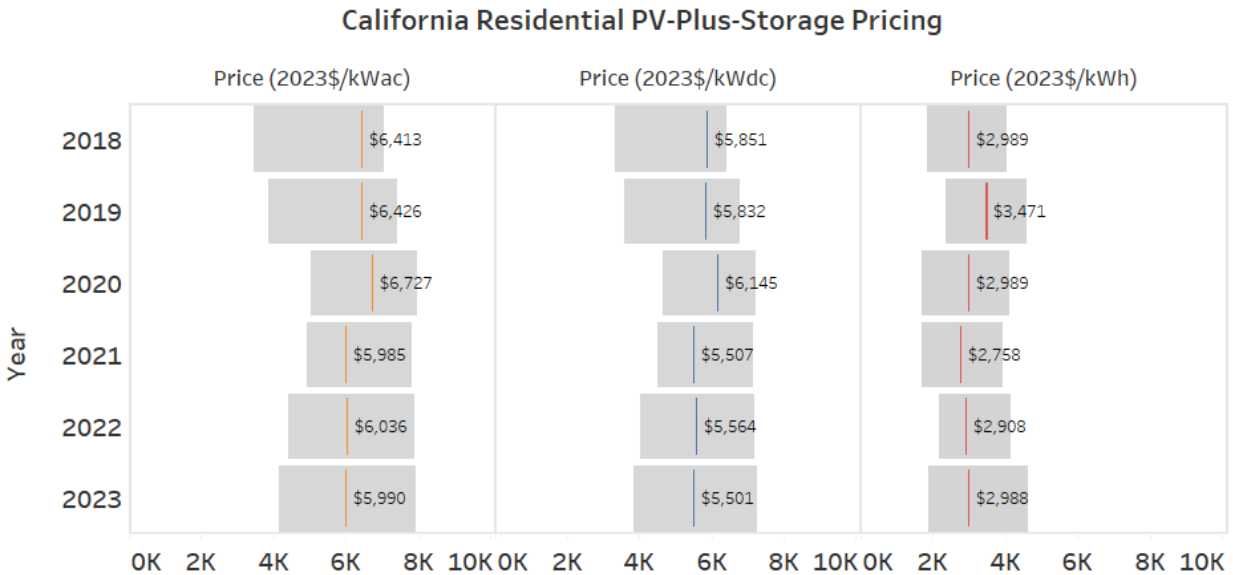
Residential PV + Storage Pricing in California

Click here to interactively view these data on Tableau Public.



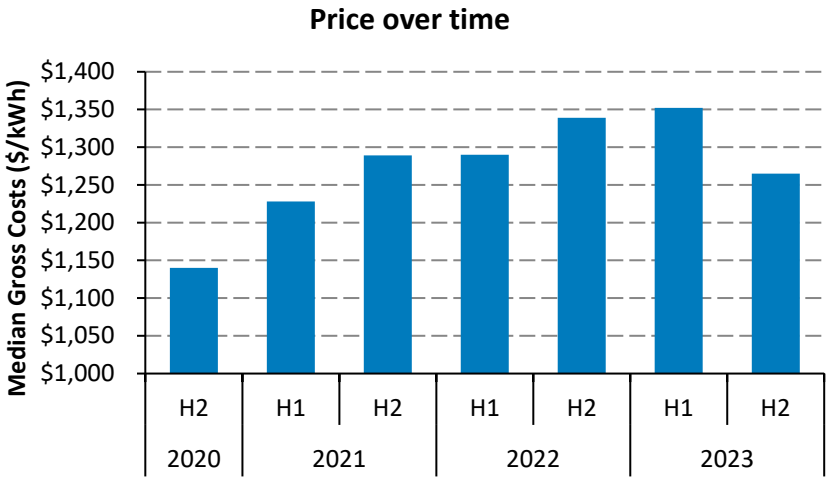
Lines represent medians. Bars represent 80th and 20th percentiles.

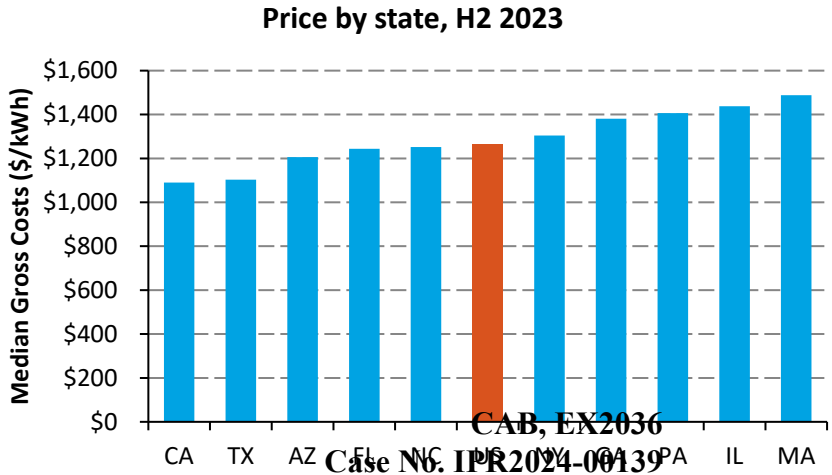
- In 2023, residential PV-plus-storage systems in California had a median system price of \$2,988/kWh, or \$5,990/kW_{ac} (\$5,501/kW_{dc})—comparable to 2022 prices when adjusted for inflation.
  - Most of these systems offer 2–3 hours of storage.
  - Units represent total system price divided by the capacity of the battery (kWh) or the capacity of the PV system (kW).

The data are filtered to PV system sizes of 10 kW_{dc} or smaller.
Source: California Distributed Generation (3/31/24).

Residential Storage Price Reported by EnergySage

- The median price for residential energy storage reported by EnergySage fell 5.5% y/y.
  - This is the first reported decrease in the median price of energy storage since EnergySage started reporting in 2020.
  - EnergySage attributed the drop in price to a 19% decrease in quoted storage prices in California, where there has been a 45% storage attachment rate since NEM 3.0 went into effect.
  - Nationally, 25% of systems sold on the EnergySage platform in H2 2023 included a battery, compared to 10% in H1 2023.
- Residential storage system price varied by state. In H2 2023, the median price of a residential storage system in Illinois and Massachusetts were 36% higher than the median price of a residential storage system in California and Texas.
  - In the EnergySage dataset, the median cost of a battery in the top ten states ranged from $11,000 to $17,000.





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

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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. Market and Policy
7. U.S. PV Imports

- **In 2023, global PV shipments were approximately 564 GW—an increase of 100% from 2022.**
- **In 2023, 98% of PV shipments were mono c-Si technology, compared to 35% in 2015.**
  - N-type mono c-Si grew to 63%—up from 51% in 2022 (and 5% in 2019).
- **In 2023, the average efficiency of modules installed in the United States was approximately 20.7% for c-Si and 18.6% for CdTe.**
- **In 2023, the United States produced about 7.2 GW of PV modules.**
- **Since IRA's passage, over 70 GW of manufacturing capacity has been added across the solar supply chain (from facilities announced pre- and post-IRA), including more than 25 GW of new module capacity.**

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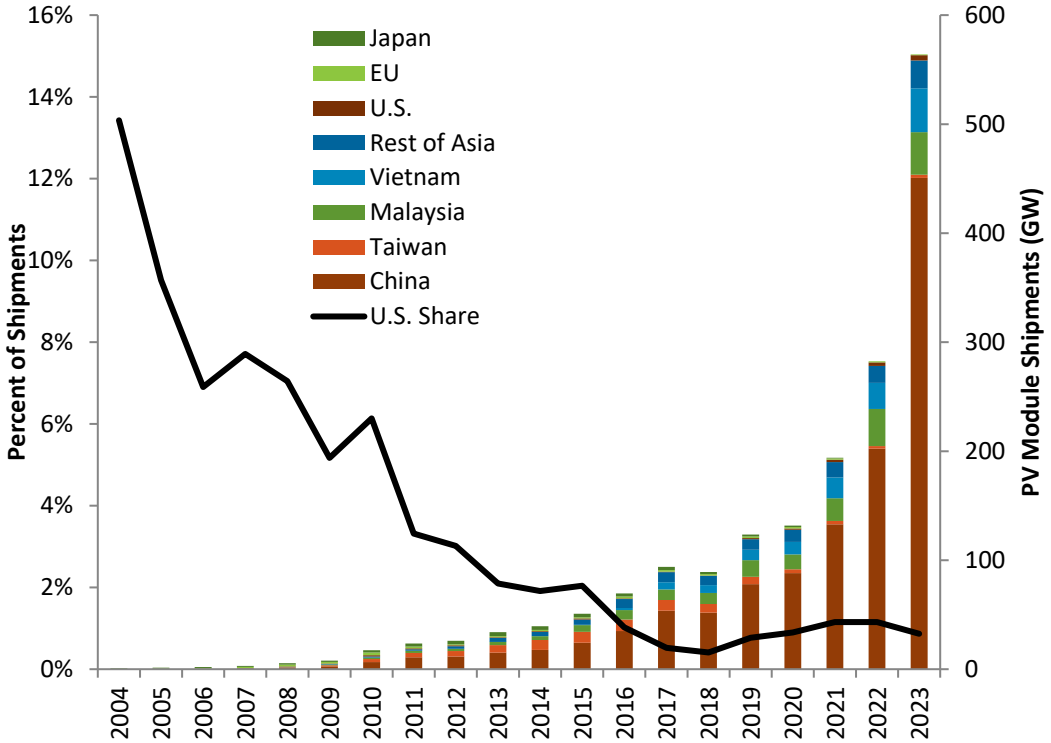
Global Annual PV Shipments by Region*



- SPV Market Research reported that 2023 global PV shipments were approximately 564 GW—an increase of 100% from 2022.
  - 88% of the increase came from China, with the remainder mostly coming from Southeast Asia, but also India and the United States.
- From 2004 to 2023:
  - The U.S.-manufactured percentage of global PV shipments declined from about 13% to 0.9%.
  - The Chinese-manufactured share of global PV shipments grew from 1% to 80%.
  - Together the Malaysian-, Vietnamese-, and South Thai-manufactured percentage of global PV shipments went from 0% to 17%.

*** Note:** excludes inventory sales and outsourcing

Source: Paula Mints. "Photovoltaic Manufacturer Capacity, Shipments, Price & Revenues 2023/2024." SPV Market Research. Report SPV-Supply12. April 2024.

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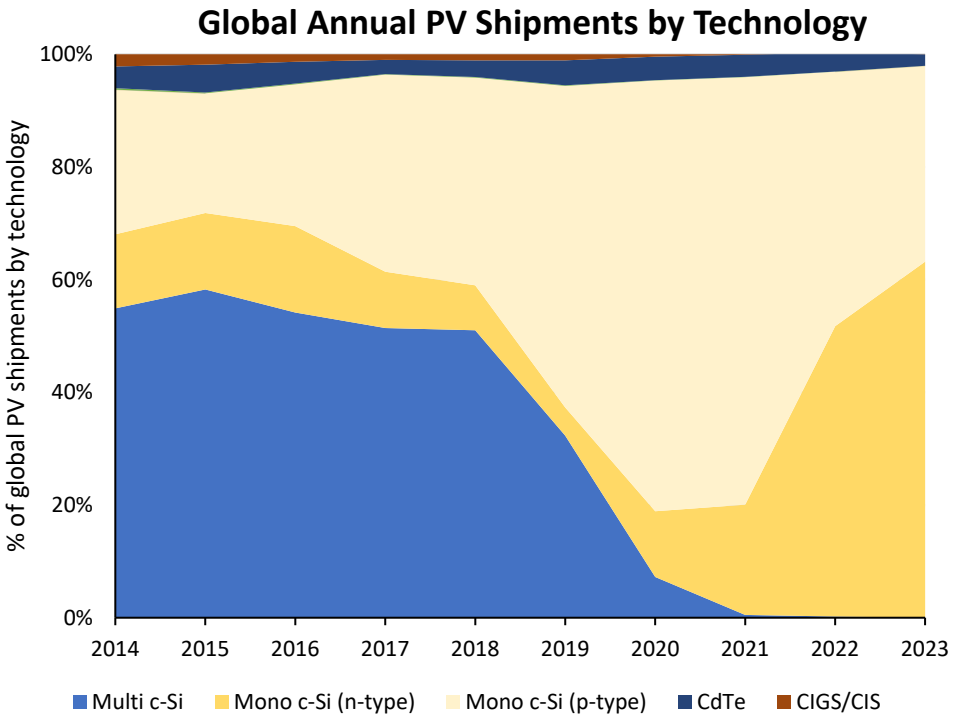
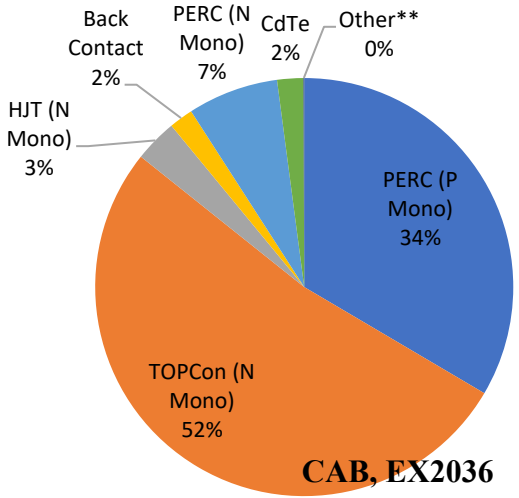
Global Annual PV Shipments by Technology*



- In 2023, 98% of PV shipments were mono c-Si technology, compared to 35% in 2015.
  - N-type mono c-Si grew to 63%—up from 52% in 2022 (and 5% in 2019).
- TopCon was the leading cell type in 2023, followed by Mono P PERC, Mono N PERC, and HJT.



***Notes:** excludes inventory sales and outsourcing
Source: Paula Mints. "Photovoltaic Manufacturer Capacity, Shipments, Price & Revenues 2022/2023." SPV Market Research. Report SPV-Supply12. April 2024.

** includes a-Si, CIS/CIGS, TOPCon (P Mono), and Multi PERC.

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Global Leading PV Manufacturers by Shipments

Ranking	2017	GWdc	2022	GWdc	2023	GWdc
1	JA Solar	6.5	Tongwei	38.1	Tongwei	65.5
2	Canadian Solar	5.4	JA Solar	36.2	Jinko Solar	60.2
3	Zhongli Talesun	5.0	Aiko	30.7	LONGi	58.4
4	Jinko Solar	4.9	LONGi	29.2	Trina Solar	55.9
5	Trina Solar	4.8	Jinko Solar	23.9	JA Solar	51.2
6	LONGi	4.5	Canadian Solar	16.8	Aiko Solar	36.8
7	Hanwha Q Cells	4.2	Trina Solar	14.5	Canadian Solar	30.7
8	Tongwei	3.8	SolarSpace	11.6	Astroenergy	19.5
9	Motech	3.2	Zhongli Talesun	9.8	Risen	18.5
10	Aiko	3.1	First Solar	9.1	Runergy	17.0
Total Above		**45.5**		**220.0**		**413.7**
Total Shipped		**93.9**		**283.1**		**564.0**

- From 2017 to 2023, shipments from the top 10 PV manufacturers grew from 46 GW to 414 GW, with some companies shipping more than 60 GW annually.
- Approximately half of 2023 shipments came from the top five companies.

***Notes:** excludes inventory sales and outsourcing

Source: Paula Mints. "Photovoltaic Manufacturer Capacity, Shipments, Price & Revenues 2022/2023." SPV Market Research. Report SPV-Supply12. April 2024.

