NREL
NATIONAL RENEWABLE ENERGY LABORATORY

# Q2/Q3 2018 Solar Industry Update

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# Executive Summary

- In H1 2018, the leading solar markets of China, the United States, India, and Japan had installation levels similar to those of H1 2017; however, analysts, on average, expect a significant decrease in annual PV deployment for the entire year.
- In 2018, analyst projections range from 75 GW to 102 GW, compared to 98 GW in 2017.
- Three CSP projects (350 MW-AC) became operational in the first nine months of 2018 and another five (450 MW-AC) are expected to be completed by the end of the year.
- California passed SB 100, requiring 60% of its electricity sales from renewable sources by 2030 (up from 50%) and 100% carbon free electricity by the end of 2045.
- In H1 2018, the United States installed 4.6 GW-DC of PV, 55% from the utility-scale PV market.
- EIA reports that 22% of all new electricity generating capacity came from solar installations in H1 2018—second to natural gas (67%).
- In the first half of 2018, the range in average U.S. PV system pricing across methods was reported to be:
  - $2.7/W to $4.2/W for residential
  - $1.5/W to $3.5/W for nonresidential
  - $1.0/W to $1.1/W for utility-scale.
- In H1 2018, U.S thin-film and c-Si module production were at approximately the same levels as in H1 2017, while c-Si cell production was down 70%, y/y.
- In October, global module ASP was reported to be $0.23/W.
- Recent analysts' reports indicate global module prices are expected to continue to drop in the next few years, falling below $0.20/W in the next five years.
- At the end of October 2018, solar stocks were down 30% for the year, compared to 5% for the broader market.

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

1 State and Federal Updates

2 Global Solar Deployment

3 U.S. PV Deployment

4 PV System Pricing

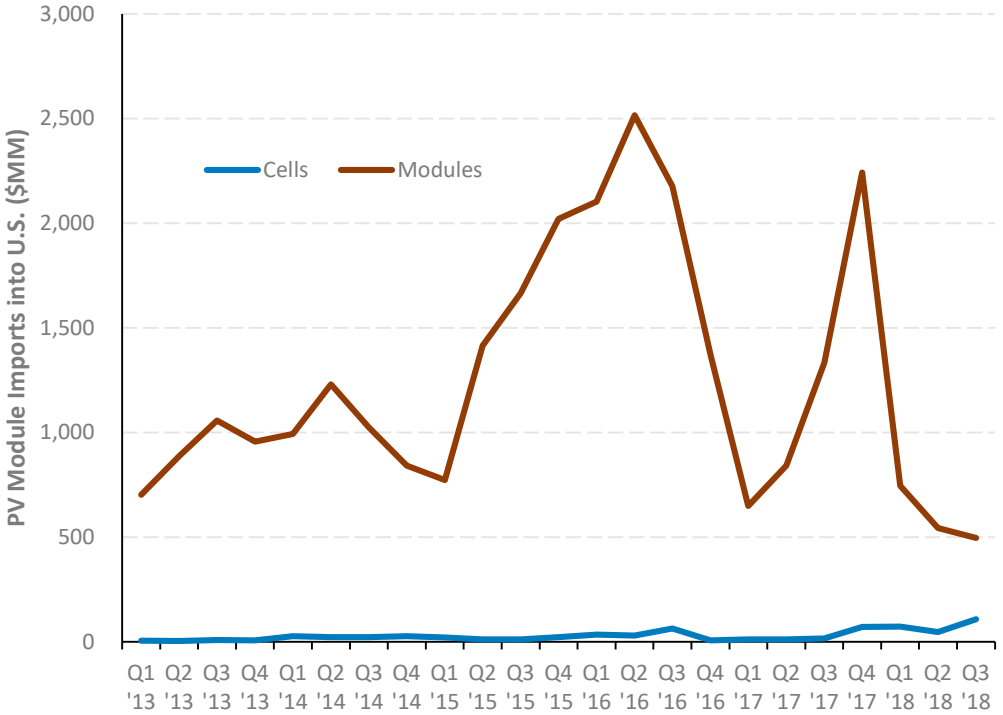
5 Global Manufacturing

6 Component Pricing

7 Market Activity

- **PV module import value has been at historically low levels ($1.3 billion in H1 2018) since the implementation of the Section 201 tariffs, while PV cell value has been relatively high ($120 million in H1 2018).**
- **In September 2018, California passed SB 100, requiring 60% of its electricity sales from renewable sources by 2030 (up from 50%) and 100% carbon free electricity by the end of 2045.**

# Federal Updates: Module and Cell Import Data




While module and cell imports into the United States fluctuate over time, PV module import value has dropped to historically low level since the implementation of the Section 201 tariffs, while PV cell value has been increasing.

- In the first nine months of 2018, the United States imported $1.8 billion in PV modules (4.5 GW, assuming $0.4/W modules) and $228 million in PV cells (1.1 GW, assuming $0.2/W cells).
- The top four countries that the United States imported PV modules from during the first nine months of 2018 were Malaysia ($505 million), South Korea ($364 million), Vietnam ($245million), and Mexico ($245 million).
- The top four countries that the United States imported PV cells from during the first nine months of 2018 were South Korea ($76 million), Malaysia ($41 million), Philippines ($32 million), Japan ($19 million), and Vietnam ($21 million).

**Sources**: Imports, by value: U.S. International Trade Commission, 2018.

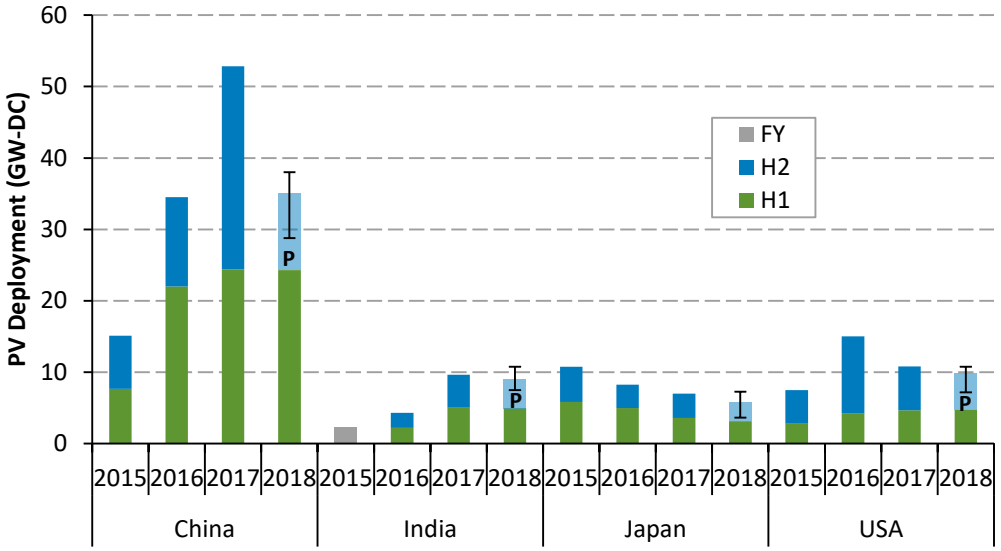
# State Updates: California Sets 100% Carbon Free Electricity Standard

- In September 2018, California passed SB 100, requiring 60% of its electricity sales from renewable sources by 2030 (up from 50%) and 100% carbon free electricity by the end of 2045.
  - The RPS standard ramps up in a stepwise manner: 33% by the end of 2020, 50% by 2026, and 60% by 2030.
    - In 2017, 29% of California's electricity came from renewables.
  - In addition to renewable energy, nuclear power and natural gas generators with advanced carbon capture also qualify for the remaining 40%.
  - PV Magazine estimates that the RPS increase from 50% to 60% could translate into an additional 10 GW of solar and wind (with the bulk coming from solar).
- This law stipulates that implementation of the plan cannot increase carbon emissions elsewhere in the western grid (i.e., to balance California's energy load).

**Sources**: CA: NY Times(05/09/2018); NY: PV Magazine (07/19/2018; 09/06/18); Wood Mackenzie Power & Renewables & SEIA, "U.S. Solar Market Insight: Q2 2018." https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB100, Acknowledgements: Christina Volpi, Jenny Heeter, and Sam Koebrich (NREL).

- **In H1 2018, the leading solar markets of China, the United States, India, and Japan, each had similar installation levels as H1 2017; however, analysts, on average, expect a decrease in annual PV deployment for the entire year.**
- **While most analysts estimate a significant decrease in global PV installations in 2018, projections range from 75 GW to 102 GW.**
- **The median analyst figures estimate that 530 GW of PV will be installed globally from 2018 to 2022, more than doubling current installed capacity.**
- **Three CSP projects (350 MW-AC) became operational in the first nine months of 2018 and another five (450 MW-AC) are expected to be completed by the end of the year.**

# Global PV Deployment: Key Markets Update

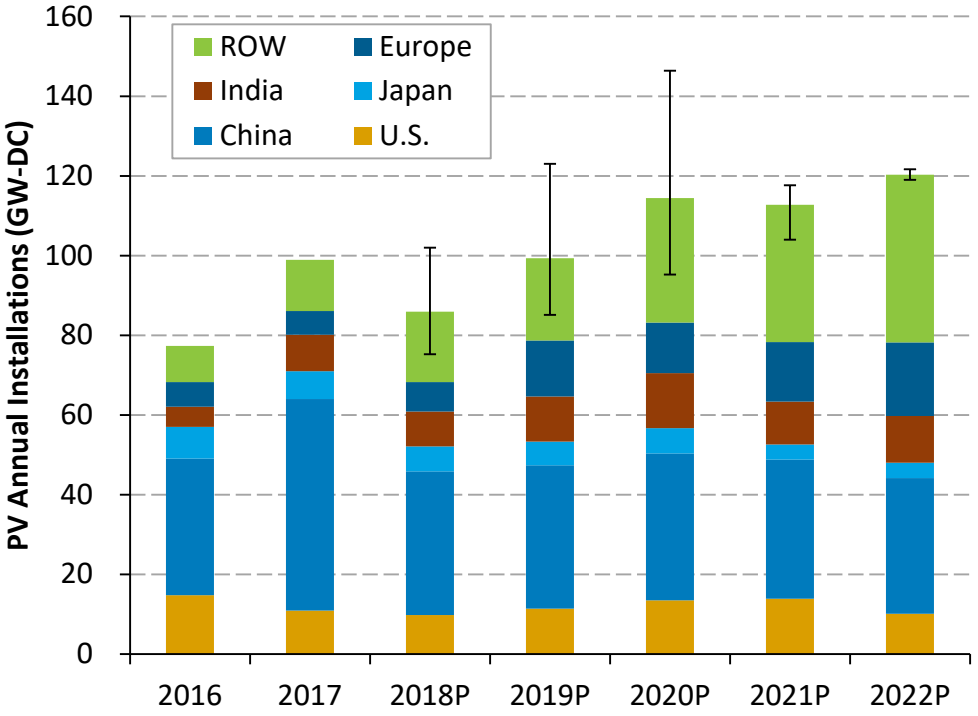



- China, India, Japan, and the United States installed approximately 80% of global PV capacity in 2017.
- In H1 2018, these top markets had similar installation levels as H1 2017; however, analysts, on average, expect a decrease in annual PV deployment for the entire year.
  - In China and India, annual deployment is expected to decrease 40% and 15% y/y respectively, though expectations vary among analysts.
  - Despite a dramatic reduction in demand, which was caused by a change in FIT policy, China is still expected to be the largest market in H2 2018.
  - Approximately half of the Chinese capacity installed in H1 2018 was DG, which represents a 72% y/y increase.
- In 2018, analysts expect China (~35 GW), the United States (~10 GW), India (~9 GW), and Japan (~6 GW) to remain the four largest markets.
  - China added another 10 GW in Q3 2018, bringing its nine-month total to 34.5 GW.

**Note:** P = projection for second half of 2018. Bar represents median projection. Error bars represent high and low projections.

**Sources:** Projections: See Slide 9. Historical: NREL, "Q2/Q3 2017Solar Industry Update;" GTM/SEIA, "U.S. Solar Market Insight, Q3 2018"; Mercom, "Q2 2018 India Solar Quarterly Market Update;" Mercom (10/15/18, 11/05/18); PV Tech (08/02/18); RTS Corporation (10/09/18).

# Annual Global PV Demand

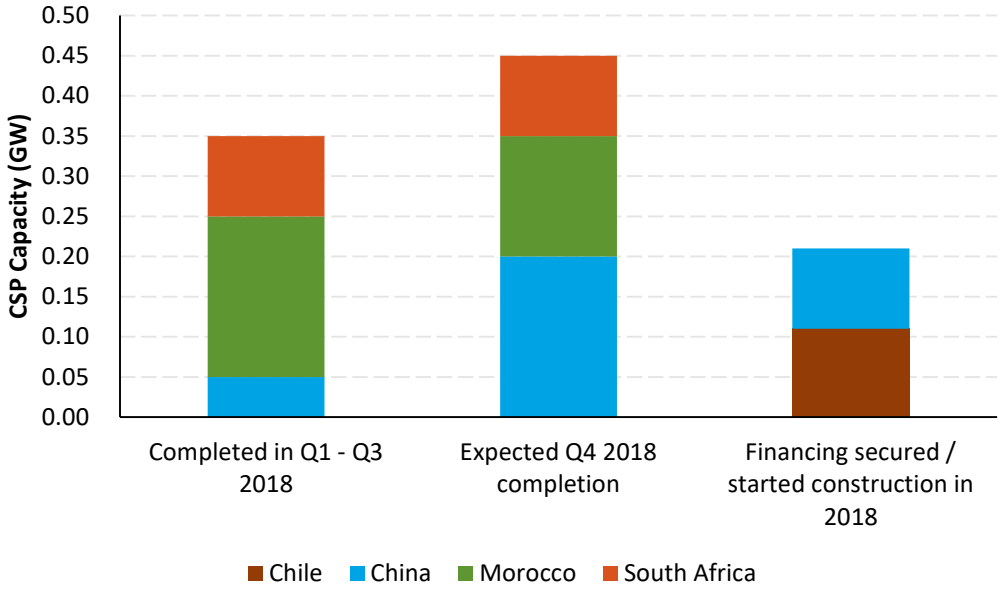



- While most analysts estimate a decrease in global PV installations in 2018, projections range from 75 GW to 102 GW.
  - The expected drop in Chinese installations in 2018 is projected to be larger than the total drop in annual global installations, offsetting significant increases in demand from ROW countries.
- Analysts expect China, with 25%–40% of the total global market, to remain the largest PV market through 2022.
- Median analysts' figures estimate that 530 GW of PV will be installed globally from 2018 to 2022, more than doubling current installed capacity.

**Note:** P = projection. Bar represents median projection. Error bars represent high and low projections.
**Sources**: BNEF (August 2018); Cowen & Co. (09/26/18); Credit Suisse (08/20/18); Goldman Sachs (09/18/18), Wood Mackenzie Power and Renewables (October 2018).