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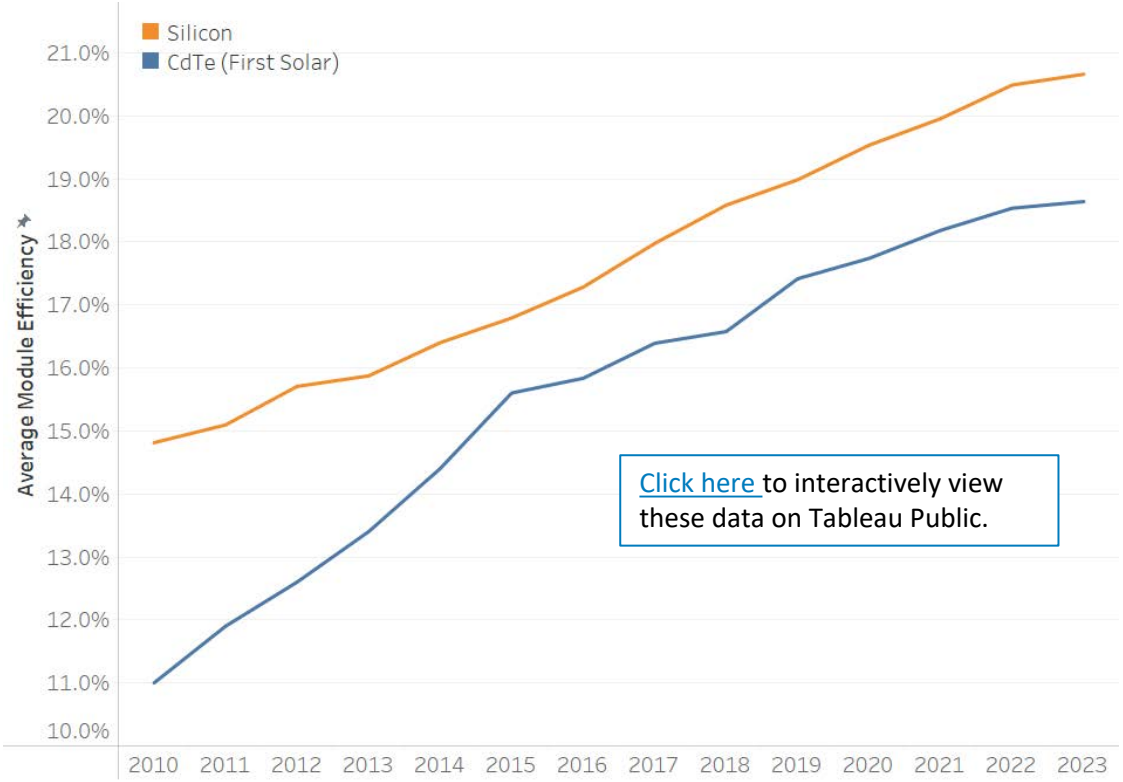
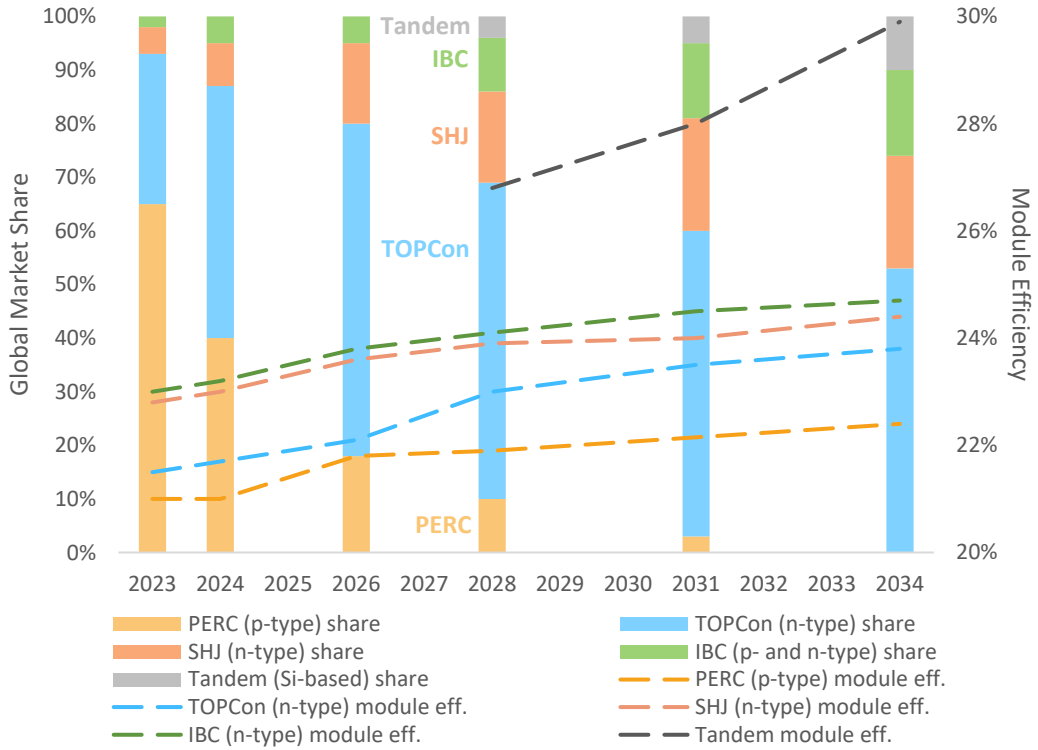
PV Module Efficiency Improvements



- From 2010 to 2023, the weighted average efficiency of installed modules increased:
  - From 14.8% to 20.7% for crystalline-silicon technologies (in California and New York).
  - From 11.0% to 18.6% for cadmium telluride (CdTe) (in the United States).
- Efficiency increases occurred through incremental improvements in given technologies as well as changes in technology market share.
  - For example, in the mid-2010s, the share of higher-efficiency monocrystalline-silicon modules overtook the share of lower-efficiency multicrystalline-silicon modules, contributing to the continual rise of average crystalline-silicon module efficiency.

Sources: CdTe: First Solar Investor Relations, average module efficiency produced. c-Si: California Distributed Generation (3/31/24); Solar Electric Programs Reported by NYSERDA (3/31/24).

Silicon Module Market Share and Efficiency Projections



- Projections from the International Technology Roadmap for Photovoltaics (ITRPV) show n-type and tandem module technologies replacing p-type passivated emitter and rear contact (PERC) technology globally over the next decade.
  - TOPCon grows most rapidly, peaking at 62% of market share in 2026.
  - Interdigitated back contact (IBC) and silicon heterojunction (SHJ) combined reach a 20% share in 2026, surpassing PERC.
  - Silicon-based tandem cells enter the market in 2028 and reach a 10% share in 2034.
  - The projected technology transition is much faster in the 2024 ITRPV than in the 2023 ITRPV, e.g., PERC still has 50% market share in 2026 in the older projection vs. 18% in the newer.
- Module efficiencies are projected to rise for all technologies.
  - Tandem efficiency grows fastest, gaining 3 percentage points between 2028 and 2034 and reaching 29.9%.
  - TOPCon, SHJ, and IBC all gain ~2 percentage points between 2023 and 2034, reaching 23.8%, 24.4%, and 24.7%, respectively.

Source: International Technology Roadmap for Photovoltaics (ITRPV), 15th Edition, Key Findings and Selected Report Presentation, March 2024.

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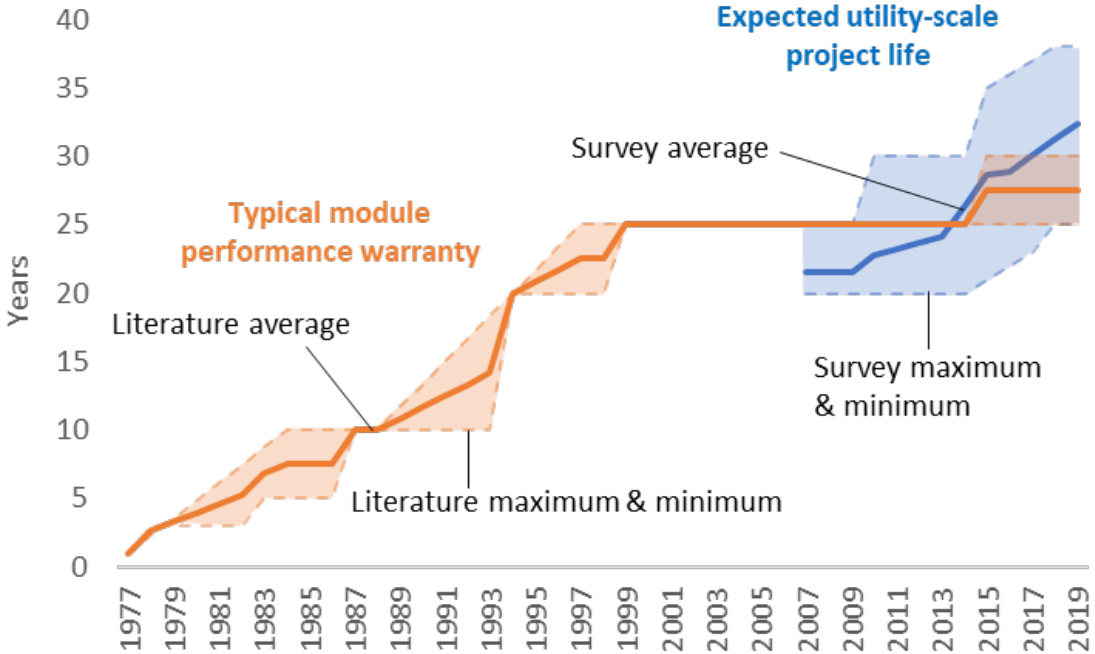
Increased PV Module and System Lifetimes



- The expected lifetimes of PV modules and systems increased dramatically over the past several decades.
- Typical module performance warranties increased from 1 year in 1977 to 25–30 years in 2019.
  - Module performance warranties guarantee a percentage of original power remaining (typically 80%–90%) after a specified number of years.
- Average lifetimes for utility-scale PV systems expected by U.S. solar industry professionals increased from 21.5 years in 2007 to 32.5 years in 2019.
  - Systems are now generally expected to outlast module performance warranties by at least several years.

Typical module performance warranties are derived from product specifications as analyzed by two separate research groups (Jordan et al. 2022, Peters et al. 2021); the literature averages represent the averages of values from those two sources for each given year, while the higher values between the two sources are the maximums and the lower values are the minimums. Expected utility-scale project lifetimes are derived from a survey of solar industry professionals and documents, resulting in 19 data points (LBNL 2020).

Sources: Jordan et al., "Photovoltaics module reliability for the terawatt age," *Progress in Energy*, 2022; Peters et al., "The value of stability in photovoltaics," *Joule*, 2021; LBNL Benchmarking Utility-Scale PV Operational Expenses and Project Lifetimes: Results from a Survey of U.S. Solar Industry Professionals, 2020.

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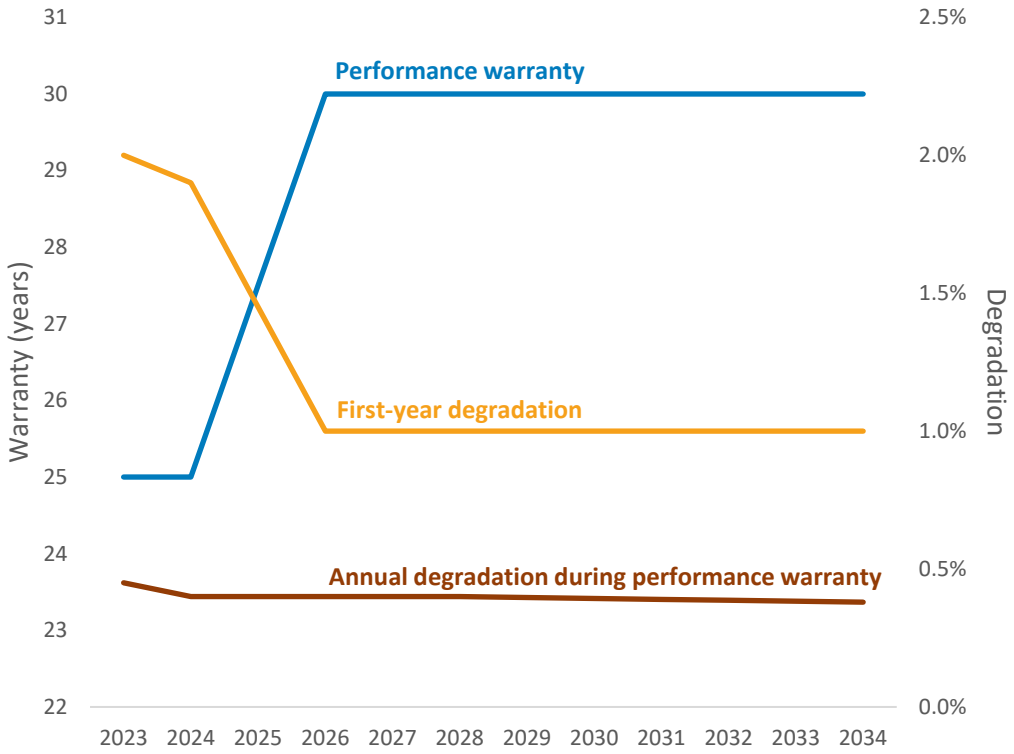
Silicon Module Warranty and Degradation Projections



- Projections from the ITRPV show improvements in expected crystalline-silicon module reliability over the next decade.
  - Performance warranties rise from 25 years in 2023 to 30 years in 2026.
  - Initial degradation after the first year of module operation falls from 2.0% in 2023 to 1.0% in 2026.
  - Annual degradation during the module warranty period declines slightly from 0.45% in 2023 to 0.38% in 2034.

Source: International Technology Roadmap for Photovoltaics (ITRPV), 15th Edition, Key Findings and Selected Report Presentation, March 2024.

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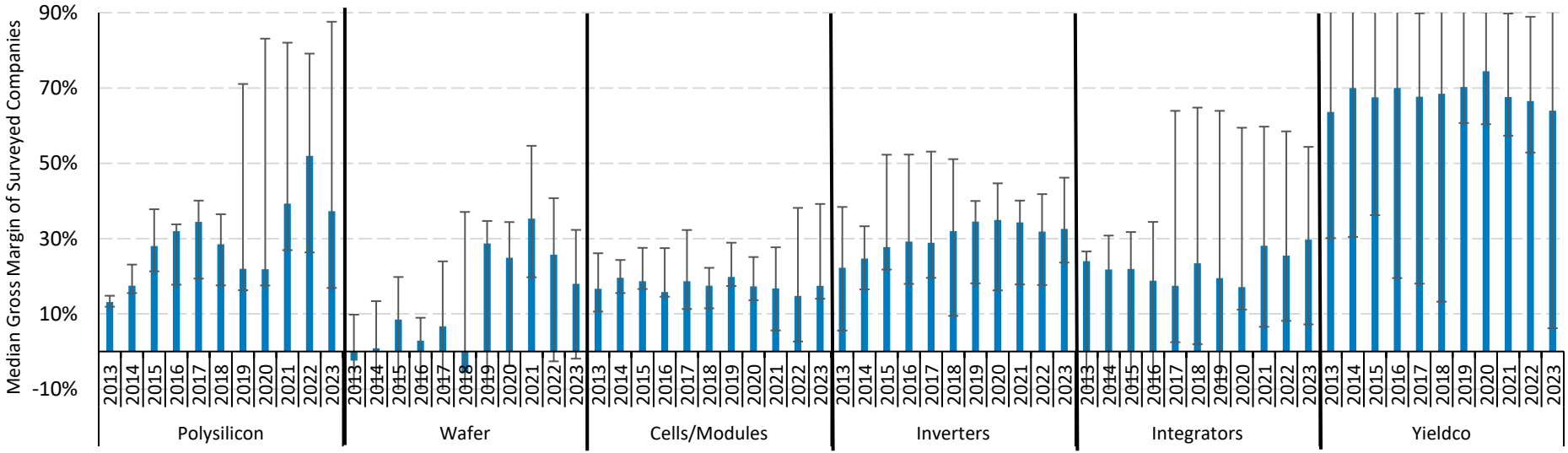
Gross Margin Across Supply Chain

- In 2023, gross margins contracted for polysilicon and wafer producers and kept fairly even for other parts of the PV supply chain, despite falling prices.
- Many companies have vertically integrated to hedge against major price changes.



Sources: Company figures from public filings and finance.yahoo.com. Error bars represent high and low values of surveyed companies. Companies surveyed are Polysilicon: GCL Poly, REC Silicon, Wacker Chemie, Ferroglobe, Xinte, Daqo; Wafers: ReneSola, Wafer Works Corp, SAS, Danen Technology Group, Green Energy Technology Inc; Zhonghuan, Hoyuan Green Energy Co., Ltd.; Cells/Modules: First Solar, JA Solar, LONGi, Tongwei, Trina Solar, Canadian Solar, Risen, Aiko, Jinko Solar, DMEGC; Inverters: SolarEdge, Enphase, SMA Solar, Advanced Energy Industries; Integrators: Real Goods Solar, SolarCity, Vivint Solar, Sunrun, SunPower, Sunworks, Emeren, Isun, SPI, Enlight Renewable Energy, Sunnova; IPP/Yieldco: Brookfield Renewable Partners, Algonquin Power & Utilities Corp, Clearwater Energy, Nextera Energy Partners, Northland Power, Pattern Energy, Terraform Power, TransAlta Renewables.

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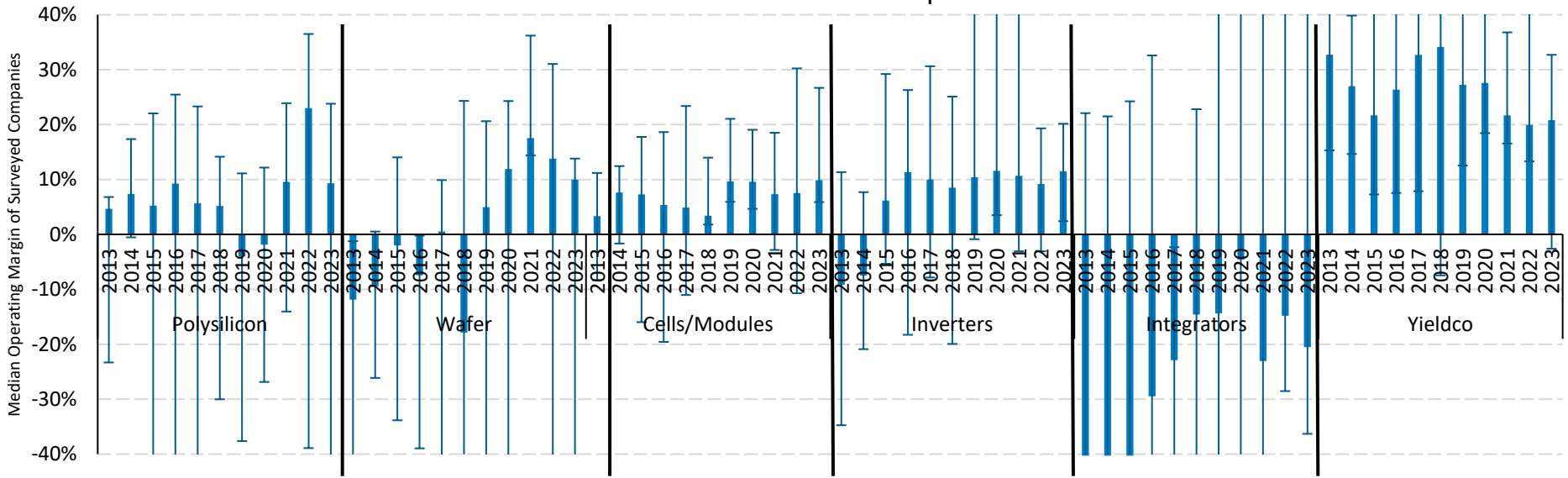
Operating Margin Across Supply Chain

- In 2023, solar companies, on average, maintained operational profitability, with the exception of integrators.
- However, financing costs are in addition to operational activities and so companies may need higher margins to attract new investors into the space.



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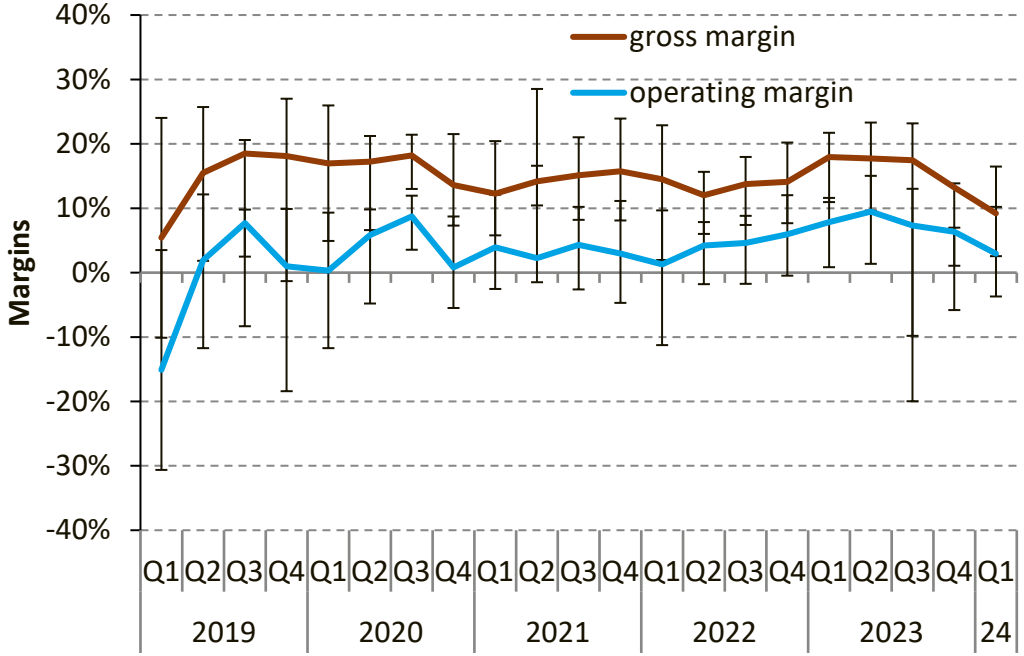
PV Manufacturers' Margins



- PV manufacturers, on average, experienced their third straight quarter of margin declines in Q1 2024, as falling prices and softer than expected demand cut into profits.
- Despite the declines, most large manufacturers have remained profitable through Q1 2024.
- First Solar's gross margin remained above 40%, and its operating margin remained above 30% for the third straight quarter.

Lines represent the median, with error bars representing 80th and 20th percentiles for the following companies in Q4 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.

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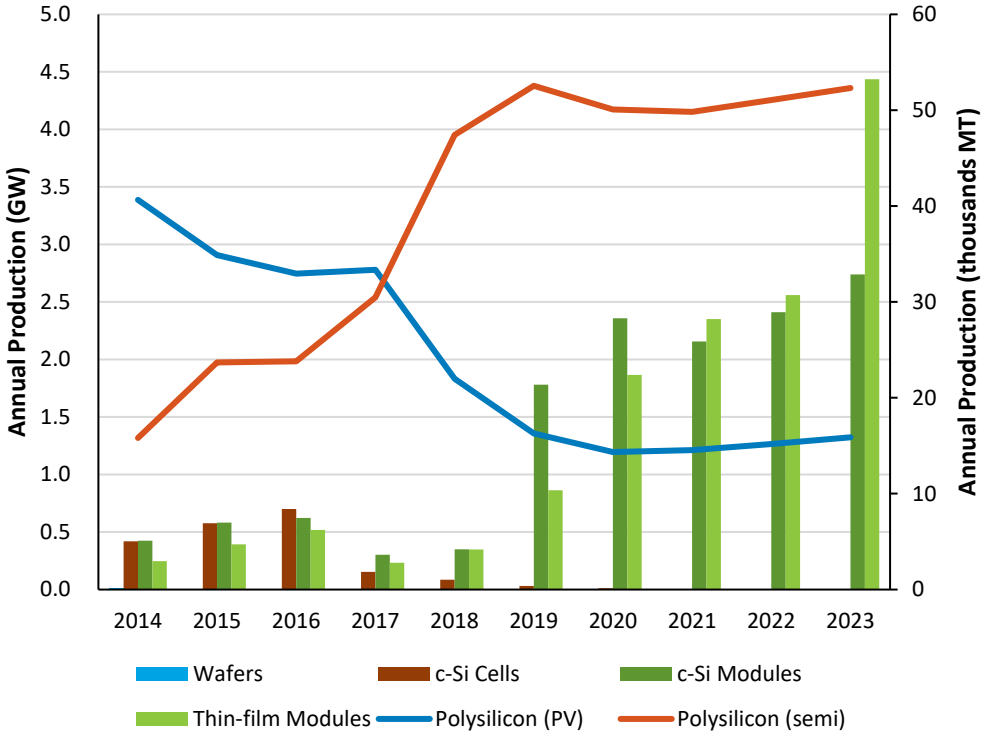
U.S. PV Manufacturing

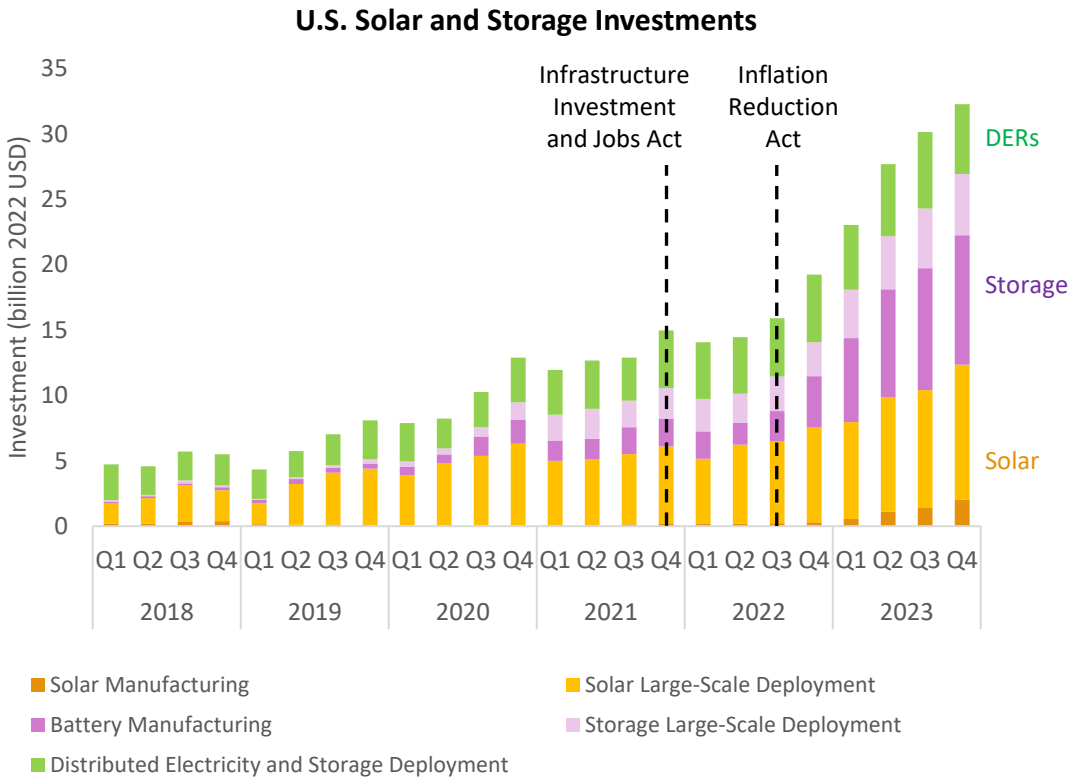


The Inflation Reduction Act (IRA) provides incentives to produce domestic polysilicon, wafers, cells, and modules. PVTech reports that at the end of 2023 PV modules and polysilicon were the only products in production.

- The U.S. produced approximately 7.2 GW of PV modules (4.4 GW CdTe, 2.7 GW c-Si) in 2023, up 44% y/y. Most of that increase came from CdTe production.
  - PV production is up 9X since 2018. In addition to IRA, manufacturers have attributed the increase in production to the reduction in the corporate tax rate in 2017, the imposition of the Section 201 tariffs in 2018, the AD/CVD anti-circumvention case in 2021, as well as other supply chain disruptions to imported PV modules.
- Polysilicon for PV increased 5% in 2023 compared to a 2% increase for semiconductor use.

Source: PVTech Research. PV Manufacturing & Technology Quarterly Report - Release 32, February 2024.

U.S. Solar & Storage Investments Through 2023



- U.S. solar & storage investments hit records in 2023:
  - Solar manufacturing: $5.1 billion (+470% from 2022)
  - Battery (vehicle and stationary) manufacturing: $33.9 billion (+240%)
  - Large-scale solar deployment: $35.4 billion (+45%)
  - Large-scale storage deployment: $17.0 billion (+71%)
  - Distributed electricity and storage deployment: $21.6 billion (+18%)
- Solar and storage investments announced in 2023 were also large, although some were below levels announced in 2022:
  - Solar manufacturing: $12.5 billion (+210% from 2022)
  - Battery (vehicle and stationary) manufacturing: $39.8 billion (-42%)
  - Large-scale solar deployment: $44.8 billion (-4%)
  - Large-scale storage deployment: $34.6 billion (+50%)
- According to the analyst report, investments in large-scale solar, storage, and wind* deployment must accelerate to reduce emissions as projected under the Inflation Reduction Act.

*Wind deployment investments declined each year from 2021 to 2023.

Sources: Rhodium Group & MIT Center for Energy and Environmental Policy Research, Clean Investment Monitor: Q4 2023 Update, 2/24; Clean Investment in 2023: Assessing Progress in Electricity and Transport, 2/24.

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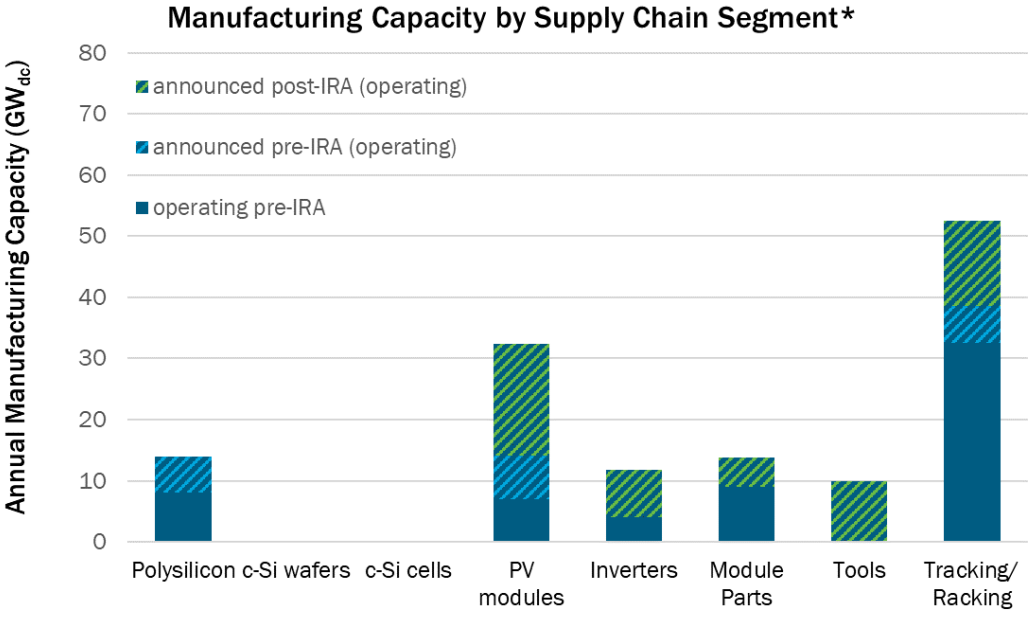
Domestic Manufacturing Growth

Since IRA's passage, over 70 GW of manufacturing capacity has been added across the solar supply chain (from facilities announced pre- and post-IRA), including more than 25 GW of new module capacity.*



Sources: U.S. Census Bureau USA Trade Online and internal DOE tracking of public announcements.

*Not all announcements include facility locations, job, operating capacity, or investment numbers.

Several large facilities have become operational in the last year:

- **Qcells**: Module expansions in Georgia are online, bringing total nameplate capacity to 8.4 GW.
- **First Solar**: Module expansion in Ohio is online, bringing total nameplate capacity to 6.3 GW.
- **Canadian Solar**: A 5 GW module facility in Texas has begun shipping modules to customers.
- **Illuminate USA (LONGi/Invenergy)**: A 5 GW module facility in Ohio has produced panels for testing.
- **REC Silicon**: Re-start of 6 GW of polysilicon production in Washington was successful.
- **Nextracker**, **Array Technologies**, and **GameChange Solar** have all significantly expanded domestic production of trackers/tracker components.

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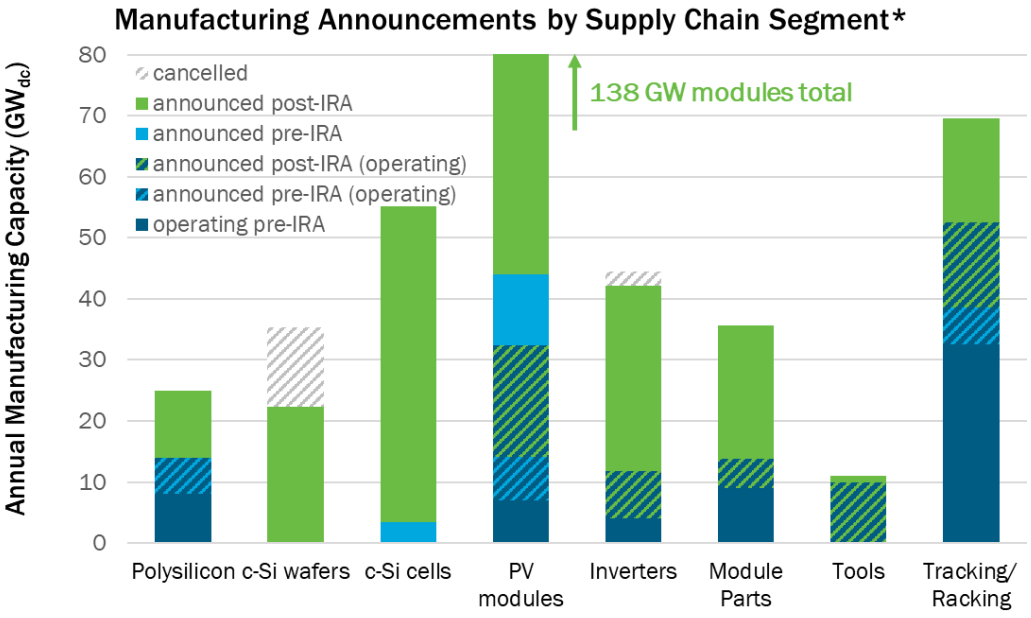
Domestic Manufacturing Announcements

Along with openings, there has also been recent news of cancellations including CubicPV scrapping their wafer plans, REC Silicon stopping production of polysilicon in MT, and Enphase closing its facility in WI.



Sources: U.S. Census Bureau USA Trade Online and internal DOE tracking of public announcements.

*Not all announcements include facility locations, job, operating capacity, or investment numbers.

Despite the headwinds noted by these companies (including surging construction costs, high energy prices, and collapsing solar component costs), recent announcements continue to span the different supply chain steps, including:

- PV modules: Boviet Solar (2 GW), Energate (0.5 GW), Imperial Star Solar (1.5 GW), Phono Solar (1 GW), Solar Depot, SolarLink (2 GW), and Toenergy (0.5 GW).
- PV cells: Boway Alloy (2 GW TOPCon)
- Inverters: Enteligent
- Wafers: NexWafe (6 GW)
- Solar Glass: Solarcycle (5.5 GW)
- Trackers: GameChange (11 GW), BCI Steel (4 GW)
- Other components: Corning

Since IRA's passage (taking into account the cancellations), over 300 GW of manufacturing capacity has been announced across the solar supply chain, representing more than 29,000 potential jobs and more than $15 billion in announced investments across 97 new facilities or expansions.*

Click here to interactively view a map of manufacturing announcements.