# 2018 Global CSP Activity (to date)

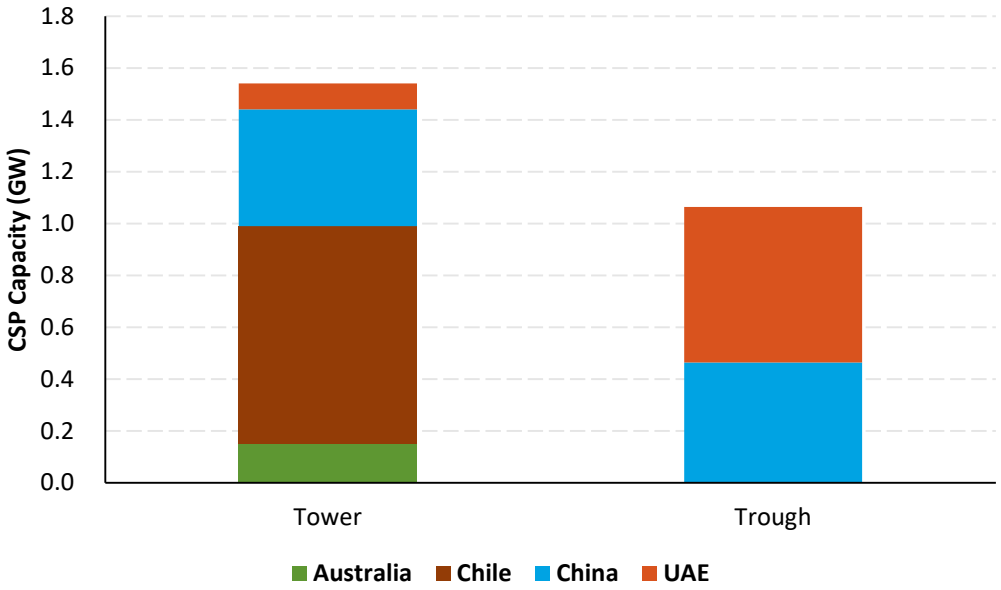
Three CSP projects (350 MW-AC) became operational in the first nine months of 2018 and another five (450 MW-AC) are expected to be completed by the end of the year.




- Phase III of the Noor CSP plant, in Morocco, is expected to be fully operational by the end of the year. When complete, it will be the largest CSP plant in the world, with a total of 560 MW-AC.
- In June, China grid-connected its first large-scale CSP plant—a trough design with nine hours of storage. This plant is now operating.
- As of October, China was close to completing a 50-MW beam down tower, which represents the largest commercial demonstration of this technology.
- Two CSP plants in China and one in Chile, with a combined capacity of 200 MW-AC, received financing in 2018.
- In September 2018, Saudi Arabia announced it was putting on hold its $200 billion plan, with Japanese company SoftBank, to build 200 GW-AC of solar by 2030.

**Sources:** BNEF, "Capacity & Generation" data set, accessed October 12, 2018; CSP Today "Global Tracker;" Wall Street Journal (09/30/18); CSP Today (September 2018).

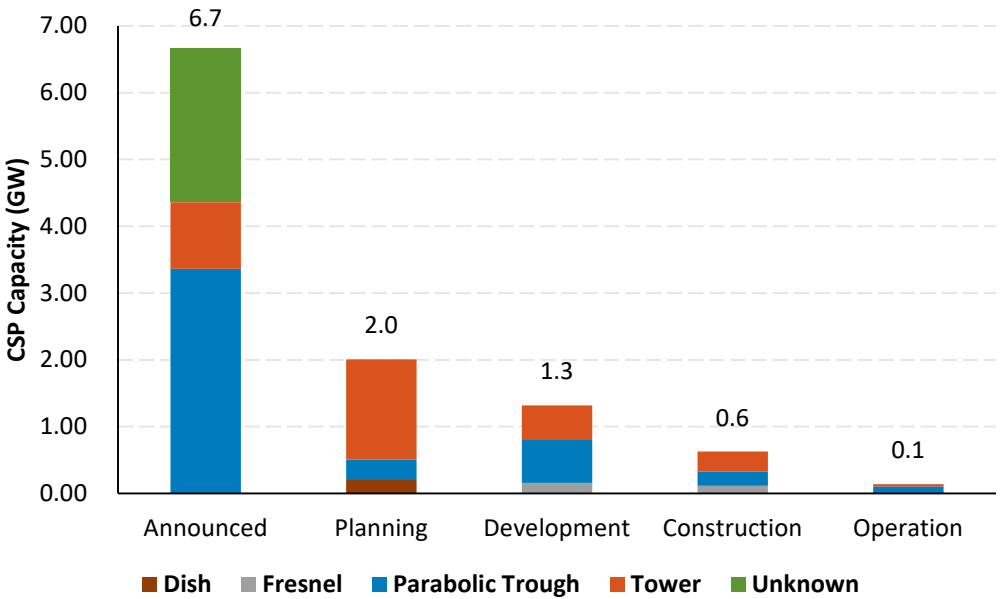
# Global CSP Projects Under Construction or with Financing Secured




- Nineteen major CSP projects in four countries are either under construction or have secured financing. They total approximately 2.6 GW-AC of generation capacity.
  - These projects include 6–15 hours of thermal storage.
  - 1.5 GW-AC of the active CSP projects have a tower design, with 84% located in Chile and China.
  - 1.1 GW-AC of the active CSP projects have a trough design, and are located in the UAE or China.
- Another 1 GW-th of CSP steam/heat generation is also under construction.

**Sources:** Shemer 2018; CSP Focus 2017; Yang, Zhu, and Guo 2018; Lilliestam and Pitz-Paal 2018.

# China's 10.8 GW-AC CSP Pipeline

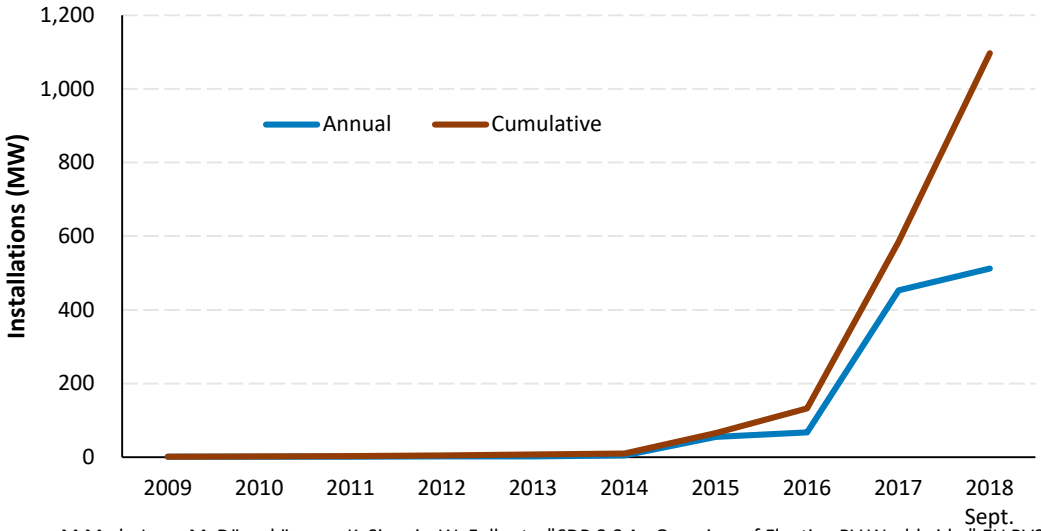



- While most of the projects are early in the development process, 71 CSP projects totaling 10.8 GW-AC are in some stage of development in China.
  - A mix of CSP technologies—including tower, Fresnel, and parabolic trough projects—either are in later stages of development or are under construction.
- In September 2016, China announced the 20 awardees of the first phase of CSP demonstration projects, totaling 1.35 GW-AC.
  - Many of the projects in the planning and development phase will join the second batch, which has yet to be announced.
  - It was announced in September 2018 that 14 of the 20 first-phase Chinese demonstration plants (or 1.0 GW-AC out of 1.35 GW-AC) would be moving forward.

**Sources:** CSP Today "Global Tracker" (August 30, 2018). CSP Today (September 2018).

# Floating Solar Overview

- Floating solar is ideally suited for areas with limited availability of low-cost flat land, such as that found in Japan, Netherlands, and China.
- New racking solutions, and installations and O&M practices have been developed during the past couple of years to cut costs significantly.




- At the end of September 2018, 1.1 GW of floating solar were operating worldwide.
  - Approximately 88% of the capacity was installed in the past 21 months.
- At least 157 floating systems are installed in 25 different countries.
  - Most *installed capacity* is in China, which is followed by Japan.
  - Most of the *installations* are in Japan, with China and Netherlands being second and third.
- While 24 companies have installed floating solar, 2 companies have installed most of the floating solar capacity:
  - Ciele & Terre, based in France
  - SunGrow, based in China.

**Sources:** M.M. de Jong, M. Dörenkämper, K. Sinapis, W. Folkerts. "6DP.2.3 An Overview of Floating PV Worldwide." EU PVSEC. September 27, 2018.
World Bank Group, ESMAP and SERIS. 2018. Where Sun Meets Water: Floating Solar Market Report—Executive Summary. Washington, DC: World Bank.

# Floating Solar Overview, cont.

Key advantages of floating solar installations:

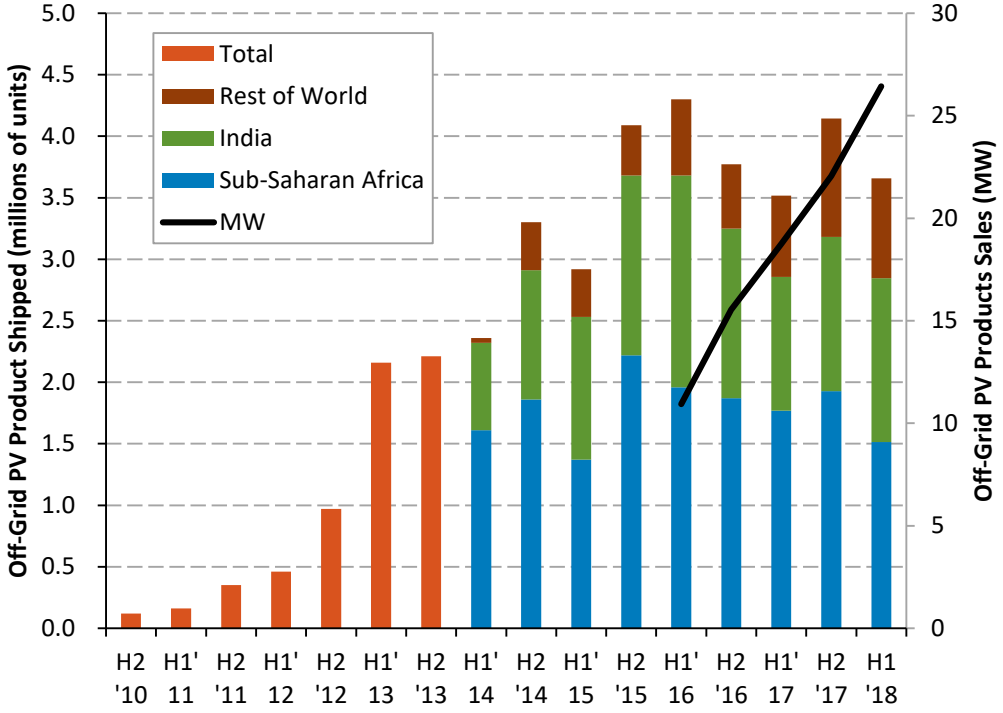
- Dual-use sites
- Proximity to transmission infrastructure at hydropower sites
- Close proximity to demand centers (e.g., reservoirs)
- Improved energy yield due to water cooling effect.

Challenges of floating solar installations:

- Nascent track record
- Uncertainty surrounding costs
- Unpredictability of environmental impact
- Technical complexity of designing, building, and operating on and in water.

**Source:** World Bank Group, ESMAP and SERIS. 2018. Where Sun Meets Water: Floating Solar Market Report—Executive Summary. Washington, DC: World Bank. Photo by Adam Warren (NREL).

# Global Off-Grid Solar Market




- The Global Off-Grid Lighting Association (GOGLA) tracked 3.7 million off-grid solar products, with a capacity of 26 MW, sold in H1 2018 for a value of $218 million.
  - GOGLA estimates they track roughly 30% of the total off-grid market, though this varies by region. This would imply that total global shipped in H1 2018 were over 12 million off-grid solar products, with a capacity of 88 MW.
  - Forty-one percent of sales in H1 2018 were in sub-Saharan Africa and 36% were in India.
- In 2017, approximately 46,000 off-grid products were sold in the United States for $1 million, at a price of approximately $16.5/W.
  - Most those products were rated under 1.5 W.
- In 2017, off-grid solar products were ~0.4% of the on-grid solar market; however, they can have a much higher dollar-per-person impacted ratio.

**Source:** Global Off-Grid Lighting Association. "Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data: January – June 2018."

# Global Off-Grid Solar Market (cont.)

| Product Size (Watts) | Use | % of H1 2018 Market Volume | % of H1 2018 MW Shipped |
|---|---|---|---|
| 0–1.5 | Single light only | 33% | 2% |
| 1.5–3 | Single light and mobile charging | 41% | 13% |
| 3–10 | Multiple lights and mobile charging | 15% | 14% |
| 11–20 | Solar home system (SHS), entry level (3–4 lights, mobile charging, powering radio, fan, etc.) | 4% | 7% |
| 21–49 | SHS, basic capacity (above plus power for TV and extended capacity) | 2% | 11% |
| 50–100 | SHS, medium capacity (above but with extended capacities) | 4% | 33% |
| 100+ | SHS, higher capacity (above but with extended capacities) | 1% | 20% |

- In H1 2018, approximately 89% of global off-grid solar volume, but only 29% of MW shipped, was for lighting products under 10 W.
  - The top-selling off-grid solar product is the single light with mobile charging. It accounted for almost half of off-grid product sales worldwide.
- In H1 2018, solar home systems (SHSs) accounted for approximately 11% of global off-grid solar volume and 71% of MW shipped.
  - Seventy-three percent of the capacity of solar home systems in H1 2018 were sold via a pay-as-you-go (PAYGO) business model, instead of cash, versus 34% for systems under 10 W.

**Source:** Global Off-Grid Lighting Association. "Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data: January – June 2018."

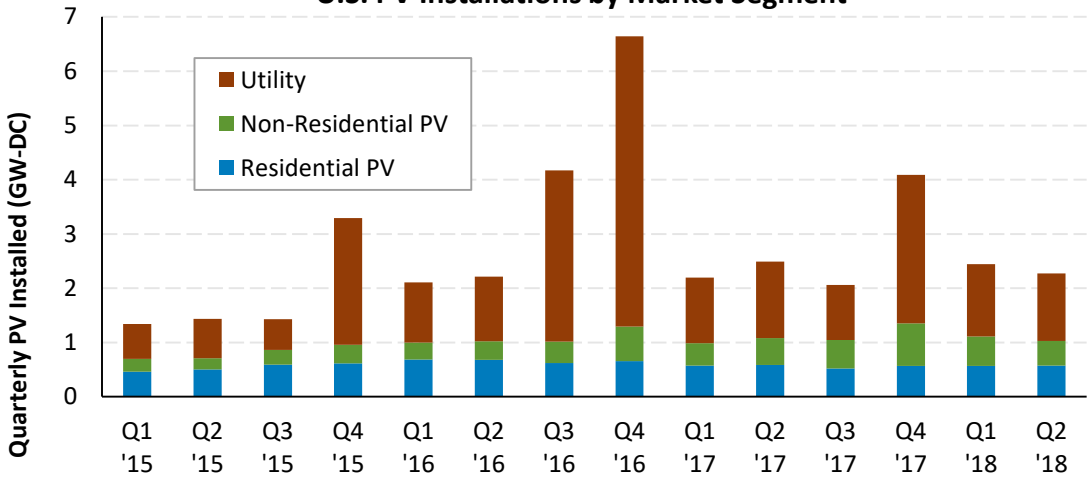
- In H1 2018, the United States installed 4.6 GW-DC of PV—55% from the utility-scale PV market.
- EIA reports that 22% of all new electricity generating capacity came from solar installations in H1 2018—second to natural gas (67%).
- The ten states with the highest percentage of solar penetration generated at least 4.0% of their total electricity from solar in the past 12 months, with California leading the way at 17.6%.
- In the first nine months of 2018, a record amount of off-site corporate solar PPAs were signed, both globally and in the United States, bringing cumulative corporate solar PPAs to just under 5.9 GW globally (4.6 GW in the United States).