Agenda

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

- **Global polysilicon spot prices fell 22% from mid-January ($8.70/kg) to late April ($6.76/kg), approaching the lowest nominal price seen over the past decade.**
- **The recent plunge in global module prices leveled off, staying around $0.11/$W_{dc}$ in Q1 2024.**
- **In Q4 2023, the average U.S. module price ($0.31/$W_{dc}$) was down 5% q/q and down 22% y/y, but at a 140% premium over the global spot price for monofacial monocrystalline silicon modules.**

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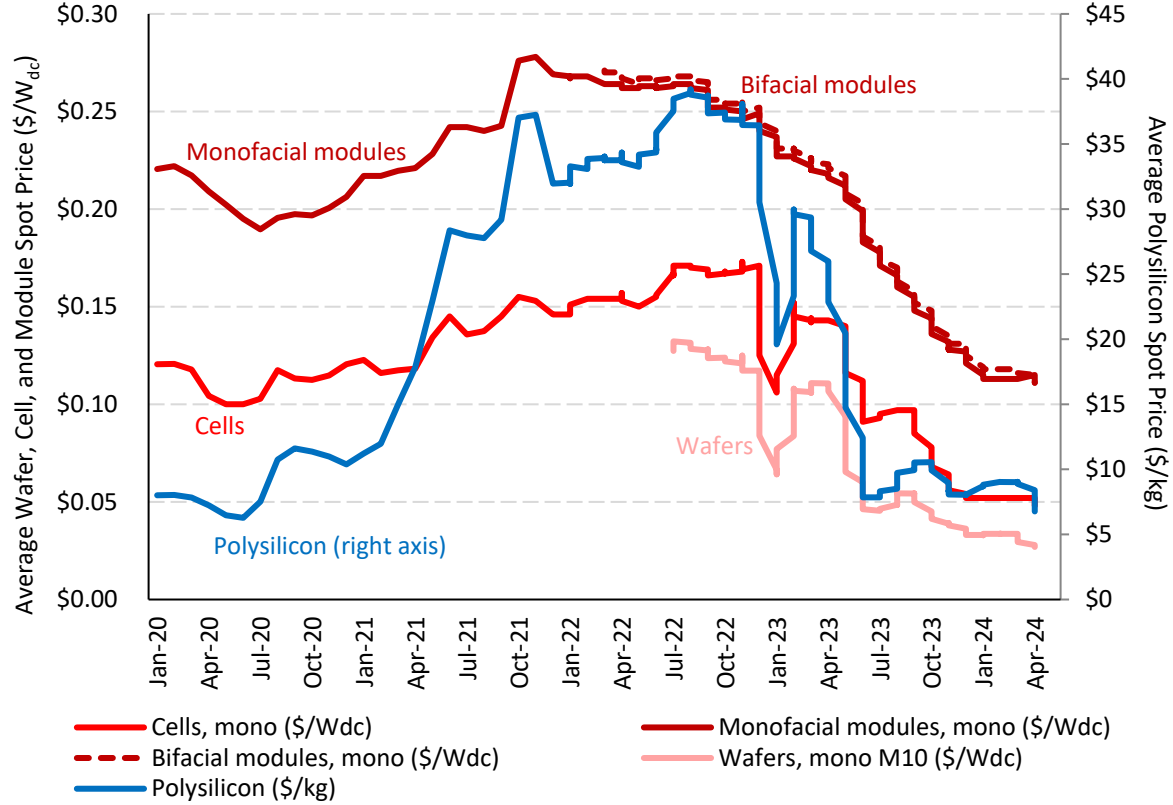
PV Value Chain Global Spot Pricing



Sources: BloombergNEF, Solar Supply Chain Index (4/2/24); PV Magazine (3/29/24).

Global polysilicon spot prices fell 22% from mid-January ($8.70/kg) to late April ($6.76/kg), approaching the lowest nominal price seen over the past decade.

- Global polysilicon production continued to rise, mostly due to production in China.
- According to the China Silicon Industry Association, China supplied enough polysilicon production in March 2024 to produce 85 GW_{dc} of modules (equivalent to > 1 TW_{dc}/year).

During the same period, global prices decreased for wafers (18%) and cells (8%).

- Reversing a historical trend, n-type wafers sold at a discount to p-type wafers on a per-piece basis.
- The premium for TOPCon cells over PERC was $0.01/W, and Chinese cell manufacturers are increasingly transitioning to TOPCon production.

The recent plunge in global module prices leveled off, staying around $0.11/$W_{dc}$.

- Strong European demand anticipated in Q2 2024 may be helping to stabilize prices.

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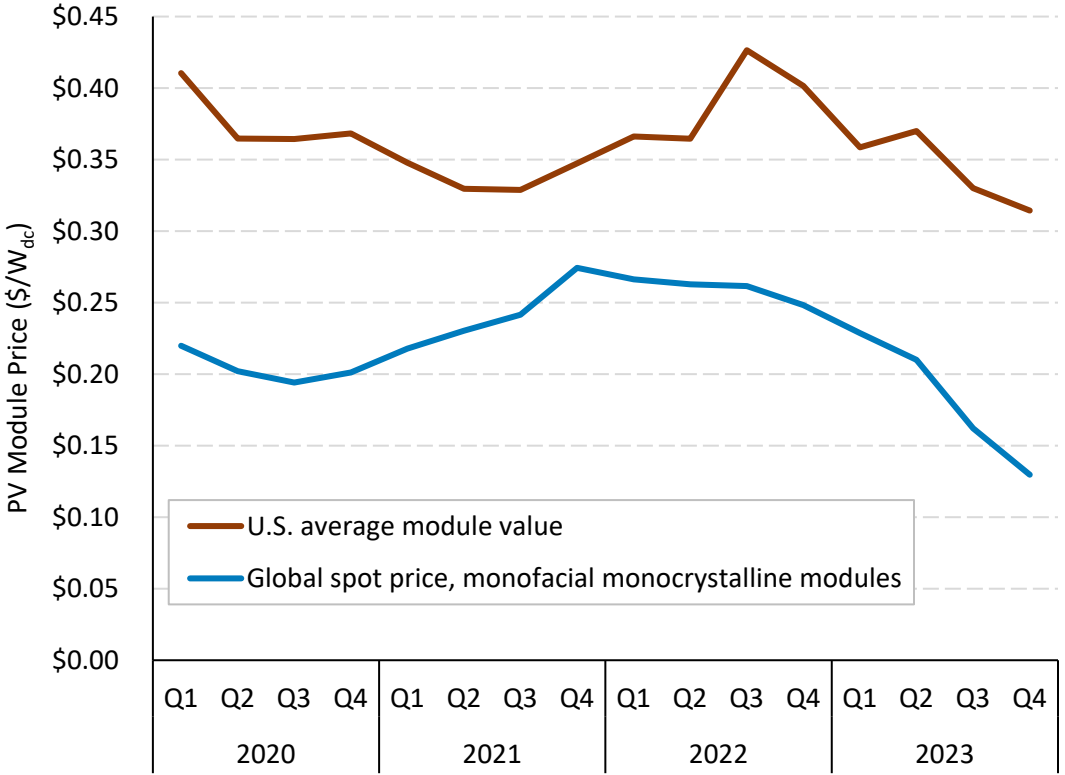
Module Prices: Global Versus United States



Source: BloombergNEF, Solar Supply Chain Index (4/2/24); EIA, Monthly Solar Photovoltaic Module Shipments Report (4/30/24); Wood Mackenzie & SEIA, US Solar Market Insight: 2023 Year in Review (3/24).

In Q4 2023, the average U.S. module price ($0.31/$W_{dc}$) was down 5% q/q and down 22% y/y, but at a 140% premium over the global spot price for monofacial monocrystalline silicon modules.

The price difference between U.S. modules and global modules increased every quarter in 2023, reaching $0.18/$W_{dc}$ in Q4.

- Global module prices plummeted in 2023.
- The world-leading module price premium in the U.S. has been maintained by tariffs on Chinese modules as well as module detainment under the Uyghur Forced Labor Prevention Act (UFLPA).
- Analysts report that the recent reductions in U.S. PV prices have been caused in part by shrinking UFLPA detainment periods and increased module supply due to a surge in imports before the antidumping and countervailing duty (AD/CVD) waiver expires in June 2024.

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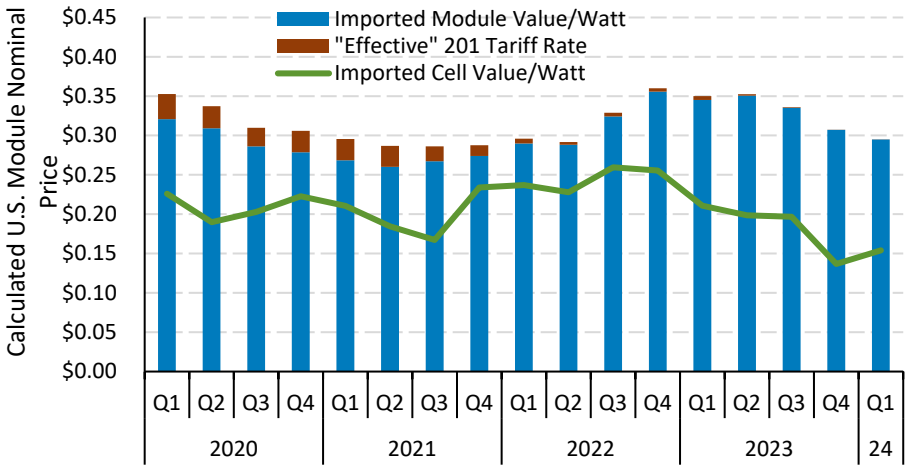
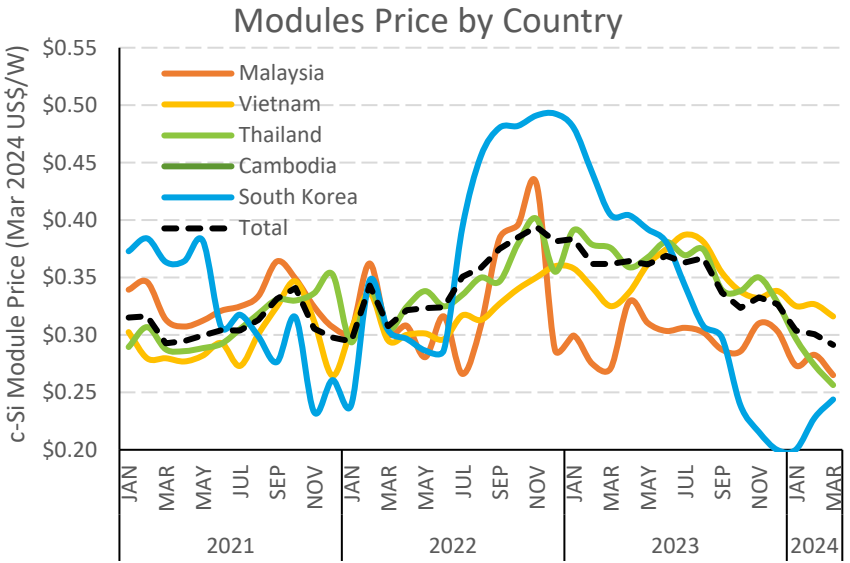
Calculated U.S. Module Pricing

- Based on the reported value and capacity of imported PV modules and cells, the average price of a PV module and cell in the United States fell over the course of 2023 to \$0.31/W_{dc} and \$0.14/W_{dc}, respectively.
  - In Q1 2024, U.S. module prices fell further to \$0.29/W_{dc} while cell prices rose to \$0.15/W_{dc}



- These module price declines were observed across all countries of import. However, prices declined most steeply for modules from South Korea. Current prices are still well within historical ranges, even when adjusted for inflation.



Note: The tariff rate was adjusted by the capacity subject to the tariffs. 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). Several GW of imports from India entered under the HTS code for thin-film modules in 2023 and 2024 but are believed to be c-Si based on news reports.

Sources: Imports by HTS code: 8541460015(2018-2021)/8541430010(2022-) and 8541460035(2018-2021)/8541430080(2022-), Second Quantity (watts) from the U.S. Census Bureau USA Trade Online tool and corrections page as of 5/6/24.

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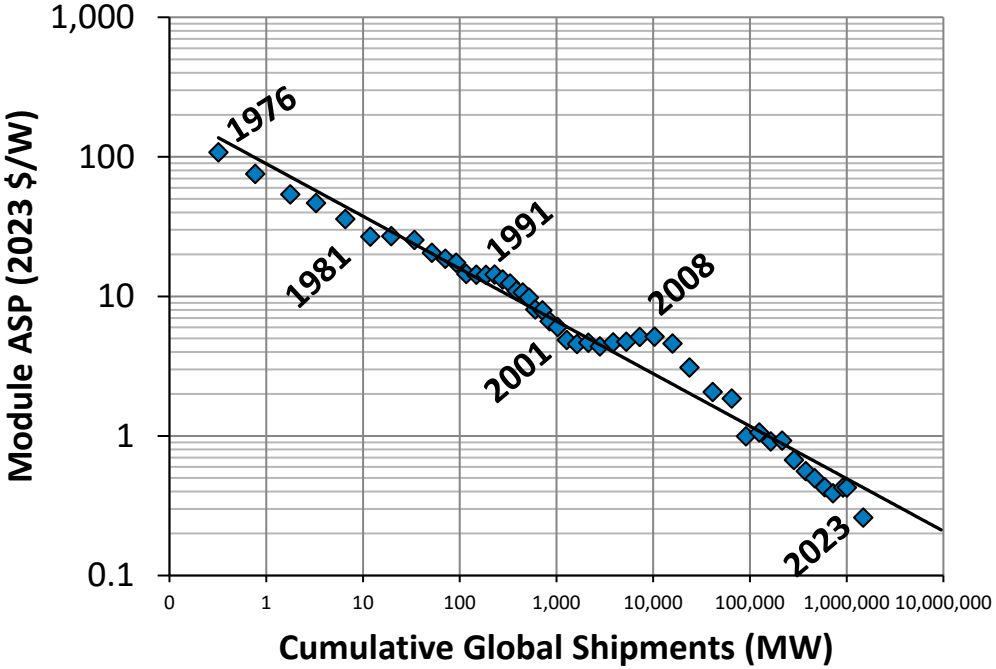
PV Experience Curve



- This solar PV experience curve, known as Swanson's Law, displays the relationship, in logarithmic form, between the average selling price of a PV module and the cumulative global shipments of PV modules.
- For every doubling of cumulative PV shipments from 1976 to 2023, there has been on average a ~23% reduction in PV module price.
- Historically, due in large part to undersupply and oversupply conditions, pricing has deviated from the experience curve.

Source: SPV Market Research. Report SPV-Supply12 April 2024.

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- **The waiver of AD/CVD anti-circumvention tariffs on Southeast Asian–manufactured cells and modules that use Chinese wafers and other Chinese products ends in June, and products must be installed by December.**
  - **The White House announced in May that it would work to strictly enforce this.**
- **New AD/CVD case filed on all Southeast Asian–manufactured cells and modules.**
  - **Preliminary determination expected in July, with final to come in October. However, this could be delayed.**
- **Section 301 Tariffs updated to increase tariffs on Chinese PV, battery, and steel products, with exceptions for PV manufacturing equipment.**
- **The White House indicated that it would remove the bifacial exemption from Section 201 duties and may increase the 5 GW tariff rate quota for cells by an additional 7.5 GW to help domestic module assembly.**

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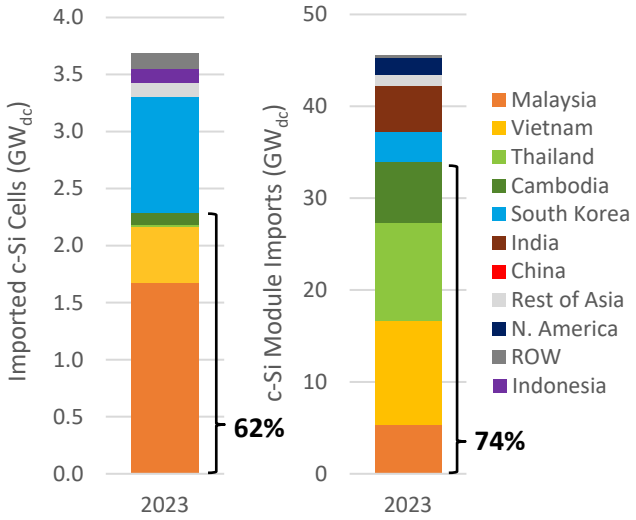
AD/CVD Tariffs on Southeast Asian Modules and Cells

- The moratorium on AD/CVD anti-circumvention tariffs on Southeast Asian–manufactured cells and modules that use Chinese wafers and other Chinese products ends June 6th. Products must be installed by December 3rd to avoid the tariffs.
  - The White House announced in May that it would work to strictly enforce this.
  - Not all Southeast Asian manufacturers were found to be circumventing.
- A separate AD/CVD case was filed on all Southeast Asian–manufactured cells and modules, alleging that imports from Cambodia, Malaysia, Thailand, and Vietnam are injuring the U.S. solar industry. An investigation is sought.
  - A preliminary determination is expected in July, with final to come in October. However, this could be delayed.
  - The Alliance filing the case includes First Solar, Qcells, Convalt Energy, Meyer Burger, Mission Solar, REC Silicon, and Swift Solar.
  - AD/CVD investigations can cause volatility in the U.S. solar market by pitting domestic PV cell and module manufacturers against the rest of the U.S. industry, making imported modules and cells more expensive, which can reduce PV installations.
- AD/CVD findings last for 5 years. But assessed duties can fluctuate significantly, are assessed annually, and have the potential to change retroactively.

U.S. Cell + Module Imports by Region



Those four countries accounted for 62% of total imported cells and 74% of total imported modules into the United States in 2023.