# U.S. Installation Breakdown

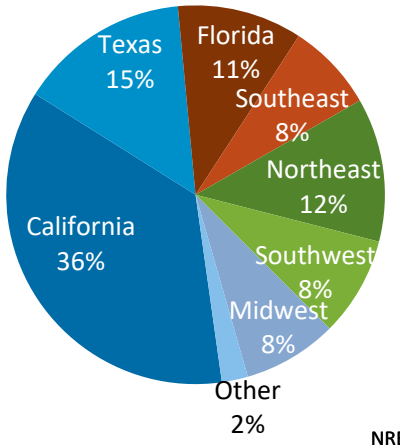
- In H1 2018, the United States installed 4.7 GW-DC of PV, flat y/y.
  - Fifty-five percent of capacity came from utility PV.
- Residential PV was relatively flat, y/y, in H1 2018
  - While larger markets contracted due to national installer pullback and customer acquisition issues, several emerging markets increased deployment.

- California, Texas, and Florida each installed more than 500 MW-DC of PV in the H1 2018.
- At the end of H1 2018, more than 1 GW of community solar were installed in the United States—up from about 100 MW in 2015.

**U.S. PV Installations by Market Segment**




**U.S. PV Installations by Region (MW-DC)**
**H1 2018**



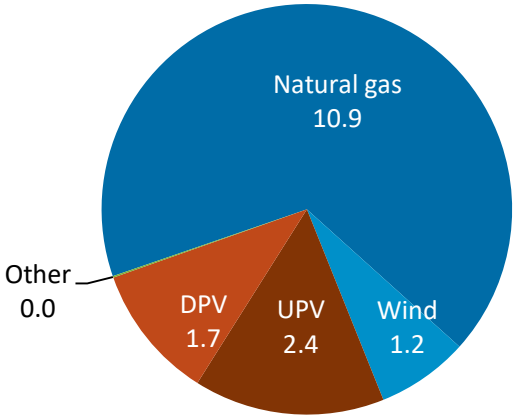

**Sources:** Wood Mackenzie Power & Renewables/SEIA: U.S. Solar Market Insight Q3 2018.

# U.S. Generation Capacity Additions by Source, H1 2018

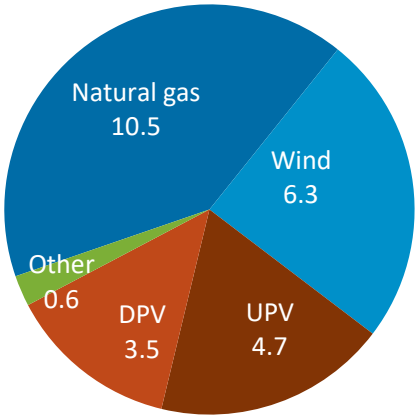
- The United States installed 16 GW-AC of new capacity in the first half of 2018, two-thirds of which were from 22 natural gas plants installed in 15 states.
- The United States installed more new generation capacity in H1 2018 than it did annually in five of the past twelve years.

- EIA reports that 22% of all new electricity generating capacity (4.2 GW-AC) in H1 2018 came from solar installation—second to natural gas (67%).
  - Wind was third, with 7% of all new electricity generating capacity (1.2 GW-AC).

**H1 2018 U.S. Generation Capacity Additions (Total 16.3 GW-AC)**

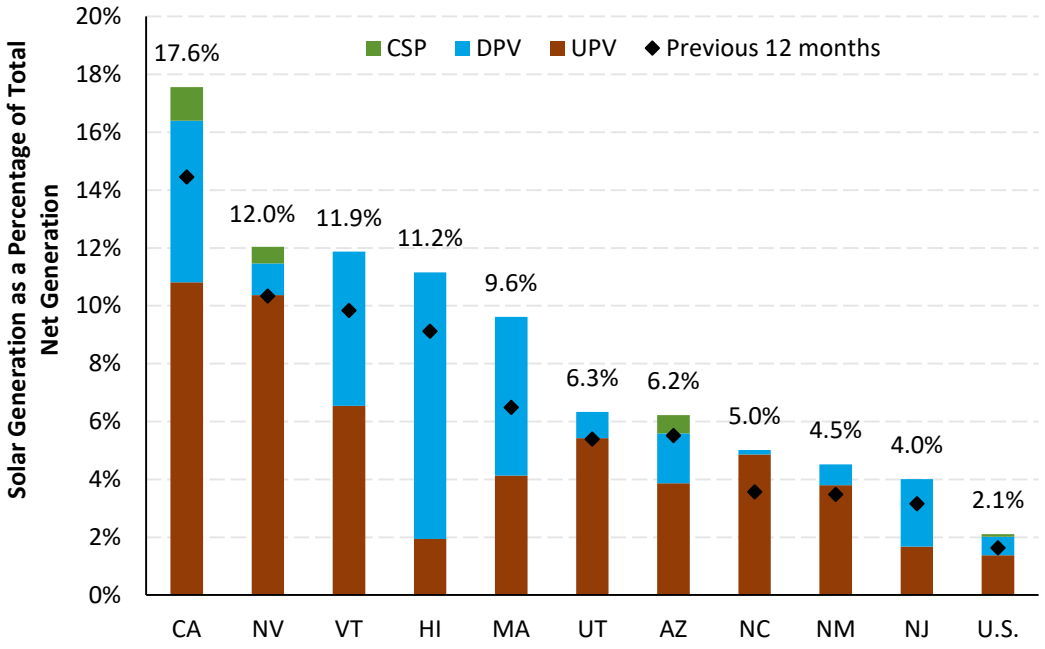



**2017 U.S. Generation Capacity Additions (Total 25.6 GW-AC)**




**Sources:** EIA "Preliminary Monthly Electric Generator Inventory" (December 2017). EIA, "Electric Power Monthly" Table 6.1; 2018. PV data prior to 2015 from Wood Mackenzie Power & Renewables / SEIA, assuming an ILR of 1.2.

# Solar Generation as a Percentage of Total Generation, July 2017–June 2018

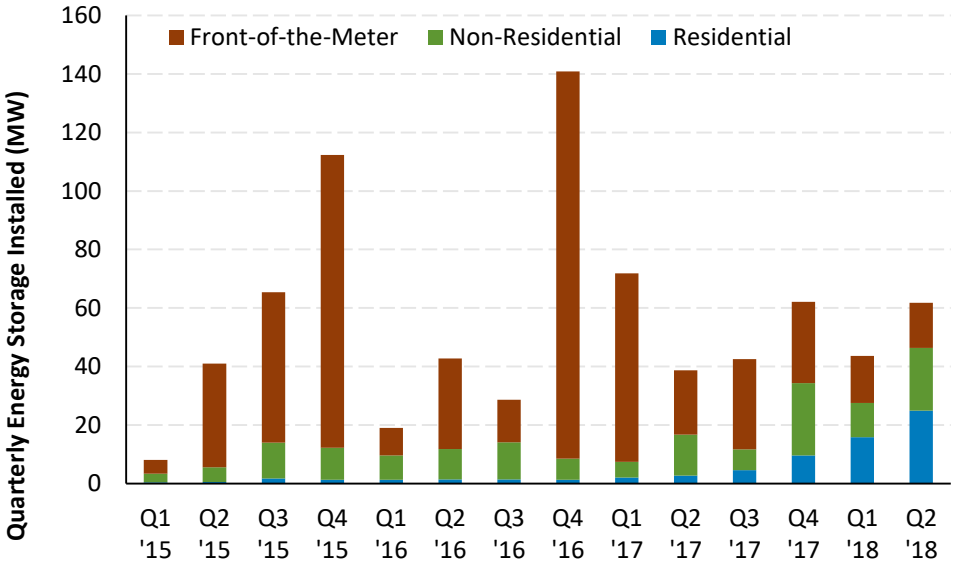



**Note:** EIA monthly data are not final. Additionally, smaller utilities report information to EIA on a yearly basis, and therefore, a certain amount of solar data has not yet been reported. "Net Generation" includes DPV generation.
**Sources:** EIA, "Electric Power Monthly," forms EIA-023, EIA-826, and EIA-861.

- The ten states with the highest percentage of solar penetration generated at least 4.0% of their total electricity from solar in the past 12 months (July 2017 – June 2018), with California leading the way at 17.6%.
  - California led with 14.4% in the previous 12 months.
- In the past 12 months (July 2017–June 2018), the United States as a whole produced approximately 2.1% of its electricity using solar technologies, compared to 1.6% in the previous 12 months.
- The role of utility versus distributed solar varies by state, with northeastern states and Hawaii relying more on DPV.

# U.S. Energy Storage Installations by Market Segment

- The United States installed approximately 105 MW (283 MWh) of energy storage onto the electric grid in H1 2018, flat y/y.
  - Over half the deployment in H1 2018 was in California.

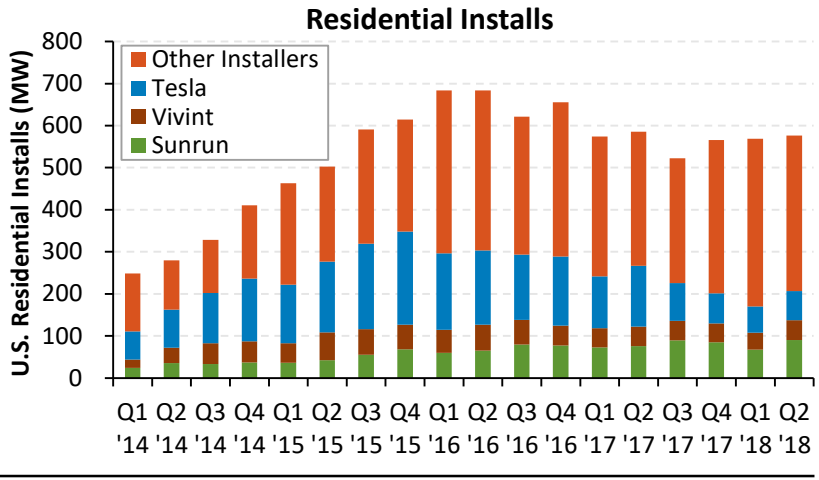


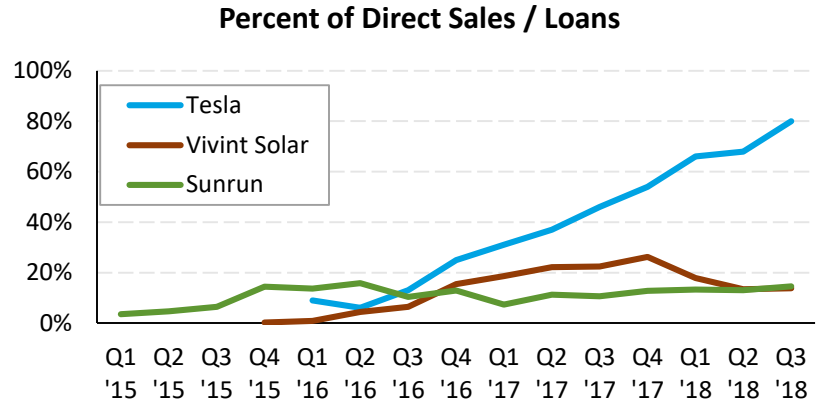

- Large-scale installed storage capacity (MW) was lower in H1 2018 than in H1 2017, however less so in terms of MWh.
  - A greater percentage of projects are coming online that have longer-duration storage, servicing capacity and load shifting needs, compared to frequency regulation projects.
- Residential energy storage deployment has increased exponentially, growing 7.5X from H1 2017 to H1 2018, and 500X from H1 2013 to H1 2018.
  - Approximately 4,700 residential storage systems were installed from 2013 – 2017 and 6,700 were installed in the first half of 2018.

**Source:** Wood Mackenzie Power & Renewables and Energy Storage Association, "U.S. Energy Storage Monitor;" Wood Mackenzie Power & Renewables and SEIA, "U.S. Solar Market Insight: Q3 2018."

# Tesla, Vivint Solar, and Sunrun Residential Market Share

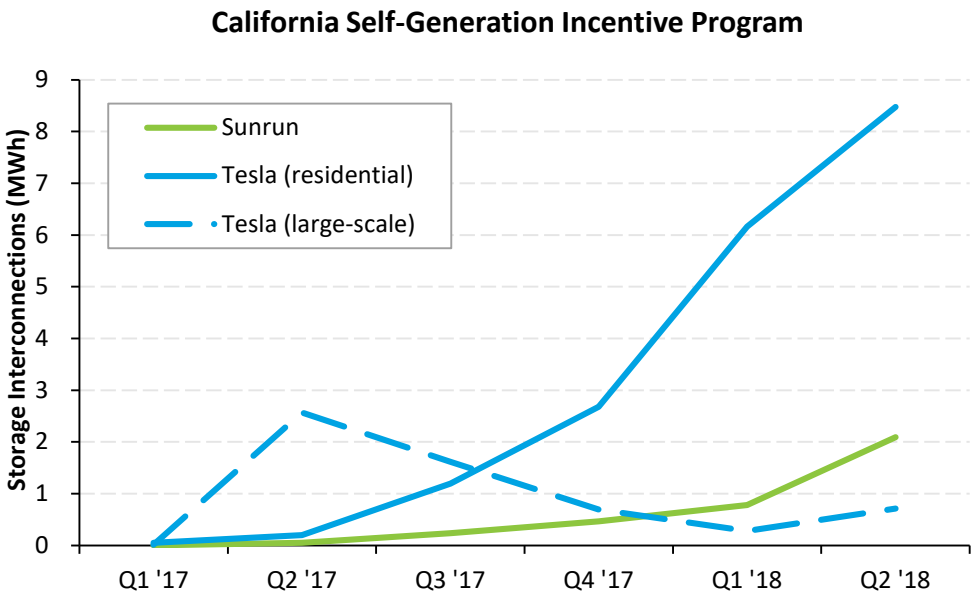
- From H1 2016 to H2 2018, Tesla, Vivint, and Sunrun combined installations shrank 37%, while the remainder of the market remained flat.
  - Tesla direct sales continue to grow as a percentage of total sales while Sunrun and Vivint still install mostly leased or PPA systems.
  - In Q2 2018, Tesla shifted its sales strategy to sell energy products exclusively at Tesla retail locations or online. Despite relatively low volumes in 2018, they expect their solar and storage businesses to remain cash flow neutral.




**Source:** Corporate filing, GTM/SEIA Solar Market Insight Q3 2018.

# Emerging Products: Tesla and Sunrun

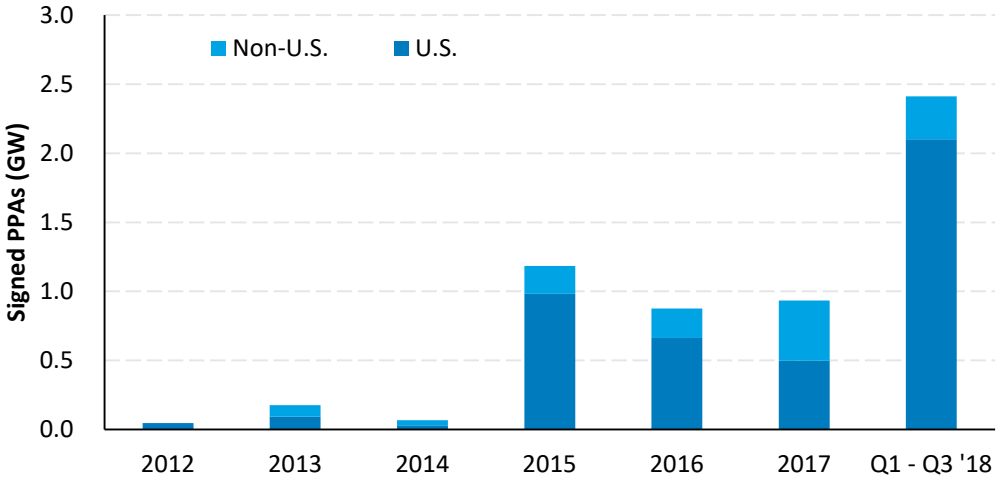



- Tesla and Sunrun are also expanding product offerings.
  - Tesla has installed over 1 GWh of storage globally—576 MWh in H1 2018 alone (129 MWh of that from an Australian installation).
  - Since 2017, Tesla (18.7 MWh, 7.1 MW) and Sunrun (3.6 MWh, 2.1 MW) have interconnected the majority of PV + storage systems under the California Self-Generation Incentive Program.
    - Residential storage system costs in 2017 and the first half of 2018 averaged $706/kWh ($1.86/W) for Tesla, and $843/kWh ($1.43/W) for Sunrun
  - Tesla also installed 17 systems (114 kW) of their solar roof tile product in California from December 2017 through July 2018.
    - The average price of these systems was $5.7/W, with 15 of the 17 systems costing approximately $5.85/W.
    - In Q3 2018, Tesla announced they were still iterating the product design and are refining the installation process. They expect to ramp production in H1 2019.

**Sources:** Corporate filings, California Self-Generation Incentive Program (https://www.selfgenca.com/report/public/); CA NEM Database (07/31/18).

# Off-Site Corporate Solar PPAs

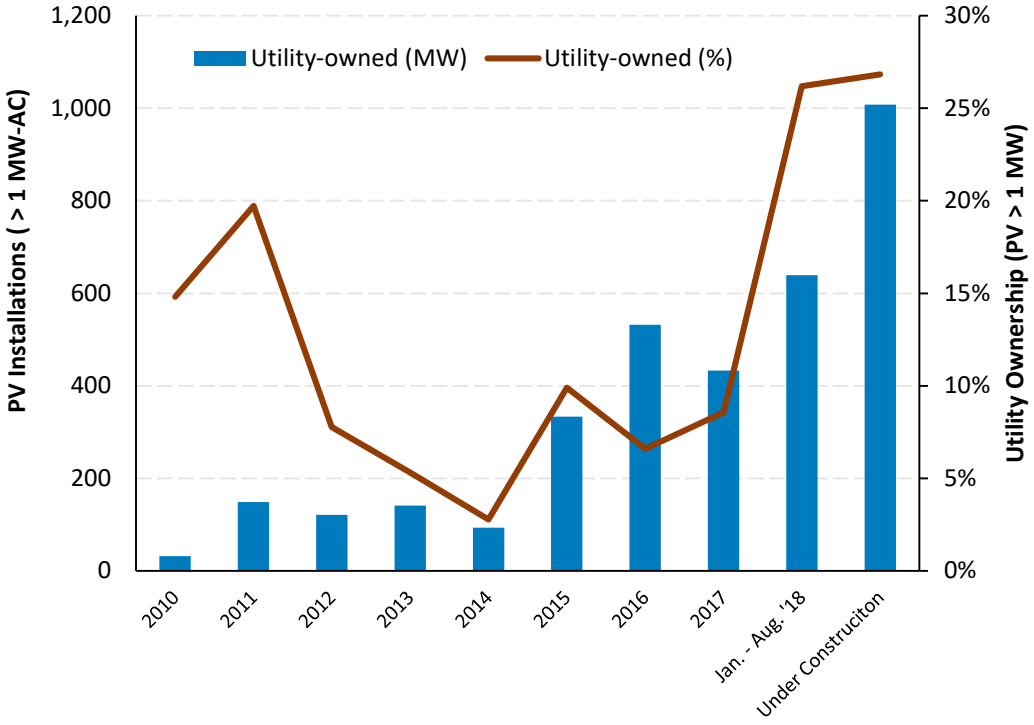
- In the first nine months of 2018, a record volume of off-site corporate solar PPAs were signed, both globally and in the United States, bringing cumulative corporate solar PPAs to just under 5.9 GW globally (4.6 GW in the United States).
  - Wind is also having a record year, with 5.4 GW of PPAs signed in the first nine months of 2018 out of a cumulative 18.3 GW (with the U.S. market providing 3.2 GW this year and 11.9 GW total).




**Sources**: BNEF, "Corporate PPA Deal Tracker: September 2018;" database of "Corporate PPAs," accessed 10/23/18; Norton Rose Fulbright (October 2018).

- In September 2018, Kaiser Permanente signed the largest renewables and storage PPA ever by a corporation, with 170 MW of solar, 50 MW of wind, and 110 MW of energy storage.
- Companies have also started purchasing off-site PPAs through joint ventures, allowing more companies to participate.
  - Aggregated arrangements comprised 40% of the deals in the first three quarters of 2018, up from 11% in 2015.
- Twelve new companies, including Lyft, RBS and Sony, joined the RE100 in September 2018, bringing the total number of signatories on the campaign to 152.
- Most top offtakers of off-site PPAs are tech companies.
  - Google, Facebook, Microsoft, and Apple all have 1 GW or more of renewable energy PPAs.
  - The majority of signed PPAs by tech companies are for wind projects, though the leading five companies each have more than 250 MW of PV PPAs.
- One potential disadvantage of corporate PPAs—versus utility PPAs —is that corporate PPAs expose firms to a higher level of risk, due to the potential for bankruptcy.
  - While regulated utilities may also go bankrupt, they are more likely to be protected by their public utility commission/ratepayers.

# Utility Ownership of Solar




**Source:** EIA Form 860M.

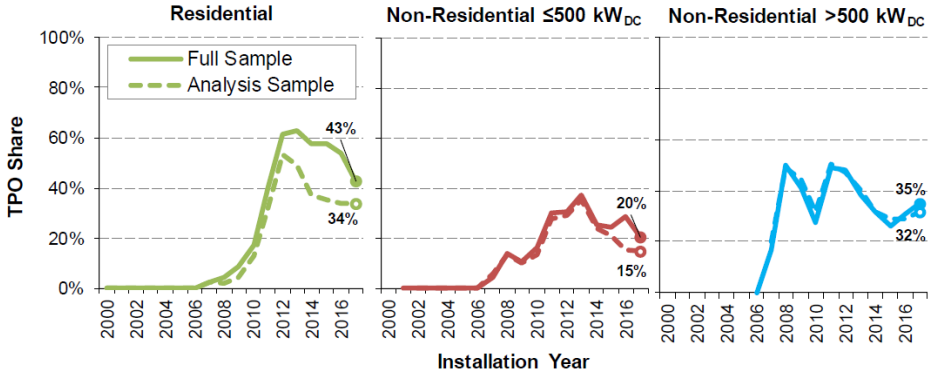
- Recently there has been a push by many utilities to own PV assets, instead of purchasing the power through an independent power producer.
  - More utility-owned solar was installed in the first eight months of 2018 than in any previous year, accounting for 26% of all PV systems above 1 MW in size.
- Historically, utilities had been hampered in owning solar due to “normalization” accounting rules which force them to spread the benefit of the solar tax credit over the life of a project when they rate-base the asset.
  - In contrast, independent power producers can immediately pass on the benefits of the ITC.
- Florida and Virginia regulators recently made rule changes that improve the economics for owning solar (see next slide). As a result:
  - Ninety-three percent of utility-owned solar installed in the first eight months of 2018 was in Florida, and 96% of the utility-owned solar currently under construction are in Virginia or Florida.

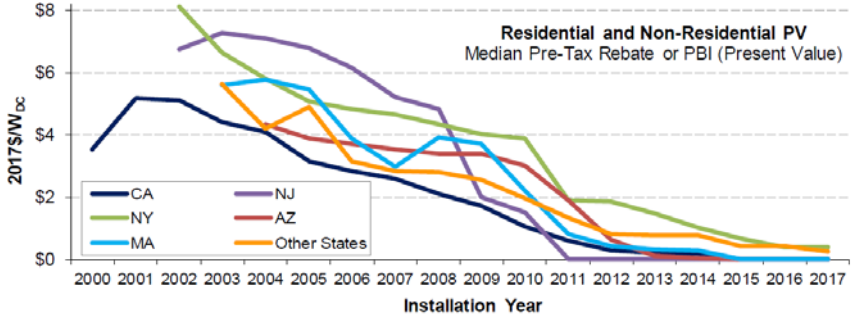
# Utility Ownership of Solar: Florida and Virginia

- In 2016, the Florida Public Service Commission approved the Solar Base Rate Adjustment (SoBRA) for Florida Power & Light (FP&L), which provides the company with a 10.55% return on equity for solar-owned projects.
  - SoBRA allows the PSC to approve solar projects without a full rate case.
  - FP&L announced in 2017 that it would install 2.1 GW of solar by 2023.
  - Tampa Bay Electric and Duke Energy Florida also announced plans to build 600 MW and 700 MW of solar over the next few years respectively.
- In 2015, the Virginia General Assembly gave Dominion Energy approval to charge customers on a "market index model" for solar energy instead of a "cost-of-service" model. In 2016, the IRS issued a private letter ruling stating that if the utility used a market index model, the solar asset would not constitute "public utility property" and therefore the ITC would not have to be normalized.
- If adopted by other states, these changes could impact markets significantly.

**Sources:** Wood Mackenzie Power & Renewables / SEIA; David Burton, "Dominion Takes on ITC Rule;" Tampa Bay Times (09/27/17); UtilityDive (10/31/18).

# Five New Things to Know from *Tracking the Sun XI*




*Notes: The figure depicts the pre-tax value of rebates and performance-based incentives (calculated on a present-value basis) provided through state and utility PV incentive programs.*

1. From 2008 to 2017, the U.S. residential PV market share of MLPE devices grew from 0% to 80%.

2. TPO is generally declining in all market segments (Figure, top), though in 2017, it had a 50% penetration rate among tax-exempt site hosts (not shown in Figure).

3. It is estimated that 40% of the long-term decline in BoS costs can be attributed to increased system size and improved module efficiency.
   - Clear economies of scale exist for distributed PV, with the median price of a 2–3 kW system being $0.8/W more expensive than the median price of an 11–12 kW system.

4. A long-term drop in rebates and PBIs for distributed PV projects equates to 67%–100% of the installed price decline among larger state markets (Figure, bottom).

**Source:** Barbose, G. and N. Darghouth. 2018. *Tracking the Sun XI The Installed Price of Residential and Non-Residential Photovoltaic Systems in the United States*. Berkeley, CA: Lawrence Berkeley National Laboratory. September 2018.

# Five New Things to Know from Utility-Scale Solar 2017

1. Tracking projects continue to dominate in 2017 (79% of newly installed capacity or 72% of newly built projects) relative to fixed-tilt projects (21% or 28%), even among thin-film projects (Chart 1).
   - Fixed-tilt is now primarily only used in low-insolation areas.
2. 2017 is the first year in which areas outside California and the Southwest accounted for the lion's share (70%) of new utility-scale solar additions.
   - The new locations are often in lower-insolation areas.
3. The median inverter loading ratio (ILR or DC:AC ratio) increased again, to 1.32 in 2017, corresponding to module price declines (Chart 2).
4. Average O&M costs for the cumulative set of PV plants have declined from about $31/kW-AC-year (or $20/MWh) in 2011 to about $16/kW-AC-year ($8.4/MWh) in 2017.
5. In 2012, when solar penetration in California was ~2%, solar earned ~125% of the average wholesale power price; in 2017, with solar penetration in California at ~15%, solar earned just 79% of the average wholesale power price.

**Chart 1. Tracking versus fixed-tilt**

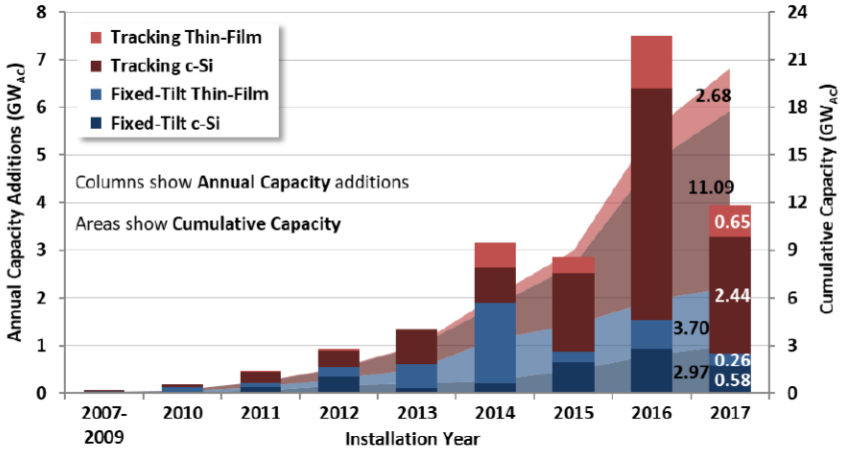
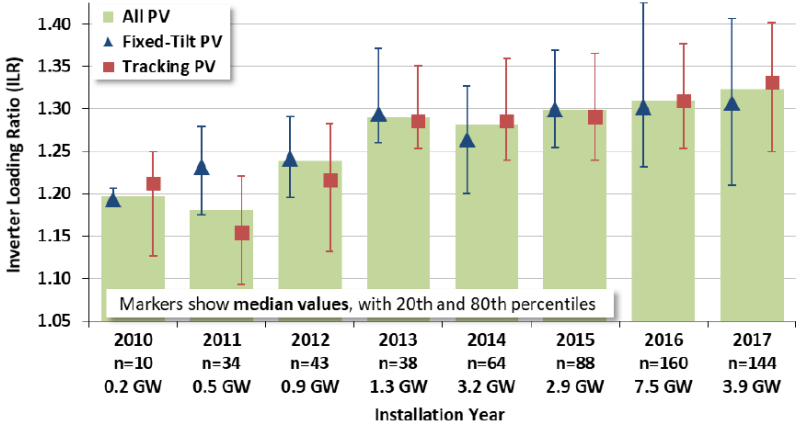



**Chart 2. Median ILR over time**




**Source:** Bolinger, M. and J. Seel. 2018, *Utility-Scale Solar 2017: An Empirical Analysis of Project Cost, Performance, and Pricing Trends in the United States*. Berkeley, CA: Lawrence Berkeley National Laboratory.