Sources: First Solar, Qcells and others launch AD/CVD petition to DOC (pv-tech.org) ; New AD/CVD petition filed against solar cells and panels from Southeast Asia (solarpowerworldonline.com) ; Department of Commerce Issues Final Determination of Circumvention Inquiries of Solar Cells and Modules from China | U.S. Department of Commerce

Other News Affecting Domestic Manufacturing

- **Section 201 Tariff**: The White House indicated in May that it would remove the bifacial exemption from Section 201 duties and may increase the 5 GW tariff rate quota for cells by an additional 7.5 GW to help domestic module assembly.
  - Importers with pre-existing contracts for bifacial solar modules will have 90 days to certify those contracts to continue using the exclusion.
  - The Administration also announced it will monitor the level of imported solar cells used to manufacture panels in the United States and will work to raise the quota by 7.5 GW if imports approach the current tariff-rate quota level under Section 201.
- **Section 301 Tariffs** were updated to increase tariffs on Chinese PV, battery, and steel products.
  - Announcement indicated that there would be an exception on PV manufacturing equipment.
- **Domestic Content Bonus:** The IRS just released updated guidance intended to make it easier to use the Domestic Content Bonus within the ITC and PTC tax credits for electric generating assets. It includes a cost table based on NREL analyses, which taxpayers can elect to use in lieu of collecting proprietary cost data from vendors. Taxpayers can also treat the cost tables as exhaustive if they elect to use the safe harbor; without the safe harbor table, taxpayers may have to assess other manufactured products within a facility.
  - On February 28, twelve U.S. senators wrote a letter to Treasury Secretary Janet Yellen and IRS Commissioner Danny Werfel asking them to include wafers and polysilicon in the equation when calculating whether or not a solar system qualifies for the ITC/PTC domestic content bonus. They argue that the current domestic content bonus guidance does not sufficiently incentivize domestic manufacturing of these key supply chain components. The new guidance does not address this issue.

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International Solar Manufacturing Incentives

U.S.

Inflation Reduction Act

Duration: 11 years+

Cost: ~370b USD (~41b USD for manufacturing)*

Description:
45X – variable, per-unit tax credit for domestic manufacturers
48C – 30% tax credit on upfront costs of investment in a manufacturing facility

Demand-side incentives?
Yes, Domestic Content Bonus for ITC/PTC

Canada

Tax Incentives via Budget 2023

Duration: 11 years

Cost: ~8.2b USD*

Description:
30% refundable tax credit for investments in new machinery and equipment for clean technologies manufacturing or critical minerals processing

Demand-side incentives?
No

India

Production Linked Incentive

Duration: 5 years

Cost: 2.92b USD

Description:
Tranche 1 – 550m USD given to 3 bidders for setting up fully integrated PV manufacturing
Tranche 2 – 2.37b USD given to 11 bidders for setting up fully/partially integrated PV manufacturing

Demand-side incentives?
Yes, the Approved List of Models + Manufacturers

Germany

Climate and Transformation Fund

Duration: 3 years

Cost: 4.5b USD

Description:
Wide range of funding types from the government to support local production capacity of raw materials and manufacturing capacity of transformational technologies, such as solar components

Demand-side incentives?
No

Australia

National Reconstruction Fund + SunShot

Duration: N/A

Cost: 2.7b + 0.65b USD

Description:
NRF – loans/guarantees to support emerging industry. 2b USD for green materials/clean energy manufacturing. 0.7b USD for advanced manufacturing.
SunShot – 0.65b USD in subsidies and grants to onshore more of the solar supply chain.
Demand-side incentives?
No

*Indicates uncertainty in cost projections

Sources: Federal Solar Tax Credits for Businesses | Department of Energy ; Federal Tax Credits for Solar Manufacturers | Department of Energy ; Production Linked Incentive (PLI) Scheme: National Programme On High Efficiency Solar PV Modules | Ministry of New and Renewable Energy | India (mnre.gov.in) ; Tax Incentives for Renewable Energy in India (sustvest.com) ; A Made-in-Canada Plan: Affordable Energy, Good Jobs, and a Growing Clean Economy - Canada.ca ; Renewable power incentives | energy.gov.au ; Australia to invest $15 billion in renewable energy, critical minerals | Reuters ; German government passes €212bn climate fund – Euractiv ; German Government Puts Extra EUR 30 Billion into Climate and Transformation Fund | Energy Transition (gtai.de ; Germany earmarks €30 billion to green infrastructure in 2024 – DW – 08/10/2023) ; Solar Sunshot for our regions | Prime Minister of Australia (pm.gov.au)

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International Solar News

China WTO case:

- On March 26, China initiated dispute settlement proceedings against the United States at the World Trade Organization (WTO) for what it considers to be "discriminatory subsidies" under the Inflation Reduction Act. In China's request, they claim that the U.S. subsidies favor domestic products over imported goods in a manner that "discriminate[s] against goods of Chinese origin in violation of provisions under the General Agreement on Tariffs and Trade 1994."
    - The dispute is regarding five of the subsidies set forth in IRA: 1) the Clean Vehicle Credit, 2) the Investment Tax Credit (ITC) for Energy Property, 3) the Clean Electricity ITC, 4) the Production Tax Credit (PTC) for Electricity from Renewables, 5) and the Clean Electricity PTC.
    - Specifically, China's case targets the domestic content adders available in the ITC and PTC, which they say "threaten to undermine international cooperation on reducing and mitigating the effects of climate change" by creating an unlevel playing field.
- WTO rulings on trade disputes are supposed to take six months after an adjunction panel is established, though they often take longer.

Maxeon files 3 lawsuits:

- Maxeon Solar recently filed three patent infringement lawsuits in the U.S. relating to its TOPCon technology. The lawsuits are not expected to affect solar projects that use the affected panels, but these cases could create near-term market turmoil by making it more expensive for panel manufacturers to supply TOPCon modules.
    - Maxeon is the manufacturing arm of Sunpower. It used to manufacture in the United States but moved to Singapore in 2020.
    - On March 29, Maxeon initiated a patent infringement lawsuit against Canadian Solar. On April 19, Maxeon initiated patent infringement lawsuits against REC Solar and Hanwha Qcells.
    - Qcells and Canadian Solar have put out statements saying they are confident that they are not infringing upon any patents.
    - These lawsuits follow a series of investigations that Maxeon carried out last November on several companies that it believed were infringing upon its TOPCon patents. Maxeon has not disclosed the full list of companies that it investigated, and more lawsuits are possible.
    - The companies being sued are major players in the U.S. manufacturing space, representing a combined 36.5% of current U.S. module manufacturing capacity.

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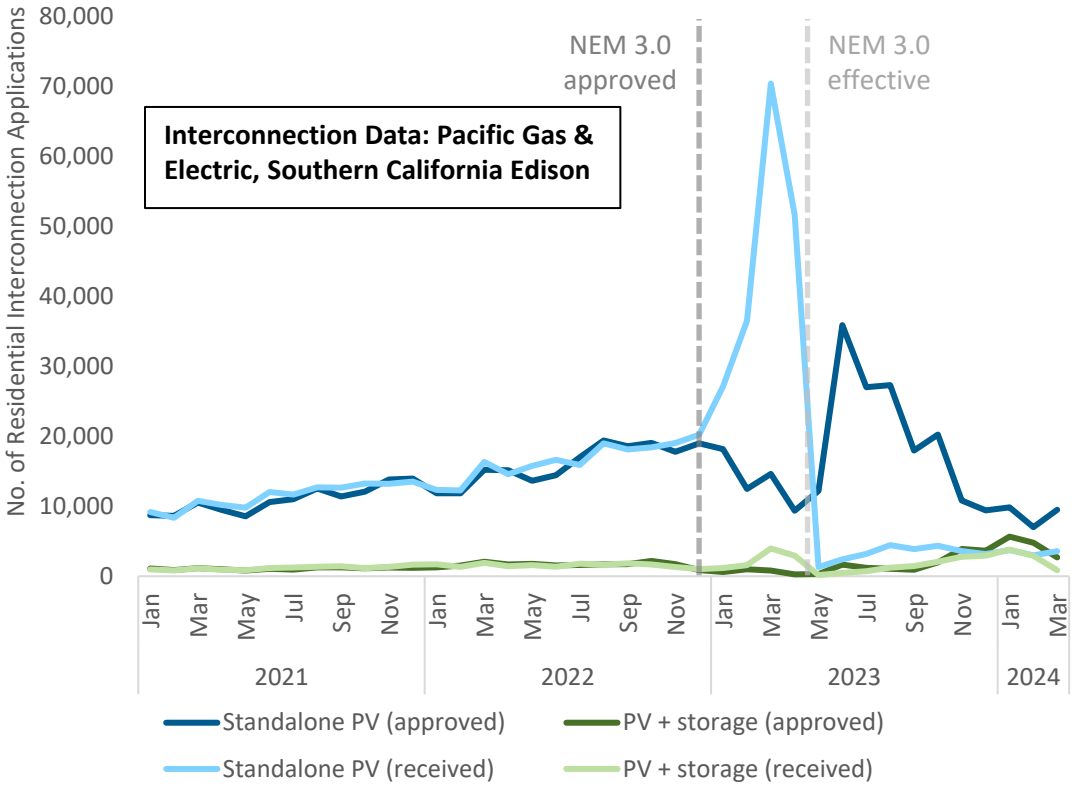
California Updates



California's Net Billing Tariff (aka NEM 3.0) rules, effective in April 2023, continue to stimulate action.

- Two bills introduced in 2024 aim to repeal NEM 3.0 and order the Public Utilities Commission to evaluate rooftop PV based on a range of non-economic costs and benefits.
- The California Energy Commission voted to incorporate a range of benefits in state energy-mix decisions.
- The California Supreme Court granted review of a lawsuit challenging NEM 3.0, which alleges the policy did not adequately consider all benefits of distributed PV.

The Public Utilities Commission approved reducing volumetric rates and instituting a $24.15 monthly fee for residential customers.

- Income-qualified customers pay a smaller fee.
- Some opponents argued that the flat fee discourages PV.

The Public Utilities Commission issued a proposed decision to change community solar policies.

- Expands a low-income program, adopts a new program with capacity reserved for low-income customers, streamlines a green tariff program, and authorizes co-location of energy storage.
- Rejects creation of a net value billing tariff promoted by community solar advocates, with the rationale of preventing a cost shift to nonparticipating customers.

Sources: California Distributed Generation (3/31/24); Canary Media (3/29/24, 4/15/24); CPUC, Community Solar Fact Sheet (3/4/24); Inside Climate News (3/14/24); PV Magazine (4/11/24); Utility Dive (3/7/24, 3/28/24, 5/10/24).

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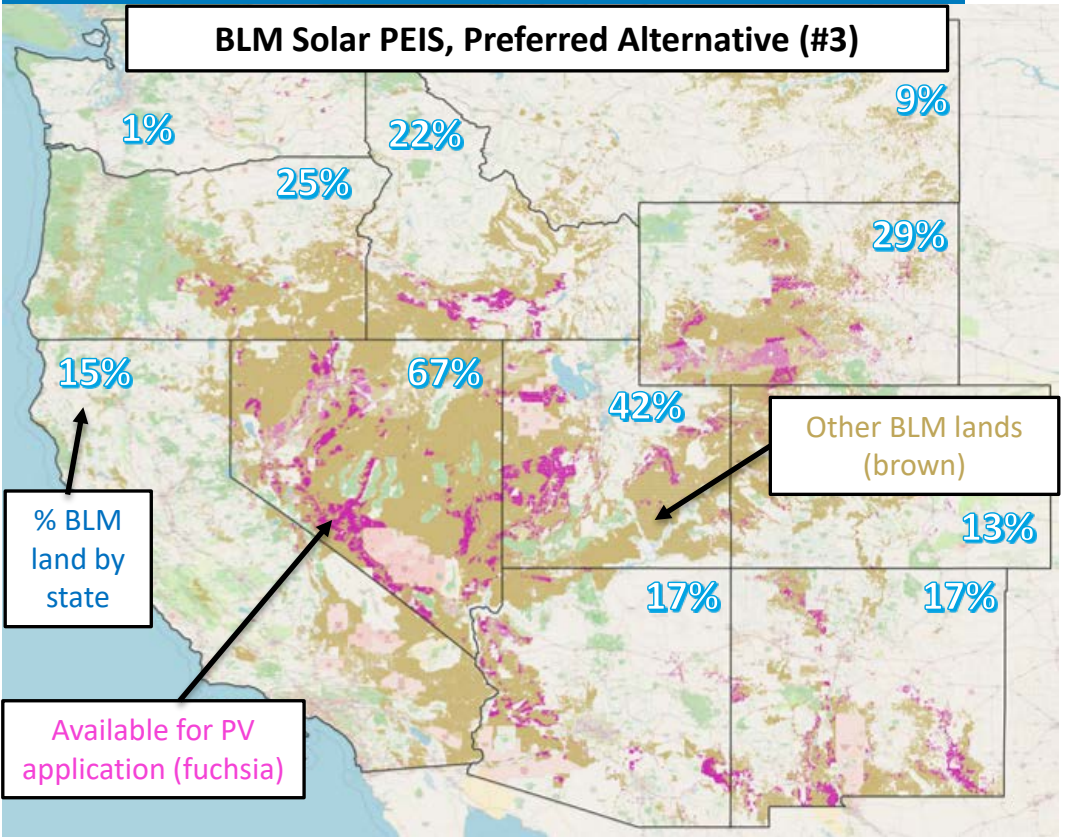
Updated Western Solar Plan



Sources: BLM, 2023/2024 Solar Programmatic EIS, 4/24.

In January, the U.S. Bureau of Land Management (BLM) released a draft roadmap—the Utility-Scale Solar Energy Development Programmatic Environmental Impact Statement (PEIS)—for western solar development.

- Designed to expand solar energy deployment by streamlining siting and permitting in target areas
- Accounts for technology advances and increased solar energy demand, including in northern states, that occurred since BLM's 2012 solar plan.
- Number of states covered expanded from 6 (AZ, CA, CO, NV, NM, UT) to 11 (+ ID, MT, OR, WA, WY).
- Presents comprehensive list of mitigation/design measures applicants must implement on BLM land.

Five alternatives (plus a no-action alternative) are proposed, making different amounts of land available to solar applications under criteria such as proximity to transmission, critical habitat, or other resources.

- Areas are either open or closed.
- The variance process—which allowed consideration of development outside Solar Energy Zones under the 2012 plan—is eliminated to focus and improve the efficiency of site review

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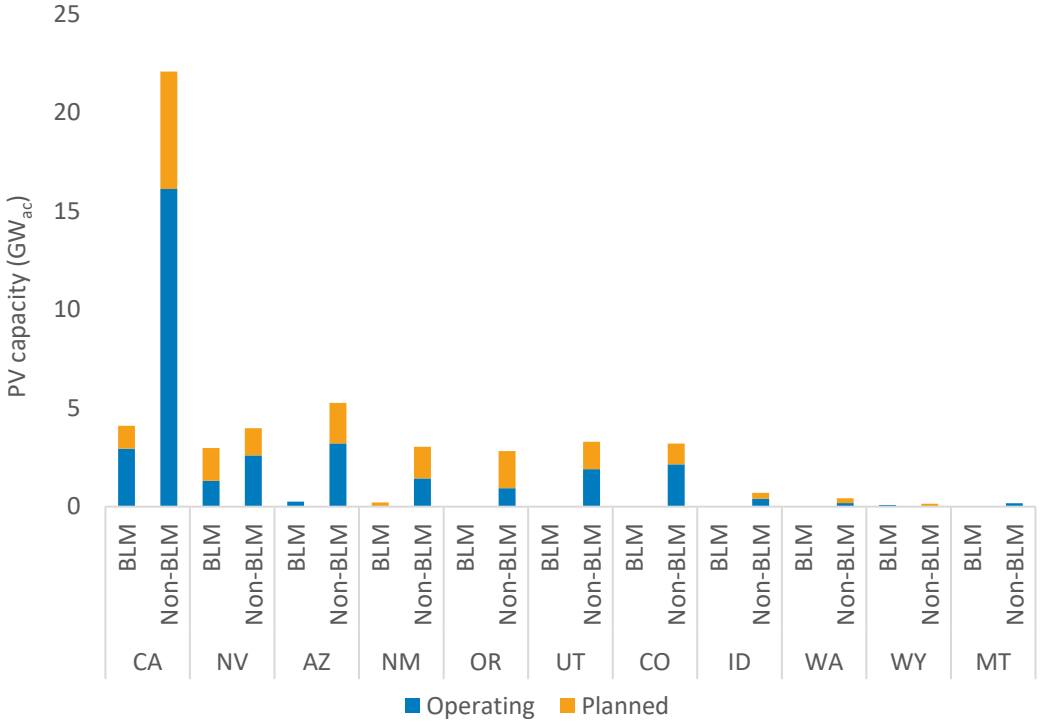
Updated Western Solar Plan

Planned & Operating PV on BLM & non-BLM Land, Early 2024



Sources: BLM, 2023/2024 Solar Programmatic EIS, 4/24; EIA, Form 860M, 4/24. RFF, Adding Solar: The Role of the National Environmental Policy Act in Solar Development, 2023.

PV deployment on BLM lands in the 11 western states has been relatively small and concentrated to date.