- **U.S. PV system pricing, or costs, are estimated and quoted in a variety of ways.**
- **In 2017, the ranges in average U.S. PV system pricing across methods were reported to be:**
  - **$2.8/W to $4.2/W for residential**
  - **$1.6/W to $3.5/W for nonresidential**
  - **$1.0/W to $1.6/W for utility-scale.**
- **In the first half of 2018, the ranges in average U.S. PV system pricing across methods were reported to be:**
  - **$2.7/W to $4.2/W for residential**
  - **$1.5/W to $3.5/W for nonresidential**
  - **$1.0/W to $1.1/W for utility-scale.**

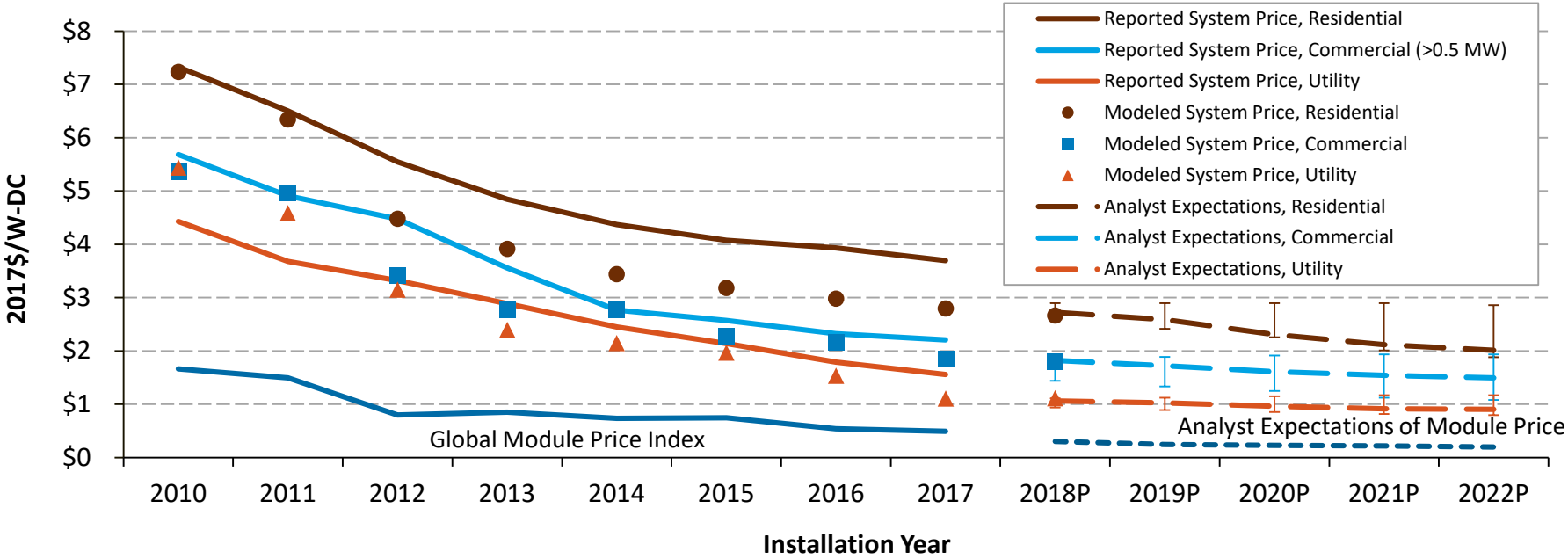
# U.S. PV System Pricing

- Most data suggest that PV system pricing, across market segments, continues its downward trajectory.
- U.S. PV system pricing, or costs, are estimated and quoted in a variety of ways, including:
  - Reported price (backward-looking)
  - Reported costs (backward-looking and may not include profit, unless incorporating “value”)
  - Developer quotes (forward-looking)
  - Bottom-up cost benchmarking (forward-looking).
- In 2017, the ranges in average U.S. PV system pricing across methods were reported to be:
  - $2.8/W to $4.2/W for residential
  - $1.6/W to $3.5/W for nonresidential
  - $1.0/W to $1.6/W for utility-scale.
- In the first half of 2018, the ranges in average U.S. PV system pricing across methods were reported to be:
  - $2.7/W to $4.2/W for residential
  - $1.5/W to $3.5/W for nonresidential
  - $1.0/W to $1.1/W for utility-scale.

# Reported, Bottom-Up, and Analyst-Projected Average U.S. PV System Prices over Time

Historically, reported pricing and modeled benchmarks have had similar results; however, residential PV system price estimates have diverged over time.

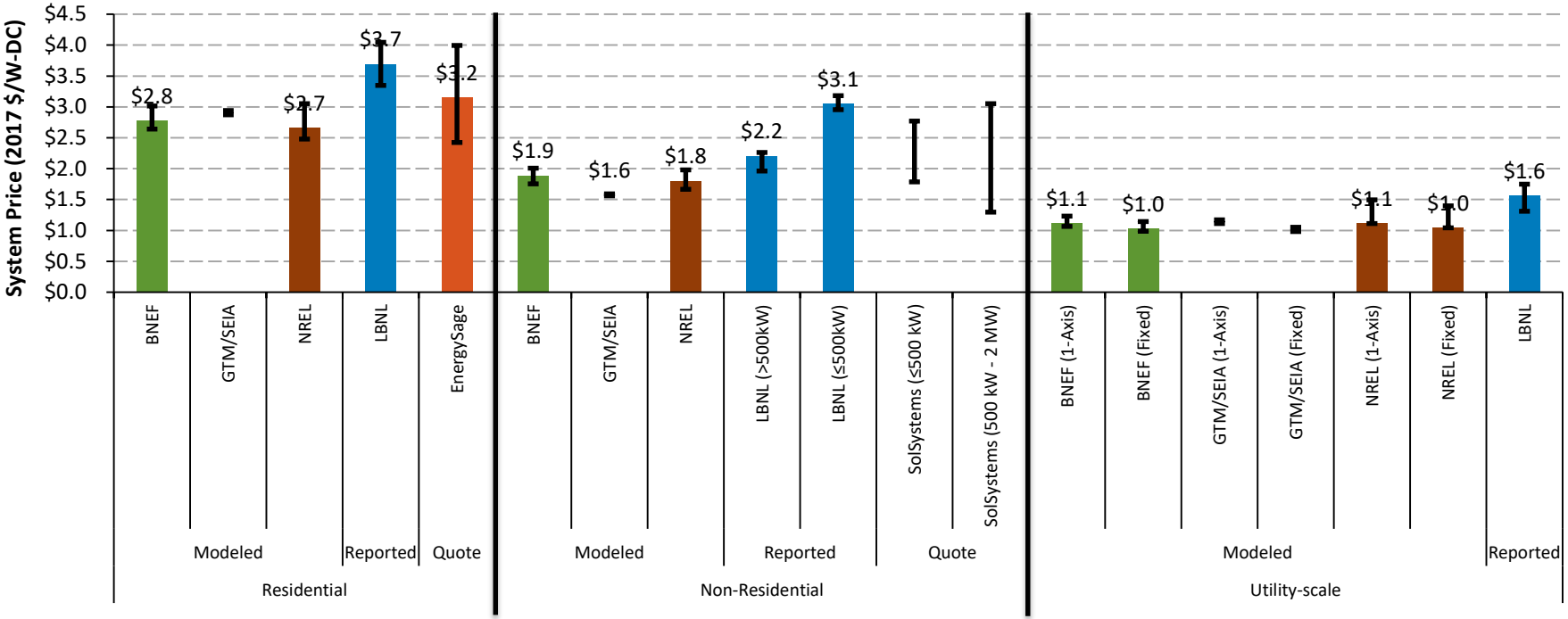
All methodologies show a downward trend in PV system pricing.




**Note:** Reported prices represent the median national U.S. averages. Error bars represent the high and low analyst expectations.
**Sources:** Reported residential and commercial system prices (Barbose and Darghouth 2018); reported utility system prices (Bolinger and Seel 2018); modeled system prices (Fu, Feldman, and Margolis 2018); analyst expectations (NREL 2018 Annual Technology Baseline); The Global Module Price Index is the average module selling price for the first buyer (P. Mints SPV Market Research); analyst expectation of module price (see Slide 52).

# 2017 Modeled, Reported, and Quoted System Price from Various Sources

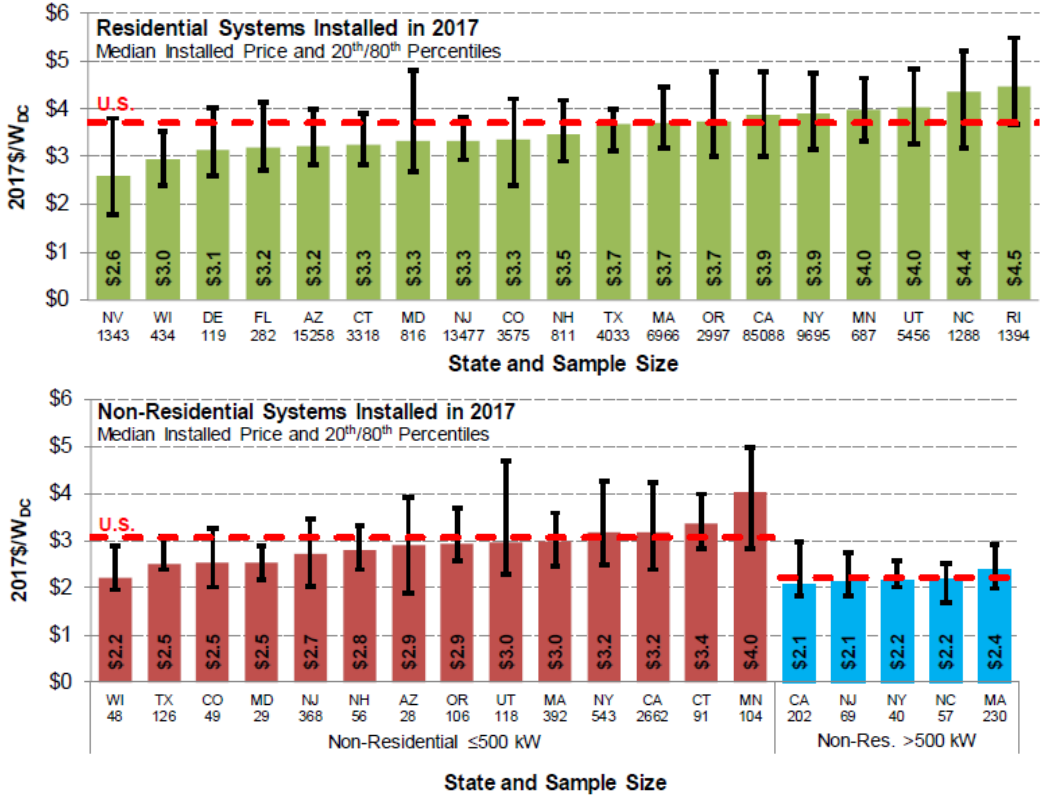
- NREL and LBNL PV system pricing figures are consistent with other sources.
- Across various sources, reported system pricing is generally higher than modeled system pricing, with quotes being in the middle.




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

**Sources:** Barbose and Darghouth 2018, "Tracking the Sun XI," 2018; Bolinger and Seel, Utility-scale 2017," 2018; BNEF, "H1 2018 U.S. PV Market Outlook," June 2018; Fu et al., "U.S. Solar Photovoltaic System Cost Benchmark Q1 2017," 2017; Wood Mackenzie Power & Renewables and SEIA, "U.S. Solar Market Insight 2017 year-in-review," March 2018.

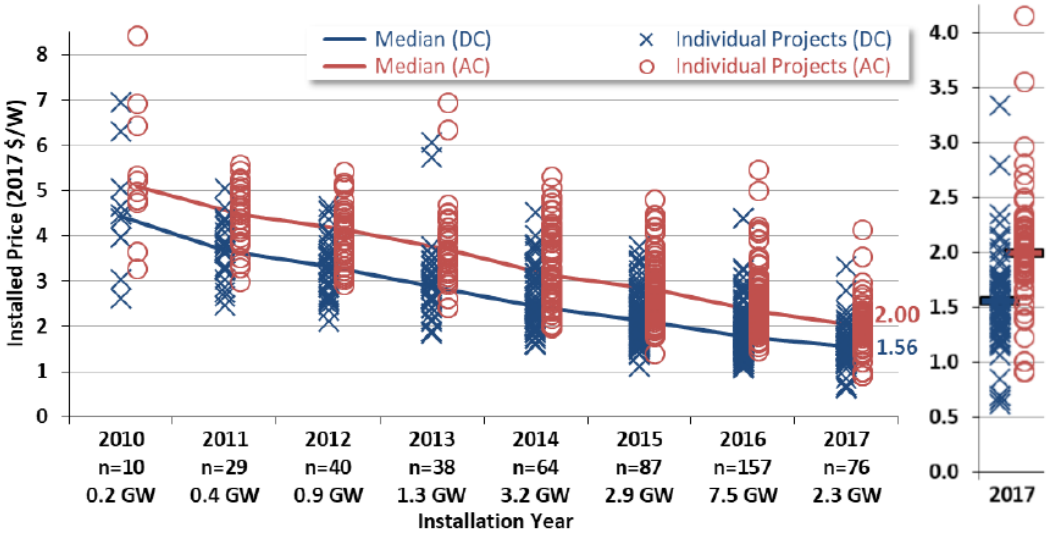
# Variation in Reported Price by State: Residential and Nonresidential PV Systems in 2017




- Some of the largest markets (California, Massachusetts, and New York) are relatively high-priced, pulling overall U.S. median reported PV prices upward.
- PV pricing in most states is below the national median.
- Cross-state variation may reflect differences in installer competition and experience, retail rates and incentive levels, project characteristics particular to each region, labor costs, sales tax, and permitting and administrative processes.
- A high degree of variability also occurs within states.

**Source:** Barbose, G. and N. Darghouth. 2018. *Tracking the Sun XI The Installed Price of Residential and Non-Residential Photovoltaic Systems in the United States*. Berkeley, CA: Lawrence Berkeley National Laboratory. September 2018.