- Based on U.S. Energy Information Administration data as of early 2024, 4.6 GW_{ac} of PV (73 projects) was operating on BLM lands vs. 29.1 GW_{ac} (1,640 projects) on non-BLM lands.
- Planned projects include 3.0 GW_{ac} (11 projects) on BLM vs. 16.0 GW_{ac} (153 projects) on non-BLM.
- 92% of planned and operating capacity on BLM lands is in CA and NV vs. 58% on non-BLM lands.
- Average utility-scale (≥ 5 MW_{ac}) projects are larger on BLM lands than non-BLM lands: 92 MW_{ac} vs. 59 MW_{ac} across operating and planned projects.

Federal initiatives starting in 2009 have had limited success in speeding up approval processes on BLM land and stimulating developer interest.

- Key implementation policies were being developed in the early years of this period.
- During 2017–2021, review of public lands policy delayed implementation of the Western Solar Plan.
- Multi-step environmental reviews for sites resulted in significant delays.

The new plan is meant to expedite development by directing it to lands with few conflicts and applying efficient review and permitting processes.

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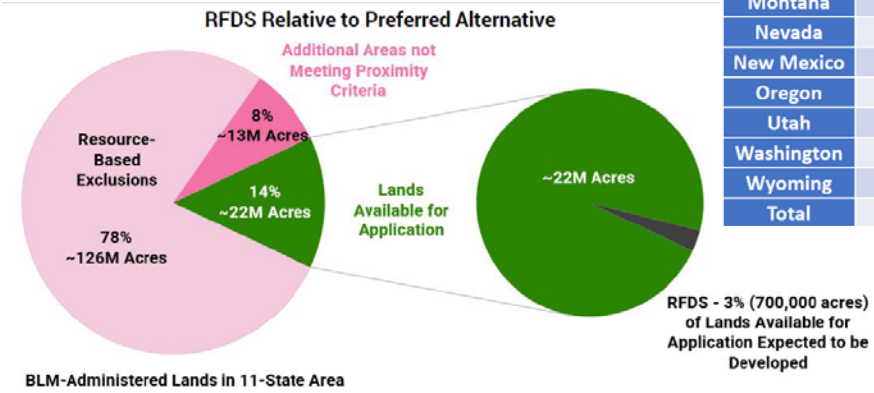
Updated Western Solar Plan

Reasonably Foreseeable Development Scenario (RFDS)



State	RFDS, Estimated BLM Area Developed by 2045 (acres)
Arizona	198,210
California	109,972
Colorado	45,207
Idaho	89,574
Montana	5,387
Nevada	48,119
New Mexico	11,123
Oregon	51,387
Utah	39,793
Washington	71,781
Wyoming	27,255
Total	697,809

BLM's Reasonably Foreseeable Development Scenario projects potential solar development.

- Based on land required to deploy 1,570 GW_{ac} of PV by 2050, from DOE's *Solar Futures Study*.
  - Assumes 174.2 GW_{ac} of utility-scale PV is deployed in 11-state planning area by 2045
  - Assumes 75% of this PV is sited on BLM land.
- Results in use of about 700,000 acres of BLM land, or about 3% of lands available for application under Alternative 3.

A final plan is expected before the end of the year.

- More than 70 cooperating agencies had opportunity to comment on the draft plan.
- Public comments were taken until April 18, 2024.
- BLM has flexibility to modify the final plan such that it differs from the originally proposed alternatives.

BLM's Renewable Energy Rule, effective July 2024, complements the Western Solar Plan:

- Reduces rents and fees for renewable projects
- Expands discretion to process applications for renewable energy rights-of-way inside designated leasing areas.

Sources: BLM, 2023/2024 Solar Programmatic EIS, 4/24; BLM, Renewable Energy Rule, 4/24.

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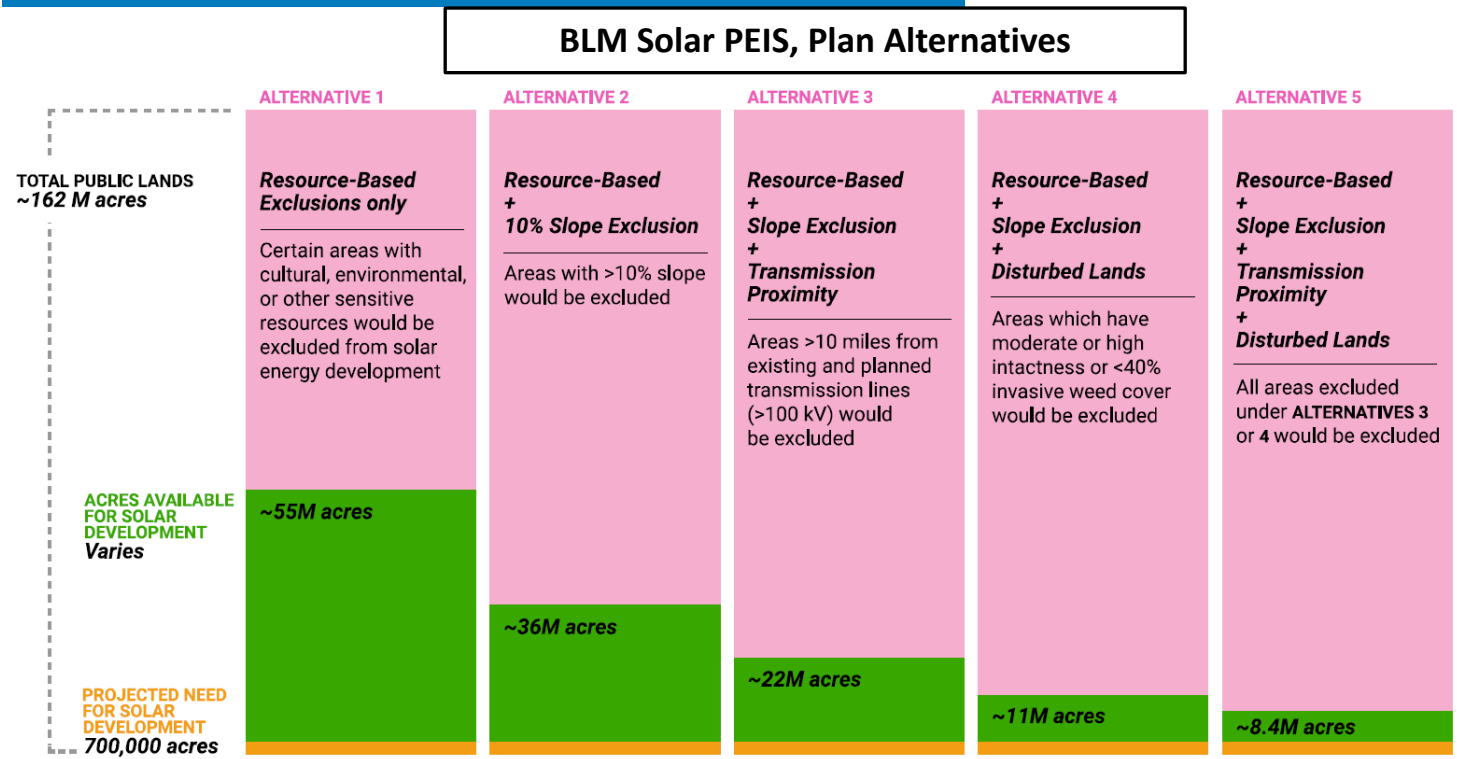
Updated Western Solar Plan



The plan alternatives are based on different sets of exclusion criteria.

- Land available for solar development ranges from about 8.4 million acres to 55 million acres.
- The projected need for solar development remains the same under all alternatives.

Sources: BLM, 2023/2024 Solar Programmatic EIS, 4/24; BLM, Renewable Energy Rule, 4/24.

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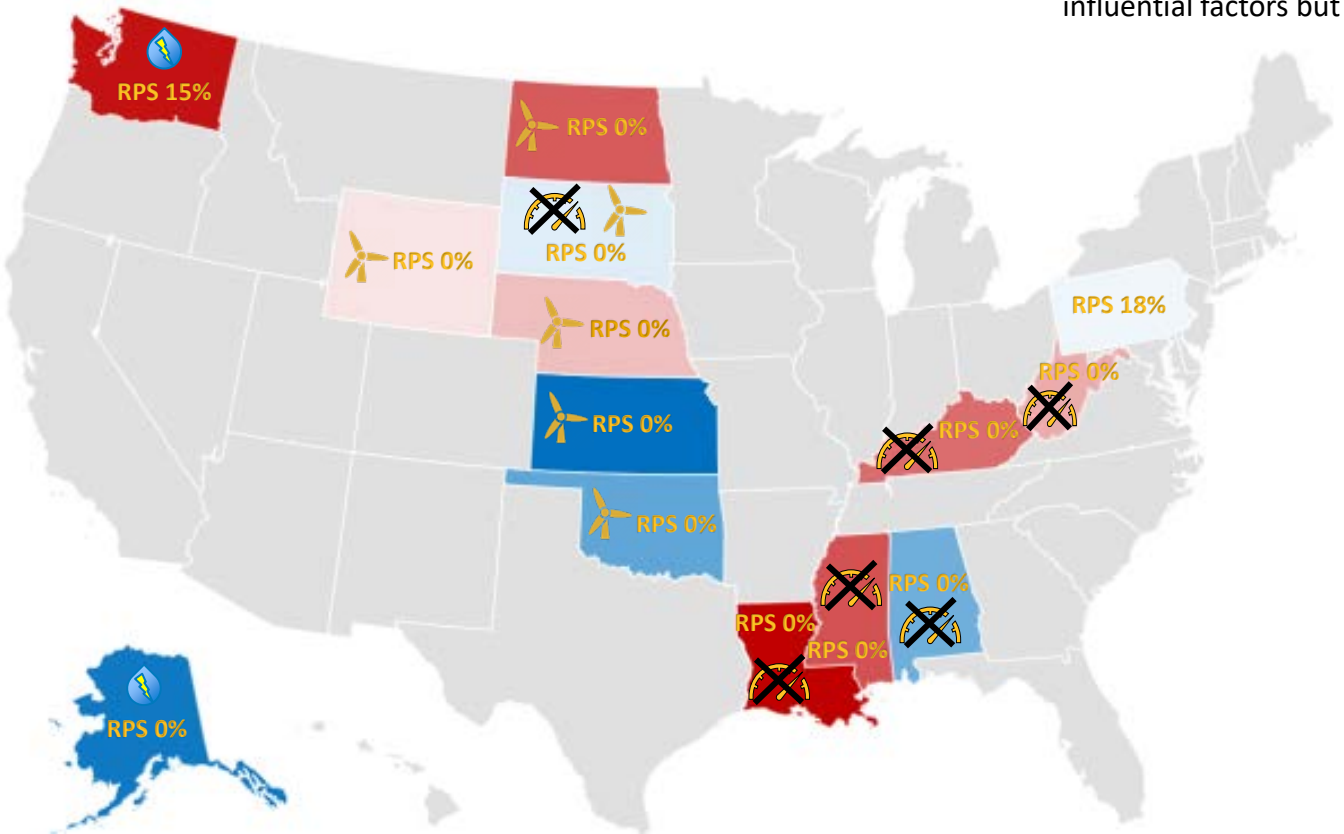
Low-Solar States

14 states generate < 1% solar electricity owing to factors such as state and local policies, electricity prices, public awareness, community opposition, geography/climate, and use of other clean energy. The map presents a subset of potentially influential factors but does not present any causal analysis.



Generates > 20% of their electricity from renewable sources (symbol represents the source, wind or hydro, that generates most of the state's clean electricity)

RPS X% Renewable Portfolio Standard (RPS) goal by 2035

Does not have state-wide net-metering

SIR Value
1.16
1.00
0.72

Savings to Investment Ratio for a modeled residential PV system over 20 years, assuming 30% investment tax credit. SIR > 1 indicates potential energy savings from installing residential PV.

Sources: Solar laggards: The five states with the least amount of solar installed, PV Magazine, 3/27/24. U.S. Energy Information Administration - EIA - Independent Statistics and Analysis, State Profiles, accessed 5/2/24. U.S. State Renewables Portfolio & Clean Electricity Standards: 2023 Status Update, LBNL, June 2023.

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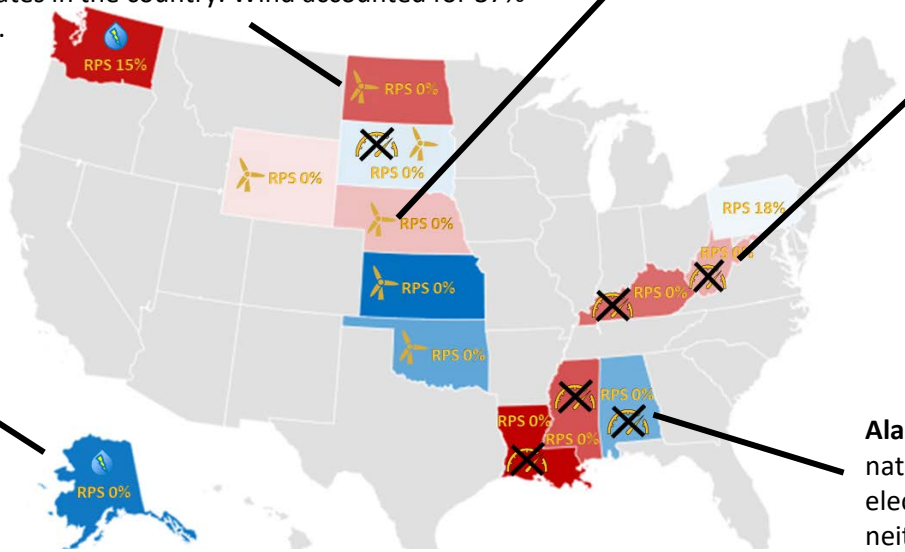
Low-Solar States

North Dakota has lower electricity prices than the national average and is one of the top 10 wind energy generating states in the country. Wind accounted for 37% of their electricity generation in 2022.

Alaska has higher electricity prices than the national average and non-binding goals of producing 50% of their electricity from renewables by 2025. In 2022, 33% of their electricity was produced by renewable sources and 90% of that renewable electricity was from hydropower. Alaska also has lower yearly average irradiance than other states.



Nebraska has lower electricity prices than the national average and is one of the top 10 wind energy generating states in the country. Wind accounted for 31% of its electricity generation in 2022. Anecdotally, the state faces significant community pushback to utility-scale solar, with Kearney and Gage counties having some of the most restrictive solar zoning regulations in the country.

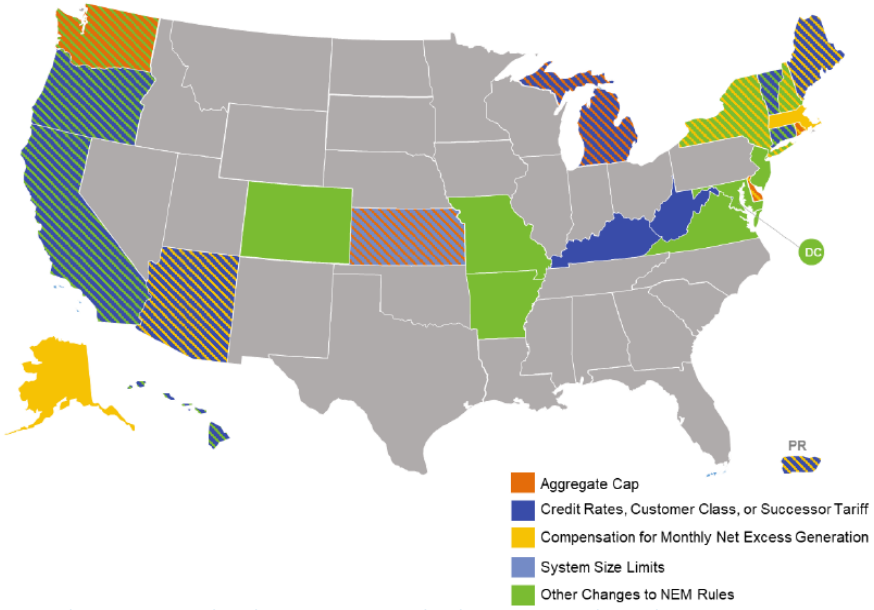
West Virginia has lower electricity prices than the national average and generates 90% of its electricity from coal. The state has neither a renewable energy portfolio standard nor a clean energy standard. Recently, the governor vetoed a bill that would have increased the maximum allowable size of utility-scale solar projects in the state from 50 to 100 MW.

Alabama has lower electricity prices than the national average and produces most of its electricity with natural gas. The state has neither renewable energy portfolio standards nor a state-wide voluntary renewable energy goal. They also do not offer net metering for distributed generation. Notably, there have been significant investments in manufacturing in the state, including a proposed First Solar facility.

Sources: A Decade of U.S. Wind Growth, Climate Central, 4/10/24 ; North Dakota Rides the Winds of Change, Clean Grid Alliance, 3/22/23 ; 50 states of solar incentives: North Dakota, PV Magazine, 2/17/23 ; Why Alabama still lags the rest of the Southeast on solar, Energy News Network, 4/6/17; Nebraska Solar Incentives, Tax Credits 1And Rebates Of 2024, Forbes Home, 1/24/24 ; Arrival of large-scale solar projects in Nebraska met with resistance, Nebraska Public Media, 6/29/23 ; A Solar Design Manual for Alaska, Sixth Edition, University of Alaska Fairbanks, October 2022 ; Alaska's big shift to renewable energy appears stalled, as future access to natural gas in doubt, Alaska Public Media, 5/18/23 ; Net Metering proposed settlement welcomed by solar advocates, WV Metro News, 2/25/24 ; Solar Panel Cost in West Virginia: 2024 Guide, EnergySage, accessed 5/2/24 ; West Virginia Governor vetoes bill that would double allowable solar project size, PV Magazine, 3/28/24.