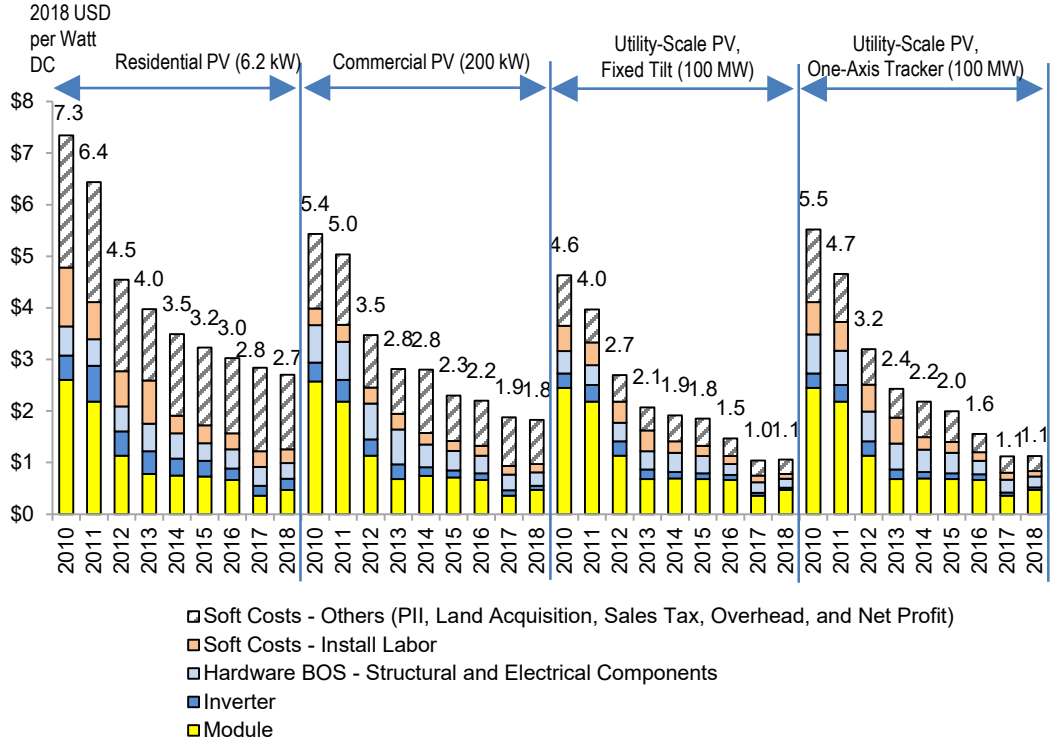
# Reported Price of Utility-Scale PV Projects over Time




- Median reported installed price of utility-scale PV fell by more than 60% since 2010, to $2.0/W-AC ($1.6/W-DC) in 2017.
- The lowest 20th percentile of project prices fell from $2.0/W-AC ($1.5/W-DC) in 2016 to $1.8/W-AC ($1.3/W-DC) in 2017.
- The lowest projects among the 67 data points in 2017 was $0.9/W-AC ($0.6/W-DC).
- This sample is backward-looking and may not reflect the price of projects built in 2018 and 2019.

**Source:** Bolinger, M. and J. Seel. 2018,*Utility-Scale Solar 2017: An Empirical Analysis of Project Cost, Performance, and Pricing Trends in the United States*. Berkeley, CA: Lawrence Berkeley National Laboratory.

# Bottom-Up Modeled System Price of PV Systems by Sector, 2010–2018



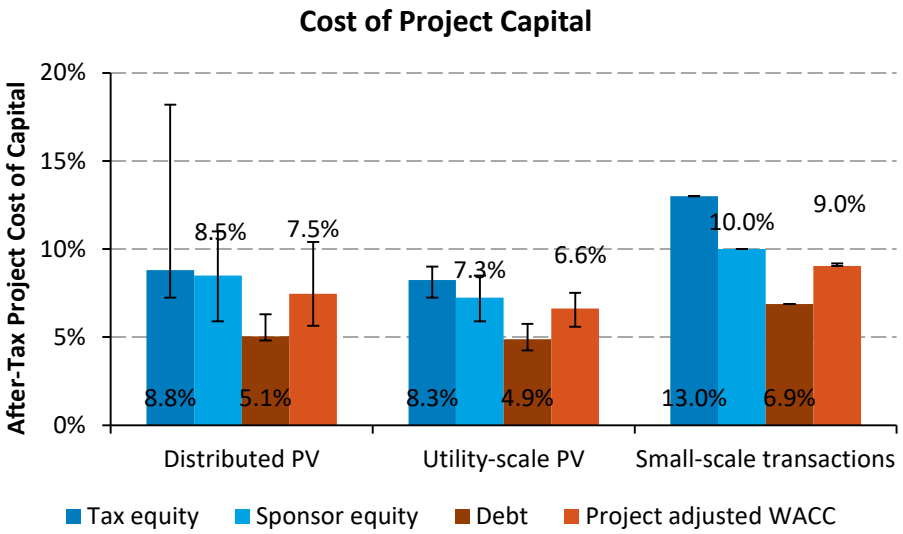

- From 2010 to 2018, modeled system prices fell 63%–80%, with 57%–79% of the reduction being attributed to hardware price reductions.
- From 2017 to 2018, there were 5% and 3% decreases in residential and commercial PV system cost benchmarks respectively; however, there was a ~1% increase in the utility-scale PV system cost benchmark.
  - The majority of that increase can be attributed to the 32% increase in module spot price, which offset cost reductions in other areas.

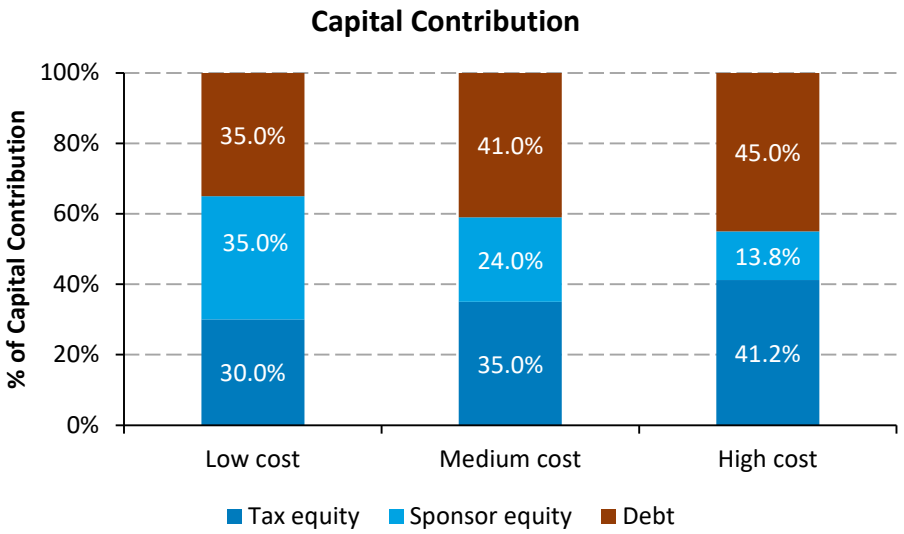
**Source:** Fu, R., D. Feldman, and R. Margolis. 2018. U.S. Photovoltaic (PV) Prices and Cost Breakdowns: Q1 2018 Benchmarks for Residential, Commercial, and Utility-Scale Systems. Golden, CO: National Renewable Energy Laboratory.

# Finance Cost Benchmarking

- NREL estimates that in 2018 the cost of capital for large projects and portfolios of projects (large and distributed) averaged 6.6% and 7.5% respectively.
- Tax equity is currently the most-expensive source of capital, while debt is the least-expensive.

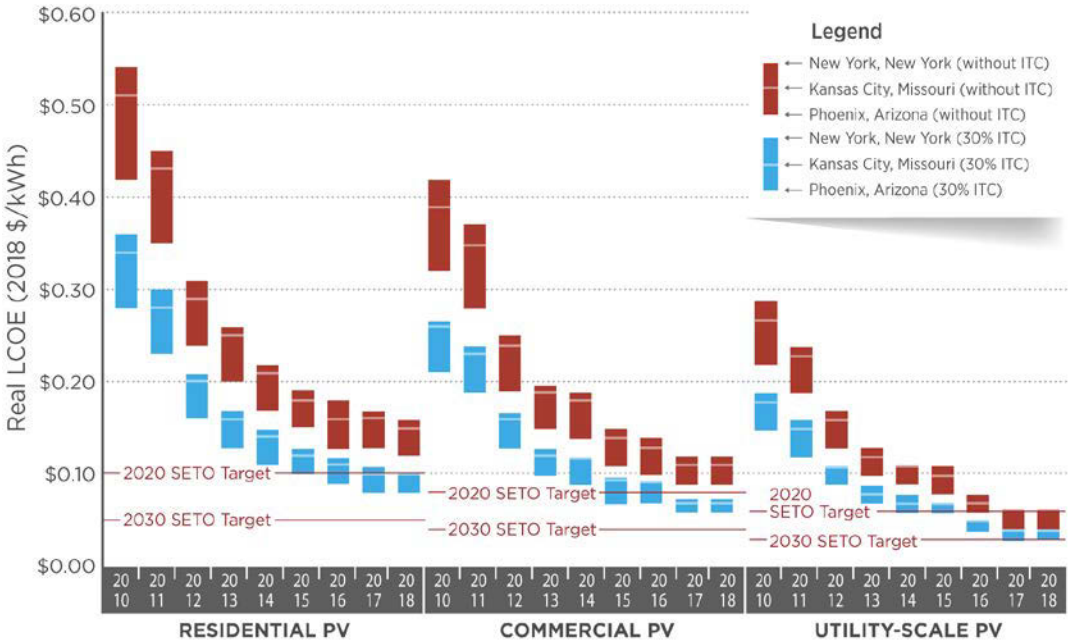
- Despite federal actions and market changes over the past year, the cost of capital for PV projects is comparable to that of recent years.
  - Tax equity providers contributed a lower share of total project costs due the corporate tax rate reduction included in the Tax Cuts and Jobs Act of 2017.
- The cost of capital is not the only cost of financing borne by a project; NREL found that in addition to bearing the cost of capital, projects may also incur set-up costs averaging $1.2 million–$1.4 million.




**Source :** D. Feldman and P. Schwabe. 2018. *Terms, Trends, and Insights PV Project Finance in the United States, 2018.* Golden, CO: National Renewable Energy Laboratory.

# Bottom-Up Modeled LCOE of PV Systems by Sector, 2010–2018

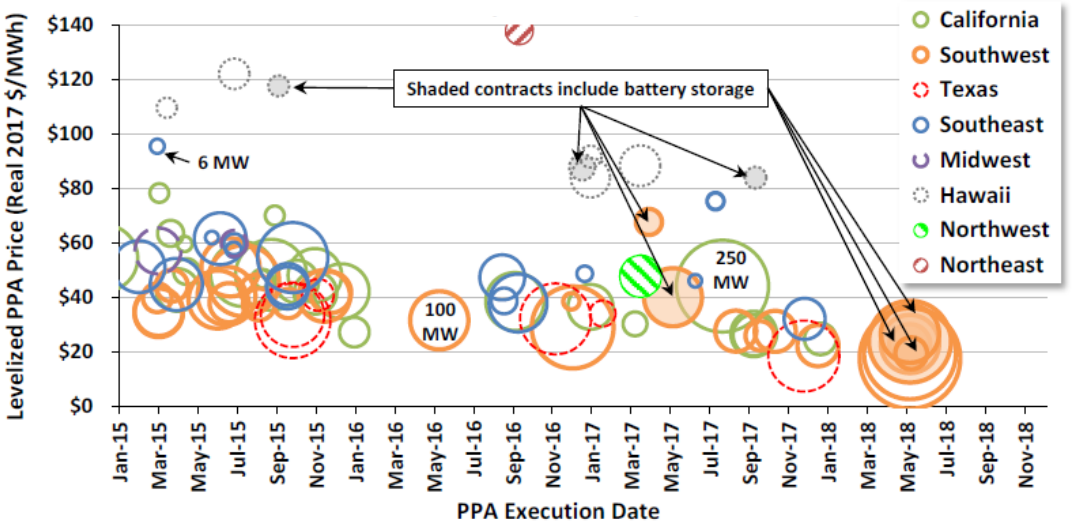



- The reductions in total capital cost, along with improvements in operation, system design, and technology have resulted in significant reductions in the cost of electricity.
- U.S. residential and commercial PV systems are at 89% and 91% of SETO's 2020 electricity price targets, and U.S. utility-scale PV systems achieved their 2020 SETO target three years early.

**Note**: The analysis uses the fixed-tilt systems for LCOE benchmarks from 2010-2015 and then switches to one-axis tracking systems from 2016 to 2018 to reflect the market share change in the utility-scale PV sector.

**Source:** Fu, R., D. Feldman, and R. Margolis. 2018. U.S. Photovoltaic (PV) Prices and Cost Breakdowns: Q1 2018 Benchmarks for Residential, Commercial, and Utility-Scale Systems. Golden, CO: National Renewable Energy Laboratory.

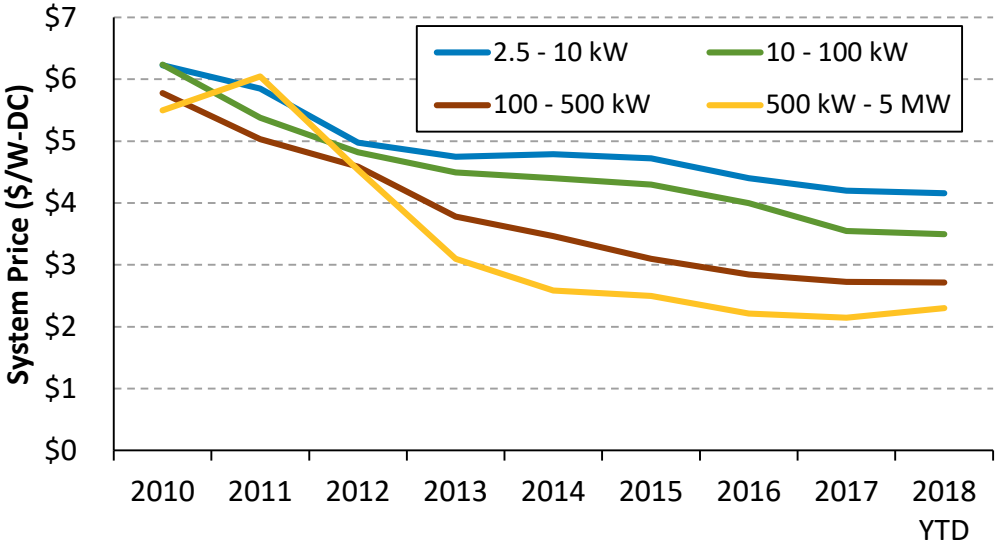
# U.S. PV PPA Pricing has Dropped Rapidly in Recent Years.




- The most recent utility-scale PV PPAs are under $40/MWh, with three recent PPAs in the Southwest being under $20/MWh.
- Eight PPAs featuring PV plus long-duration battery storage (4–5 hours, shaded in the graphs at left) do not seem to be priced at a prohibitive premium to their PV-only counterparts.
- Hawaii projects show a consistent and significant premium of ~$40/MWh over mainland projects.
- Smaller projects (e.g., 20–50 MW) are priced similarly to larger projects.
- More than 80% of the sample is currently operational.

**Source:** Bolinger, M. and J. Seel. 2018,*Utility-Scale Solar 2017: An Empirical Analysis of Project Cost, Performance, and Pricing Trends in the United States*. Berkeley, CA: Lawrence Berkeley National Laboratory.

# System Pricing from Select States




**Preliminary 2018 YTD MW**: AZ (82), CA (473), CT (14), MA (158), NY (175)

**Note:** System prices above $20/W and below $1/W were removed from the data set.

**Sources**: CA NEM database (07/31/18); MA SREC program (09/26/18); Arizona Public Services and Salt River Project, accessed 07/31/18; CT Green Bank (06/30/18); NYSERDA (09/30/18).

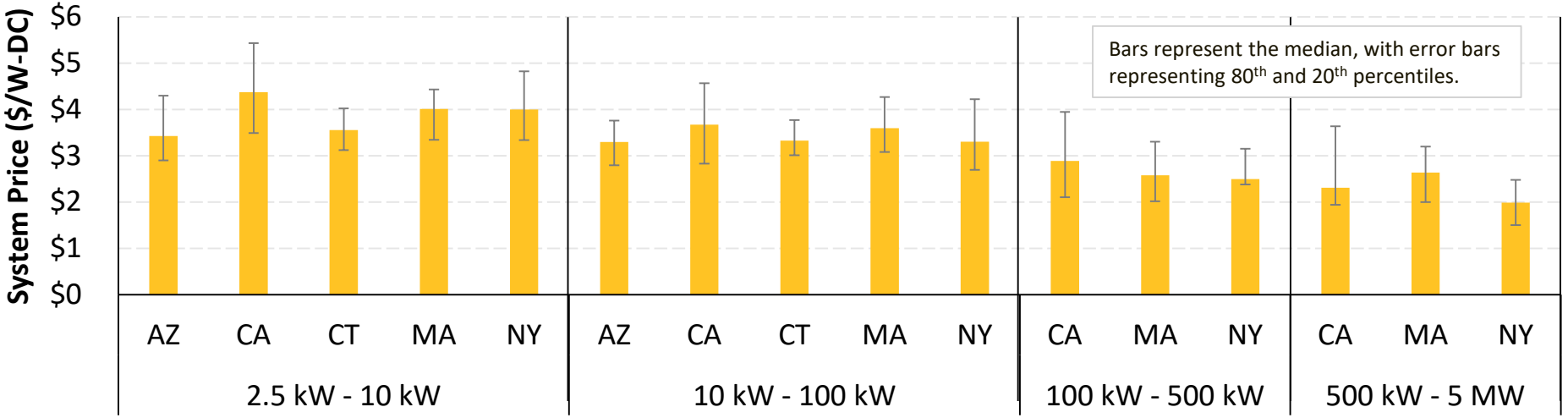
Based on preliminary data, from 2017 to H1 2018, the median reported PV system price in Arizona, California, Connecticut, Massachusetts, and New York:

- Fell 1% to $4.16/W for systems from 2.5 kW to 10 kW
- Fell 1% to $3.50/W for systems from 10 kW to 100 kW
- Remained flat at $2.72/W for systems from 100 kW to 500 kW
- Increased 7% to $2.30/W for systems from 500 kW to 5 MW.

# System Pricing from Select States, 2018 YTD

- In addition to price differences based on system size, there is also variation between states and within individual markets.

- Based on initial data in 2018 (YTD), the median price of a small system in Arizona was about 22% less than the median price in California.
- In 2018 (YTD), the 20th and 80th percentile prices in California for a small system were $3.49/W and $5.43/W respectively.



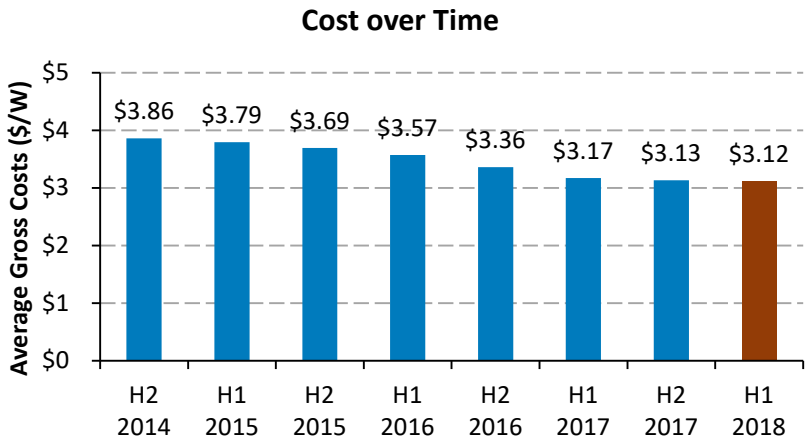

**Preliminary 2018 YTD MW**: AZ (82), CA (473), CT (14), MA (158), NY (175)

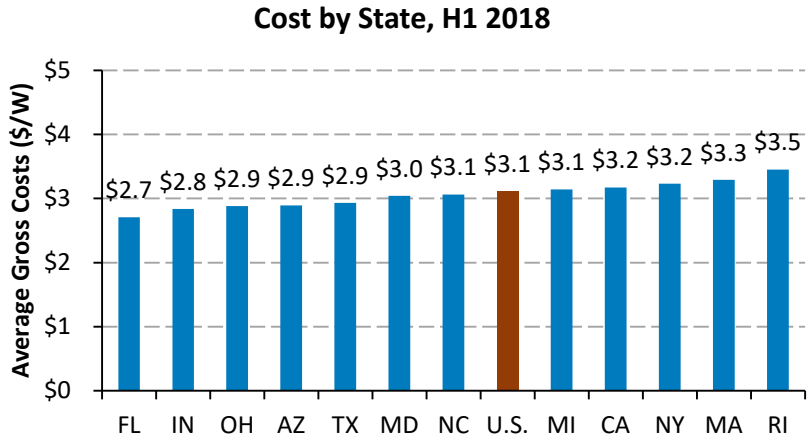
**Note:** System prices above $20/W and below $1/W were removed from the data set.

**Sources**: CA NEM database (07/31/18); MA SREC program (09/26/18); Arizona Public Services and Salt River Project, accessed 07/31/18; CT Green Bank (06/30/18); NYSERDA (09/30/18).

# System Costs Reported by EnergySage, H1 2018

- For H1 2017 to H1 2018, EnergySage reported a 2% reduction in the average gross costs of a residential system.
- EnergySage quotes also reported an average system payback period of 7.8 years.
- Residential system quotes varied by state. In H1 2018, the average gross cost of a residential system in Rhode Island was 27% higher than the average gross cost of a residential system in Florida.

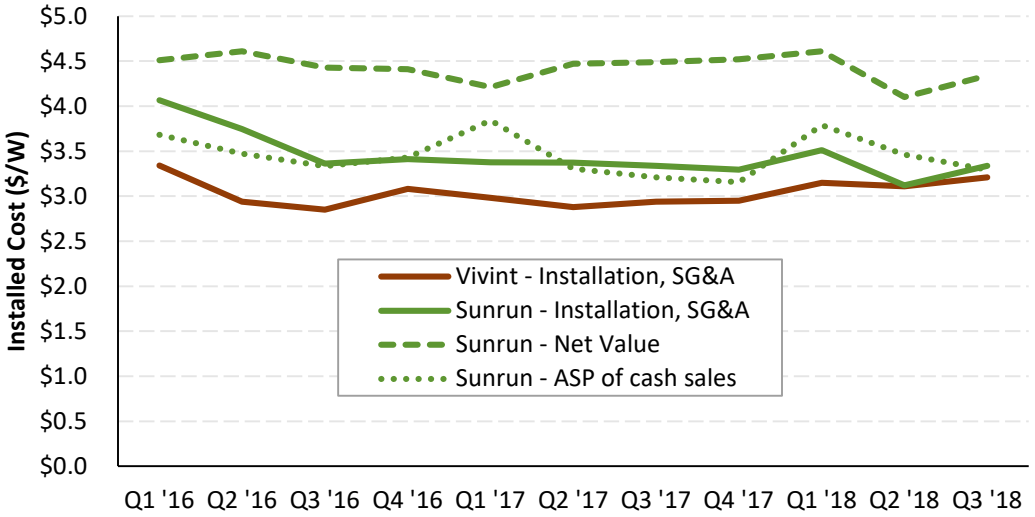


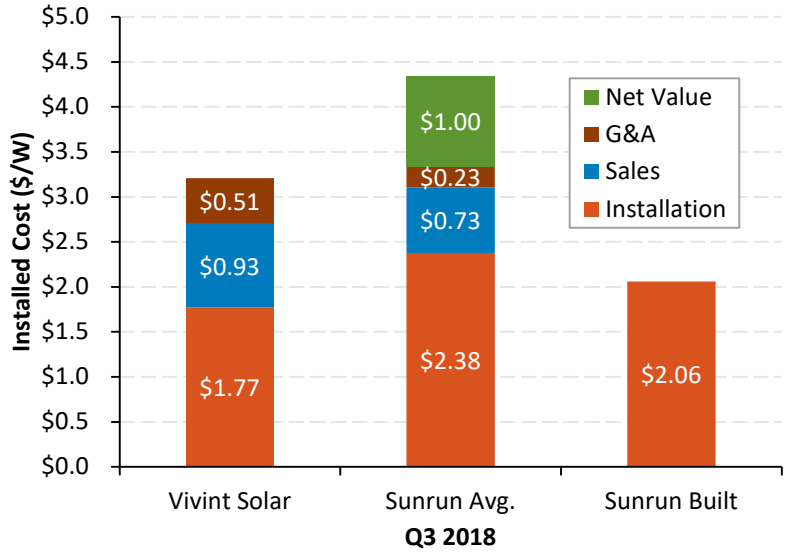

**Source:** EnergySage, "Solar Market place Intel Report H2 2017 – H1 2018."

# Vivint Solar and Sunrun Cost and Value

- For the past two years, Vivint Solar and Sunrun total system costs have remained relatively flat.
  - The average price of Sunrun's cash sales is approximately the same as their costs.



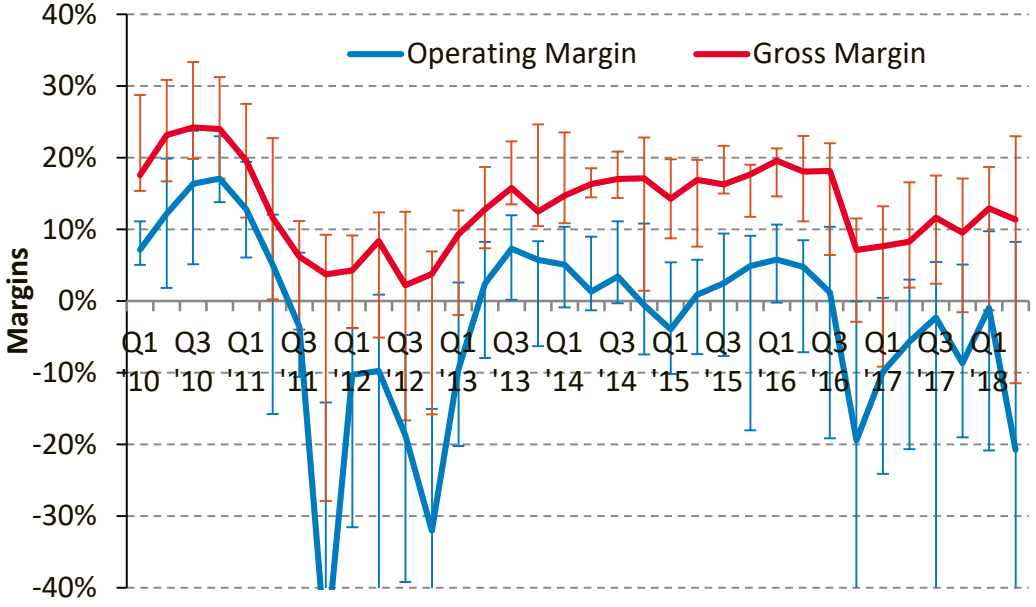

- In Q3 2018, totals costs for Vivint- and Sunrun-built systems were approximately $3/W.
- Sunrun still reports a PV system net value of approximately $4.5/W.




**Sources:** Corporate filings.

- **Company performance was mixed in Q2 2018, as the new low-priced environment, trade barriers, and a reduction in Chinese incentives have shaken up the industry.**
- **While the vast majority of PV manufacturing capacity uses c-Si technology, western companies (Manz and Avancis) have recently partnered with Chinese firms with the goal of significantly expanding CIGS manufacturing.**
- **In H1 2018, U.S thin-film and c-Si module production were at approximately the same levels as they were in H1 2017, while c-Si cell production was 70% down, y/y.**
- **In H1 2018, U.S. produced polysilicon was 22% lower than in H1 2017 and 43% lower than in H1 2014.**

# PV Manufacturers' Margins



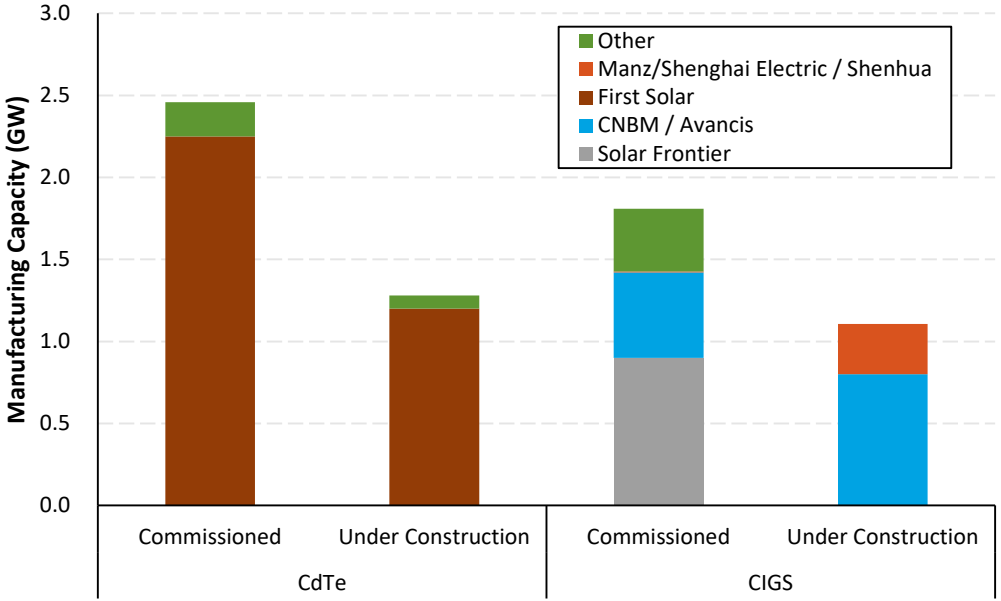

Line represents the median, with error bars representing 80th and 20th percentiles for the following companies in Q2 2018: Canadian Solar, First Solar, Hareon Solar, HT-SAAE, Jinko Solar, LONGi, Motech Industries, Neo Solar Power, Renesola, and SunPower. Margin data from Hanwha Q-Cells, JA Solar, Trina, and Yingli are also included from Q1 2010 to Q4 2017 where available.

- Company performance was mixed in Q2 2018, as the new low-priced environment, trade barriers, and a reduction in Chinese incentives have shaken up the industry.
  - First Solar's operating margin declined due to costs associated with ramping its new generation of modules.
  - Hareon Solar's PV manufacturing subsidiary was forced into bankruptcy proceedings.
  - REC Silicon's margins grew, due to trade barriers limiting access to China, as well as market disruption caused by China's change in FIT policy.
- Yet, 5 of the 11 companies tracked in Q2 2018 reported an increase in operating margin.

**Sources**: Company figures based on data from Bloomberg Terminal and SEC filings by the respective companies; PV Tech (09/03/18).