State Net Metering Policies

Distributed Generation Policy Activity in Q1 2024



Sources: Massachusetts expands solar net metering, bucking a national trend, PV Magazine, 3/1/24. Massachusetts order expected to boost distributed solar, could be model for other states, official says, Utility Dive, 2/21/24. Massachusetts expands solar net metering , Environment America, 3/7/24. As states slash rooftop solar incentives, Puerto Rico extends them, Grist, 2/6/24. APS customers face electric rate increase, rooftop solar surcharge, AZ Central, 2/22/24. Settlement reached in net-metering case, WV Metro News, 2/18/24. Puerto Rico's rooftop solar boom is at risk, advocates warn, Canary Media, 5/20/24. Q1 2024 50 States of Solar, NC Clean Energy Technology Center, 4/24 (map reproduced with permission).

In Q1 2024, 26 states, DC, and Puerto Rico were working on PV compensation changes. For example:

- **Arizona** added a monthly rooftop solar surcharge of $2.50–$3.00.
- **West Virginia** approved an agreement setting export credit rates for distributed solar generation for Mon Power and Potomac Edison from 8.9 to 9.3 cents per kWh depending on customer rate class. The two utilities proposed changing WV's 1-to-1 net metering system to base credits of 6.6 cents per kWh. The proposal garnered large-scale protest. Ultimately, the two parties were able to settle on higher base rates.
- **Massachusetts** raised the net-metering cap exemption for small systems from 10 to 25 kW, added cap exemptions for large public and private systems, and became the first state to allow net-metering facilities to transfer credits to customers using a different electricity provider. Credit transfers and sales will allow larger facilities to gain benefit from their unused net-metering credits.
- **Puerto Rico** extended the lifetime of its 1-to-1 bill credit program until at least 2030. (Note: this law is now facing pushback from the Financial Oversight and Management Board.)

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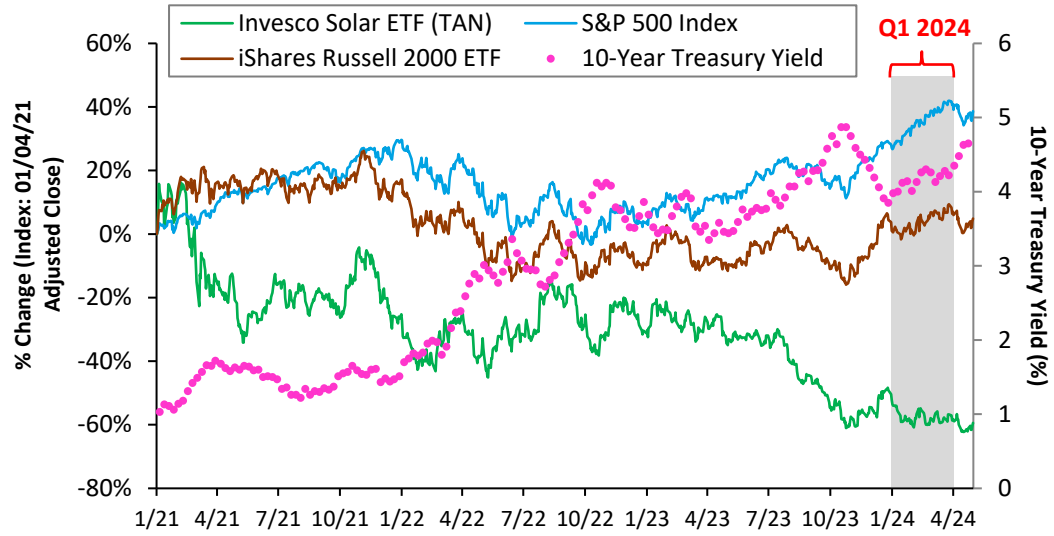
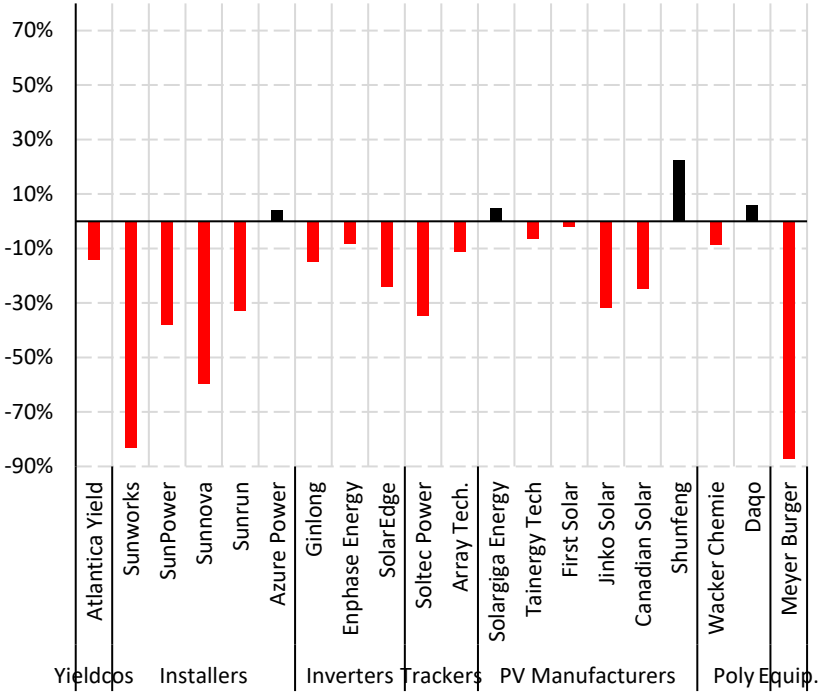
Stock Market and Policy

The Invesco Solar ETF fell 18% in Q1 2024, resuming its long slide after an uptick at the end of 2023, compared with a 1%–8% increase across the broader market. In the face of persistent inflation, hopes of imminent Federal Reserve interest rate cuts faded and Treasury yields rose, reducing profitability and hindering financing for potential PV customers. Reduced demand for residential PV due to California's NEM 3.0 policy also continued to weigh on the market. In addition, conflict in the Red Sea region and drought affecting the Panama Canal increased the costs of shipping modules.



Individual Stock Performance (Q1 2024)



Note: The TAN index is weighted toward particular countries and sectors. As of 5/3/24, 54% of its funds were in U.S. companies and 16% were in Chinese companies. Its top 10 holdings, representing 60% of its value, were First Solar, Enphase, NEXTracker, SolarEdge, GCL, Hannon Armstrong, Xinyi, Sunrun, Array Technologies, and Encavis.

Sources: CNET (3/18/24); Federal Reserve Bank of St. Louis (accessed 5/3/24); Invesco (5/3/24); PV Magazine (3/21/24); Reuters (3/14/24); Yahoo Finance (accessed 5/3/24).

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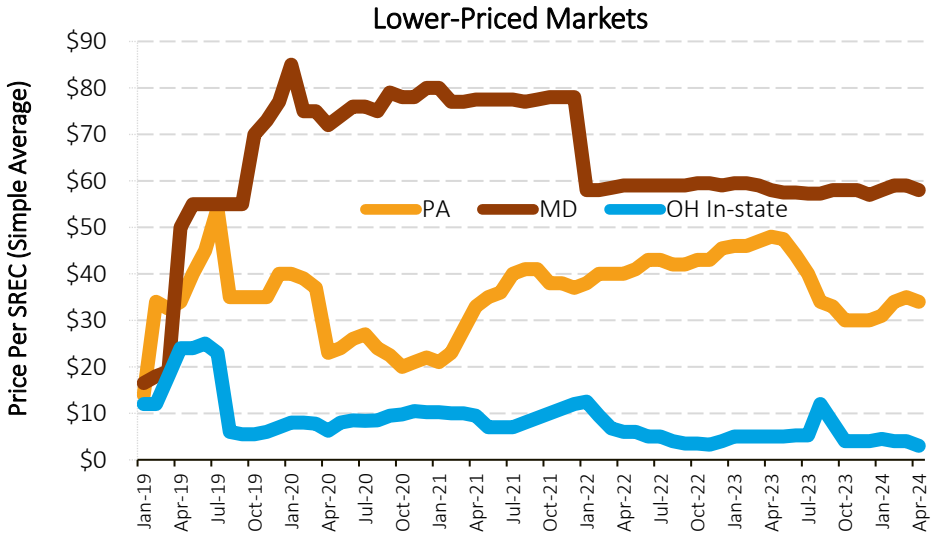
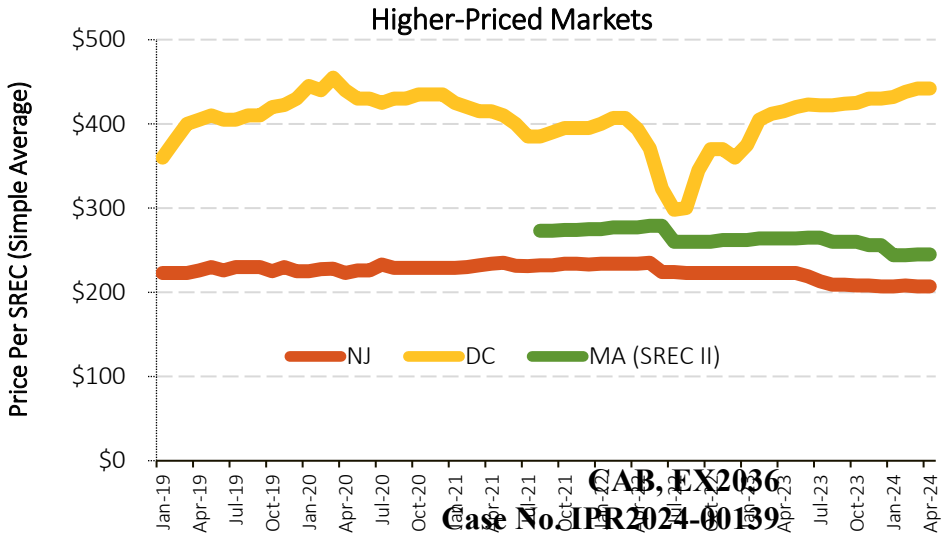
SREC Pricing

- 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.





Source: SRECTrade, https://www.srectrade.com/, accessed 05/16/24.

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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. Market and Policy
7. **U.S. PV Imports**

- **According to U.S. Census data, 55.6 GW_{dc} of modules and 3.7 GW_{dc} of cells were imported in 2023, an increase of 87% y/y and 46% y/y, respectively.**
  - **In Q1 2024, PV module imports held relatively steady for the third straight quarter at 15.2 GW_{dc}.**
  - **Collectively, Malaysia, Vietnam, Thailand, and Cambodia represented 78% of module imports (79% including c-Si cells).**
  - **Imports from India and Indonesia grew significantly in 2023.**
- **According to U.S. Census data, the United States imported nearly 2 GW_{dc} of cells in Q1 2024—the fourth straight quarter of growth. If this trend continues, the United States could hit its cell import quota of 5 GW_{dc} by September, at which point U.S. manufacturers will pay a tariff on importing cells.**
- **The proportion of modules exempt from Section 201 duties has grown from 40% in 2019 to 96% in 2023. The President has just removed the major Section 201 exemption, which is for bifacial modules.**

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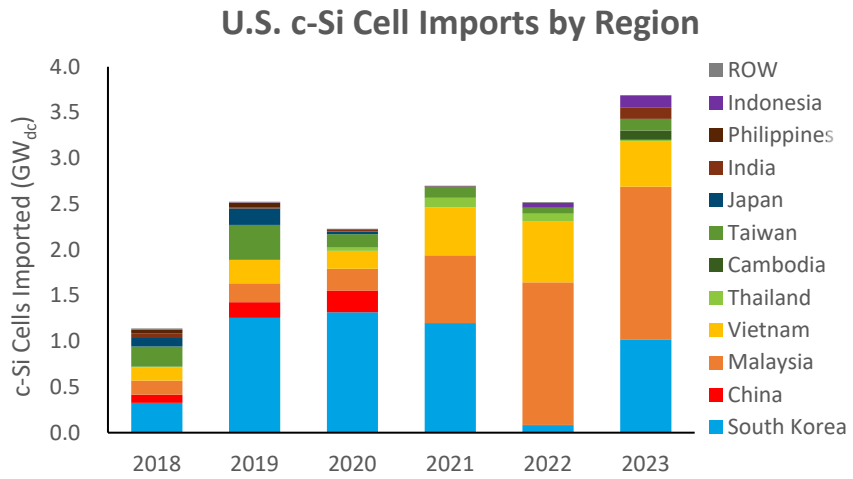
Annual c-Si Cell + Module Imports

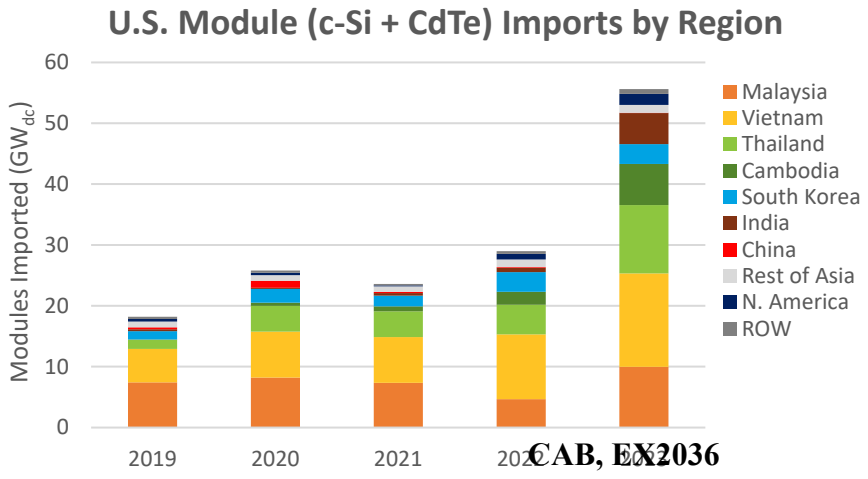
According to U.S. Census data, 3.7 GW_{dc} of cells were imported in 2023, an increase of 46% y/y (1.2 GW).

- In 2023, Malaysia represented 45% of cell imports (1.7 GW), just exceeding 2022 imports (1.6 GW). After minimal production in 2022, South Korea represented 28% of module imports in 2023 (1 GW), falling just short of 2021 imports (1.2 GW).
- Imports from India and Indonesia grew in 2023, each representing about 5% (125 MW).

According to U.S. Census data, 55.6 GW_{dc} (45.5 GW c-Si and 10.1 GW CdTe) of modules were imported in 2023, almost double the imports in 2022.

- In 2023, 18% of modules were imported from Malaysia, 28% from Vietnam, 20% from Thailand, and 12% from Cambodia for a total of 78% of all module imports (or 74% of c-Si modules) coming from the four countries under AD/CVD investigation. These four countries represent 79% of c-Si cell and module imports.
- An additional 9%* of module imports in 2023 were from India.





*Several GW of imports from India entered under the HTS code for thin-film modules in 2022/2023, but are believed to be c-Si based on known capacities and [redacted]. These 2022/2023 modules may not owe duties.

Sources: Imports by HTS code: 8541460015(2018-2021)/8541430010(2022-) and 8541460035(2018-2021)/8541430080(2022-), Second Quantity (watts) from the U.S. Census Bureau USA Trade Online tool and corrections page as of 5/6/24. Several GW of imports from India entered under the HTS code for thin-film modules in 2022/2023, but are believed to be c-Si based on news reports.

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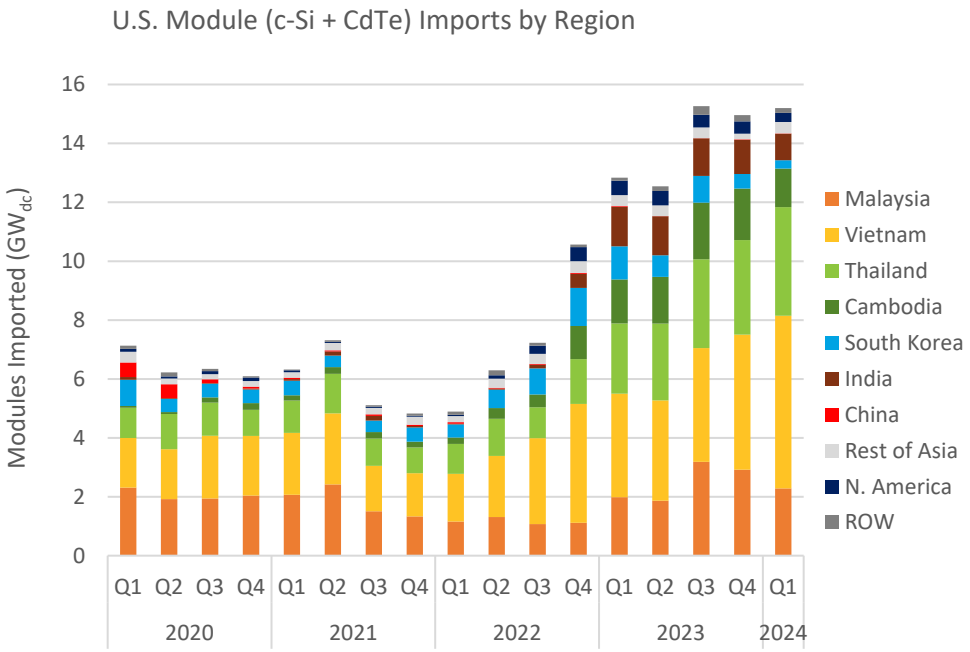
U.S. Module Imports Q1 2024 by Region



According to U.S. Census data, in Q1 2024, U.S. module imports held relatively steady for the third quarter in a row (15.2 GW, +2% q/q).

- Imports from Vietnam represent an expanding percentage, growing from 25% in Q3 2023 to 39% in Q1 2024. In Q1 2024, Vietnam alone was responsible for 5.9 GW of modules (5 GW of c-Si + 0.9 GW thin film)
- After experiencing significant growth in 2023, imports from South Korea and India have slowed, although they still collectively accounted for 15% of module imports in 2023 and 8% of imports in Q1 2024.

Looking historically, import levels had 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 2022 after the announcement of a U.S. anti-circumvention investigation and the implementation of the Uyghur Forced Labor Prevention Act. However, after the 2-year waiver of new AD/CVD duties was announced in June 2022, imports had grown steadily over the course of about a year and a half before hitting a plateau in Q3 2023.

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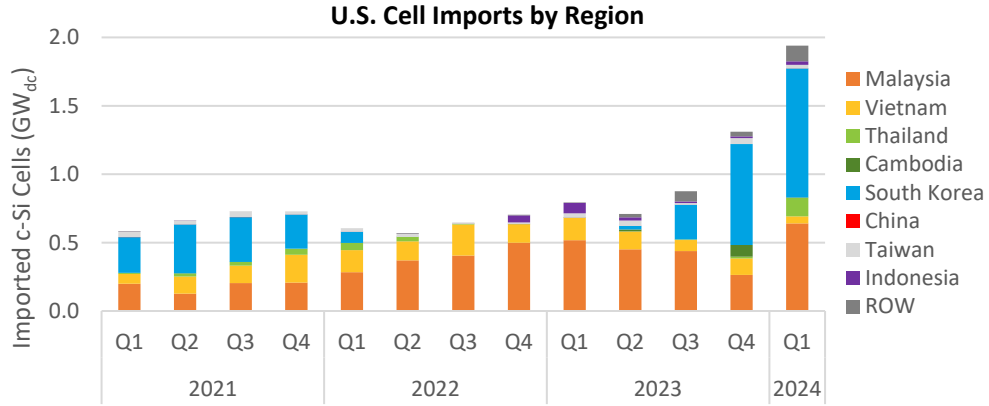
Sources: Imports by HTS code: 8541460015(2018-2021)/8541430010(2022-) and 8541460035(2018-2021)/8541430080(2022-), Second Quantity (watts) from the U.S. Census Bureau USA Trade Online tool and corrections page as of 5/6/24. Several GW of imports from India entered under the HTS code for thin-film modules in 2022/2023, but are believed to be c-Si based on news reports.

c-Si Cell Import Data Q1 2024

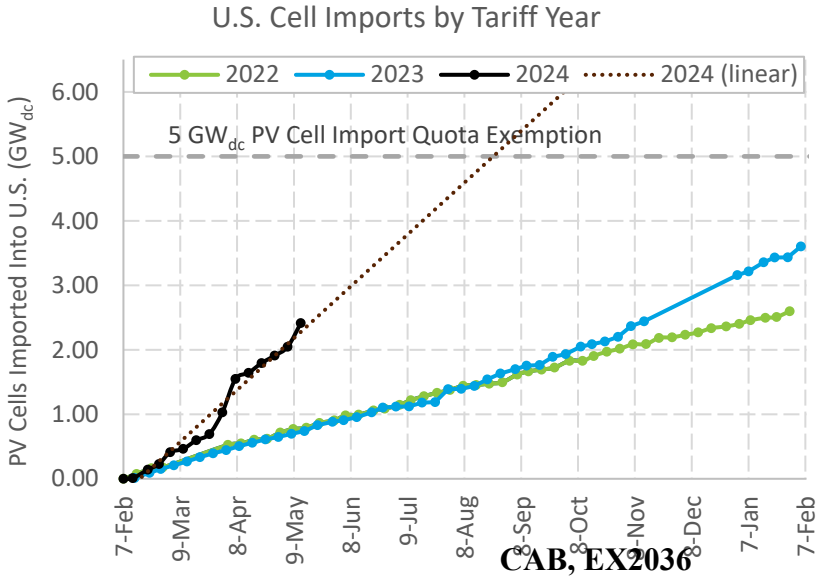
According to U.S. Census data, the U.S. imported nearly 2 GW_{dc} of cells in Q1 2024—the fourth straight quarter of growth (and 2nd straight 50%+).

- Most of the growth has come from South Korea, which represented 50% of imports in Q4 2023 (740 MW) and Q1 2024 (940 MW).
  - The largest c-Si module manufacturer in the United States is Korean-headquartered Q Cells.
- Comparing to Q1 2023, c-Si cell imports have nearly tripled y/y.



After several years of relatively steady import volumes, c-Si cell imports have begun to rise substantially even as new domestic module manufacturing capacity comes online.

According to CBP Commodity Status Reports, cell imports since February (the date the annual tariff rate quota for Section 201 Tariffs is counted from) have grown significantly relative to prior years, hitting 2 GW in May. If imports continued at the average rate of imports, the 5.0 GW TRQ would be exceeded by September.



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 4/11/23; U.S. Customs and Border Protection Commodity Status Reports February 2019–April 2023.

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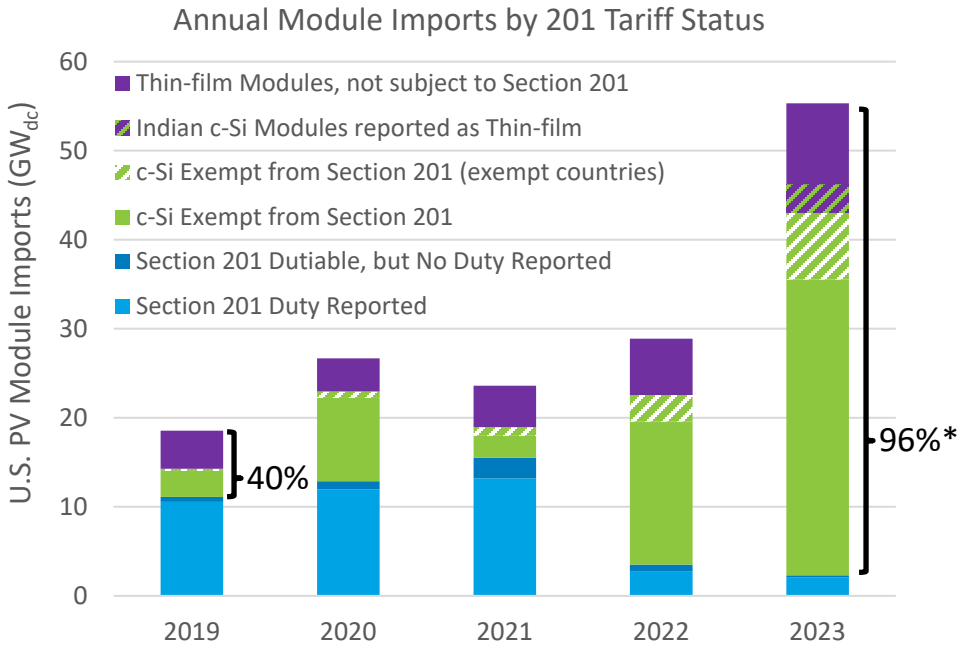
2023 U.S. Module Imports by Tariff



Sources: Imports by HTS code: 8541460015(2018-2021)/8541430010(2022-) and 8541460035(2018-2021)/8541430080(2022-), Second Quantity (watts), and Rate Provision Code from U.S. Census Bureau USA Trade Online tool and corrections page as of 3/11/24.

*Several GW of imports from India entered under the HTS code for thin-film modules in 2022/2023, but are believed to be c-Si based on known capacities and news reports. These modules may or may not owe duties.

The proportion of modules exempt from Section 201 duties has grown from 40% in 2019 to 96%* in 2023.

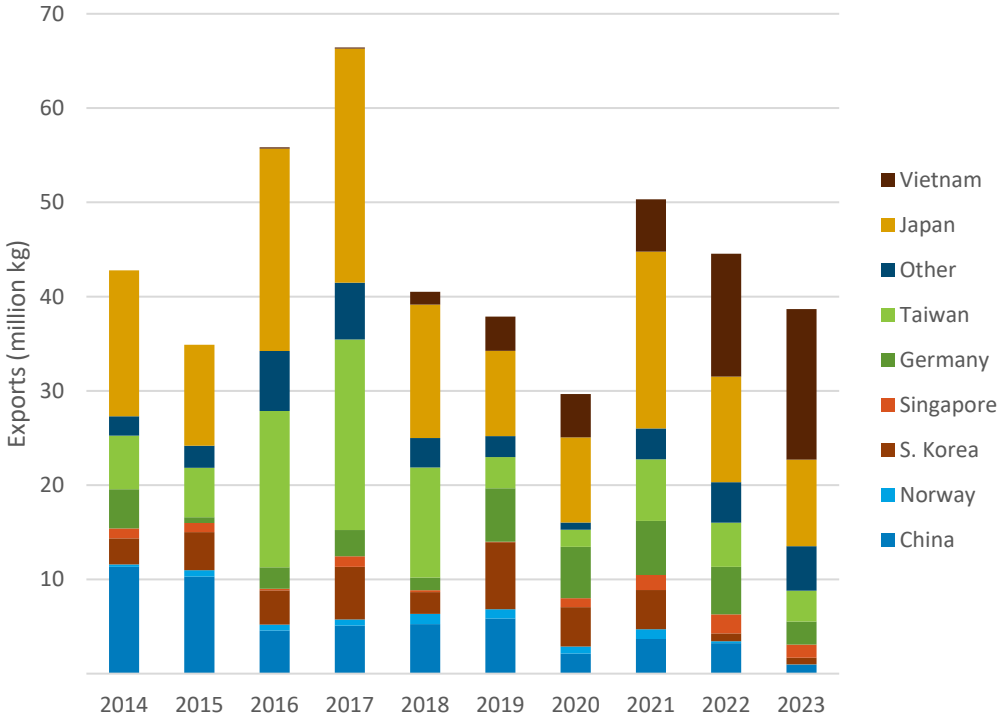
- In 2023, just over 2 GW of modules reported paying a tariff, compared to over 13 GW in 2021.
- Thin-film module imports grew to 9 GW* in 2023, up from 6.3 GW in 2022, and accounting for 16% of imported modules.

Modules can be exempt from Section 201 duties if they are:

- Thin-film modules (including CdTe)
- Bifacial modules
- Imported from certain exempt countries (including Canada, but most notably Cambodia, which accounted for 12% of imports in 2023)
- IBC (Interdigitated Back Contact) modules.

Bifacial modules are used primarily in utility-scale applications.

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



Note: The U.S. tracks the export of silicon, with a purity exceeding 99.99% (HS Code 2804610000), which is used within the semiconductor industry (9N+), for fire-resistant material (4N+. e.g., spray coating), and for PV wafers (9N).

Sources: U.S. Census Bureau; PV Magazine (02/29/24).

- After China placed duties of 57% on U.S.-manufactured polysilicon, the United States shifted exports to other markets, particularly Japan and Taiwan.
  - U.S. exports rose after the Chinese tariffs, because of an increase in domestic manufacturing capacity, mostly from a new Tennessee Wacker plant.
    - U.S. polysilicon capacity would have likely been higher if not for the Chinese tariffs, as plans for other U.S. polysilicon plants were canceled.

- However, China continued to increase its polysilicon and wafer manufacturing capacity, making U.S. polysilicon less competitive to foreign buyers, and non-Chinese wafer manufacturing less competitive internationally (causing them to produce less and therefore buy less U.S. polysilicon). As a result, U.S. exports dropped, shifting its exports almost entirely to the semiconductor industry.
- Since 2021, U.S. trade policies against China (e.g., UFLPA) have created a bifurcated market, resulting in more demand for polysilicon for semiconductors (in Japan, Taiwan, and Germany) and for PV wafers in Vietnam (where three of the four largest Chinese PV module companies have set up wafer plants).

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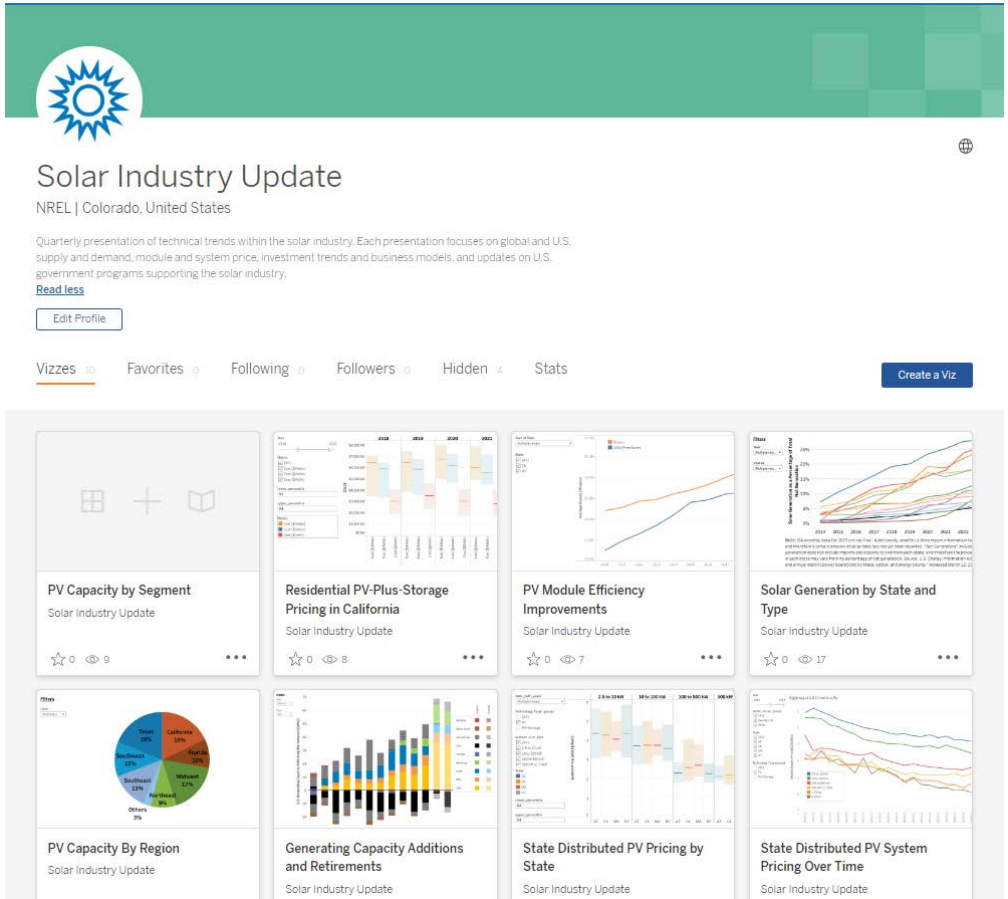

Interested in checking out more of our data in Tableau? Click here

Thank You

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List of Acronyms and Abbreviations

AD: antidumping
ac: alternating current
ASP: average selling price
BIPV: building-integrated photovoltaics
BLM: U.S. Bureau of Land Management
c-Si: crystalline silicon
C&I: commercial and industrial
CC: combined cycle
CBP: U.S. Customs and Border Protection
CdTe: cadmium telluride
CIGS/CSI: copper indium gallium selenide
CPI: consumer price index
CPUC: California Public Utility Commission
CRA: Congressional Review Act
CSP: concentrating solar power
CT: combustion turbine
CVD: countervailing duty
dc: direct current
DPV: distributed photovoltaics
DOE: U.S. Department of Energy
EIA: U.S. Energy Information Administration
ETF: exchange traded fund
ETS: Economic Transition Scenario
EU: European Union
FPC: Federal Power Commission
GW: gigawatt
GWh: gigawatt-hour
H1: first half of year
H2: second half of year
HJT: heterojunction technology
HTS: harmonized tariff schedule
IEA: International Energy Agency
ILR: Inverter Loading Ratio
IOU: investor-owned utility
IRA: Inflation Reduction Act of 2022
IRS: Internal Revenue Service
IBC: interdigitated back contact
ITC: investment tax credit
ITRPV: International Technology Roadmap for Photovoltaics
kW: kilowatt
kWh: kilowatt-hour
LBNL: Lawrence Berkeley National Laboratory
LMI: low- and moderate-income
MW: megawatt
MWh: megawatt-hour
NEA: China's National Energy Administration
NEM: net energy metering
NOPR: Notice of Proposed Rulemaking
NREL: National Renewable Energy Laboratory
PERC: passivated emitter and rear contact
PPA: power purchase agreement
PTC: production tax credit
PV: photovoltaics
Q: quarter
q/q: quarter over quarter
SEIA: Solar Energy Industries Association
SETO: Solar Energy Technology Office
STEPS: Stated Policies Scenario
TAN: Invesco Solar ETF
TOPCon: tunnel oxide passivated contact
TRQ: tariff rate quota
TW: terawatt
TWh: terawatt-hour
UFLPA: Uyghur Forced Labor Prevention Act
UPV: utility-scale photovoltaics
USD: U.S. dollars
VPP: virtual power plant
W: watt
Wt avg: weighted average
WRO: Withhold Release Order
WTO: World Trade Organization
y/y: year over year
YTD: year to date

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