# Thin-Film Expansion

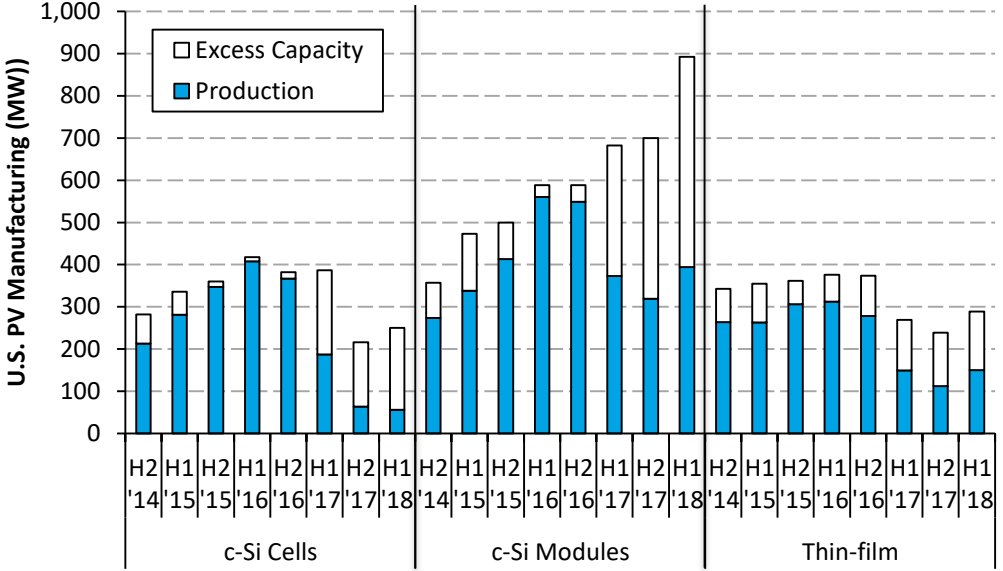
- BNEF estimates there are currently 140 GW of global c-Si cell manufacturing capacity and a little over 4 GW of non c-Si thin-film PV capacity.
  - First Solar (CdTe) and Solar Frontier (CIGS) have been the only thin-film manufacturers to expand to GW-scale operations, to-date.




**Sources**: BNEF, database of "Equipment Manufacturers," accessed 10/22/18.

- However, western companies (Manz and Avancis) have recently partnered with Chinese firms with the goal of significantly expanding CIGS manufacturing.
  - They have not achieved GW-scale yet and the timetable of when this might occur is unclear, though CNBM announced its intention to expand its 300-MW Chinese CIGS plant to 1.5 GW.
    - BNEF reports that CNBM has a combined 800 MW of manufacturing capacity under construction (which would bring its cumulative global manufacturing capacity to 1.3 GW).
    - CNBM also has a combined 220 MW of CIGS manufacturing capacity in South Korea and Germany.
  - First Solar has also announced plans to expand global CdTe capacity to 7.6 GW by the end of 2020.
- If all of the thin-film manufacturing expansion plans come to fruition, thin-film PV technologies would still represent less than 10% of global PV manufacturing capacity (a level it has achieved in the past); however, achieving GW-scale production would likely allow firms to better compete in the global marketplace.

# U.S. Module and Cell Manufacturing

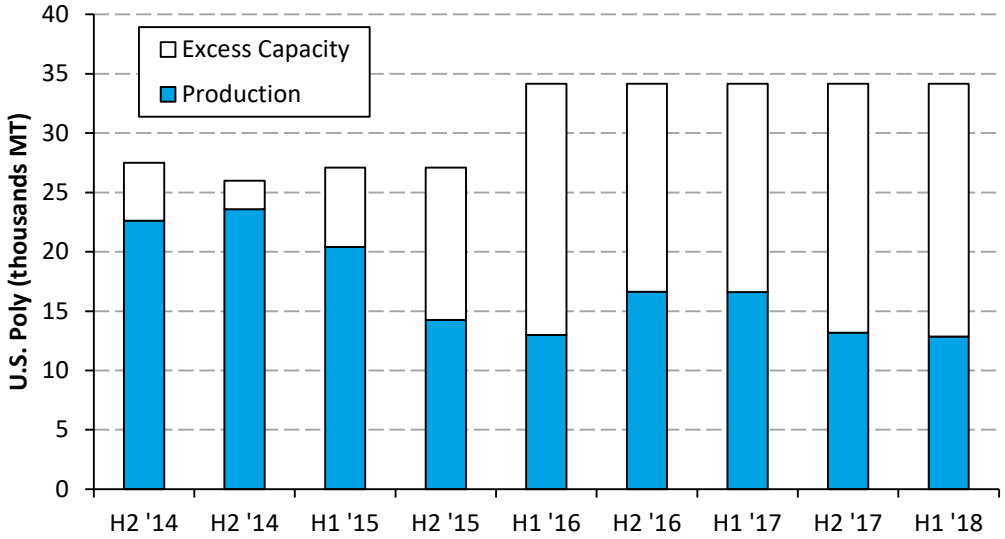



- In H1 2018, U.S thin-film and c-Si module production were at approximately the same levels as they were in H1 2017, while c-Si cell production was 70% down, y/y.
- That said, significant capacity is expected to come on-line in the next year which would greatly increase production of PV cells (Panasonic, SunPower) and modules (Jinko Solar, Hanwha Q-Cells, LG, Heliene, and Silfab).

**Source:** Wood Mackenzie Power & Renewables & SEIA, "U.S. Solar Market Insight" (2014–2018).

# U.S. Polysilicon Manufacturing

- Almost all of U.S.-produced polysilicon is manufactured by Hemlock, REC Silicon, and Wacker.

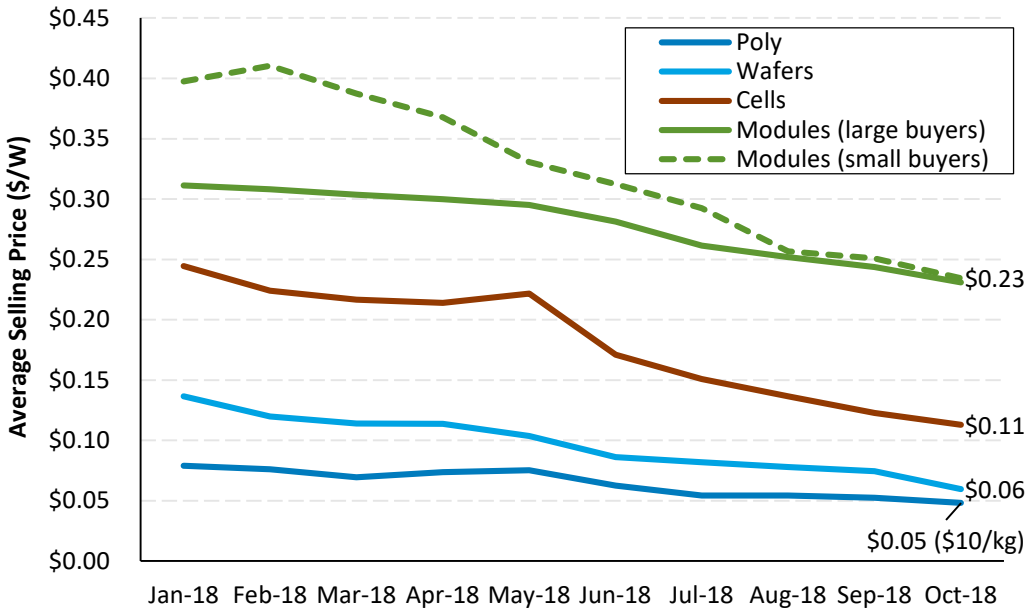



**Source:** Wood Mackenzie Power & Renewables & SEIA, "U.S. Solar Market Insight" (2014–2018).

- In January 2014, China began applying a 57% tariff on U.S.-produced polysilicon, significantly hindering U.S. manufacturers, given the limited market outside China.
  - The duties are effective for five years (i.e., January 2019), though China and the United States are currently in a trade dispute.
- In H1 2018. U.S.-produced polysilicon was 22% lower than in H1 2017 and 43% lower than in H1 2014.
  - Wacker's Tennessee facility had to temporarily stop production in September 2017 due to an explosion, but it is expected to reach full capacity again this fall.

- **Module, cell, and wafer prices have dropped since the beginning of the year, but they accelerated in June and July after China terminated subsidies on new utility-scale PV projects in 2018 and reduced its FIT. In October, global module ASP was reported to be $0.23/W.**
- **Recent analysts' reports indicate global module prices are expected to continue to drop in the next few years, falling below $0.20/W in the next five years.**
- **In Q2 2018, U.S. module prices continued to fall but were still trading at a significant premium over global module ASP.**

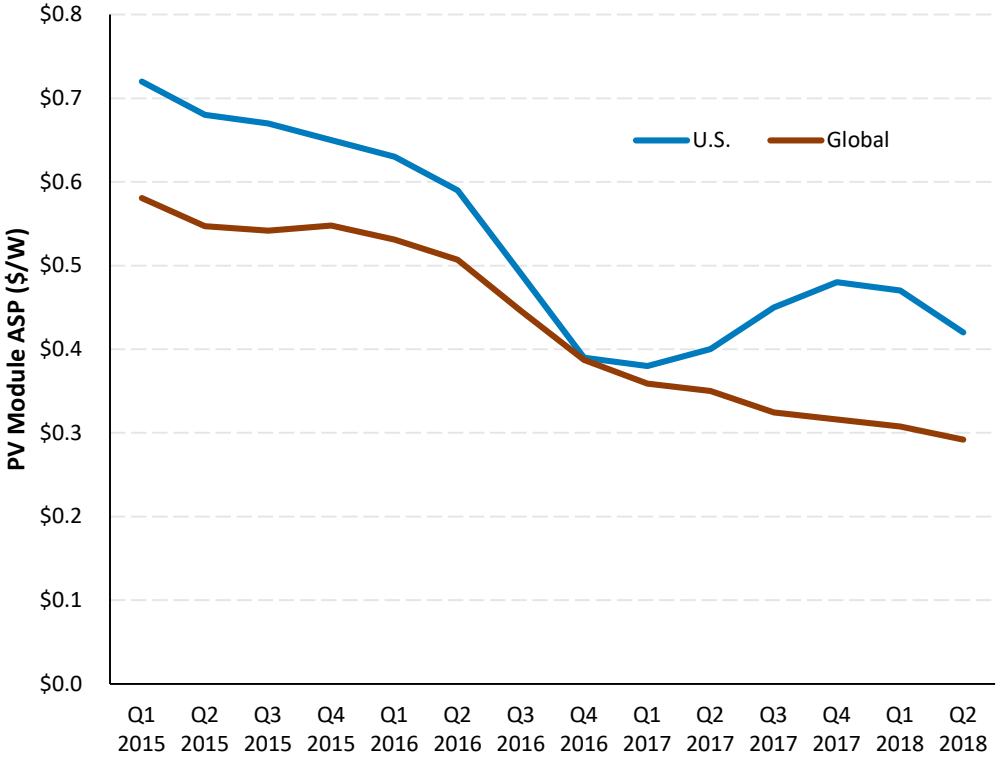
# PV Value Chain Spot Pricing




- Module, cell, and wafer prices have dropped since the beginning of the year, but they accelerated in June and July after China's announcement on May 31, terminating subsidies on new utility-scale PV projects in 2018 and reducing its FIT.
- Global PV module and subcomponent pricing are currently all at record lows.

**Sources**. "Modules (large buyers)" from PVinsights, accessed 10/24/18. Remaining pricing data from BNEF Solar Spot Price Index (10/24/18).
Kilogram to Watt conversion: 4.78 grams per watt (2016); 4.73 grams per watt (2017, 2018), from Cowen & Co. (05/11/17); Deutsche Bank (07/19/17).

# Module Average Selling Price—Global versus United States



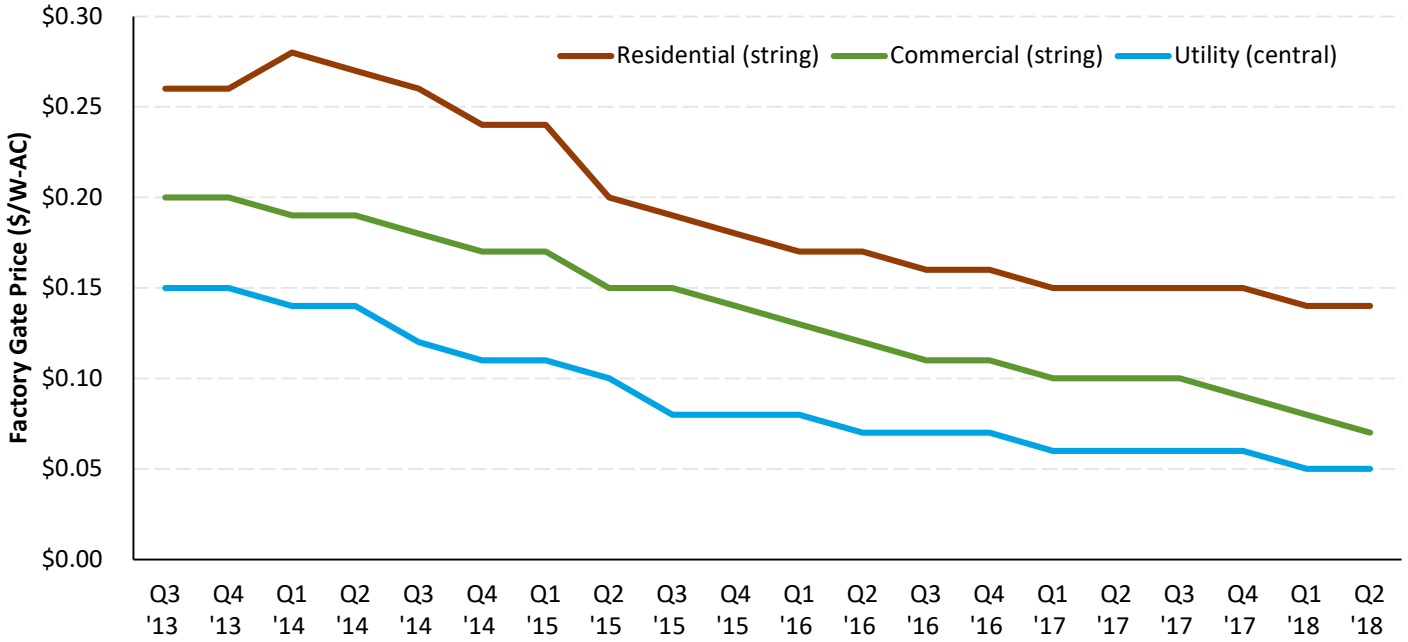

- In Q2 2018, U.S. module prices continued to fall but were still trading at a significant premium over global module ASP.
  - Modules sold in the United States in Q2 2018 were 5% higher than modules sold in the United States in Q2 2017 and 44% higher than the global average.
- BNEF estimates the ASP of mono PERC modules sold in the United States will reach $0.37/W by the end of 2018 and $0.33/W by the end of 2019.
  - BNEF states that larger manufacturers are already quoting prices of $0.35/W–$0.40/W for a Q4 2018 delivery to the United States.

**Sources**. U.S. (Wood Mackenzie Power & Renewables / SEIA); Global (PVinsights/Mercom); PV Magazine (10/19/18).

# Inverter Pricing

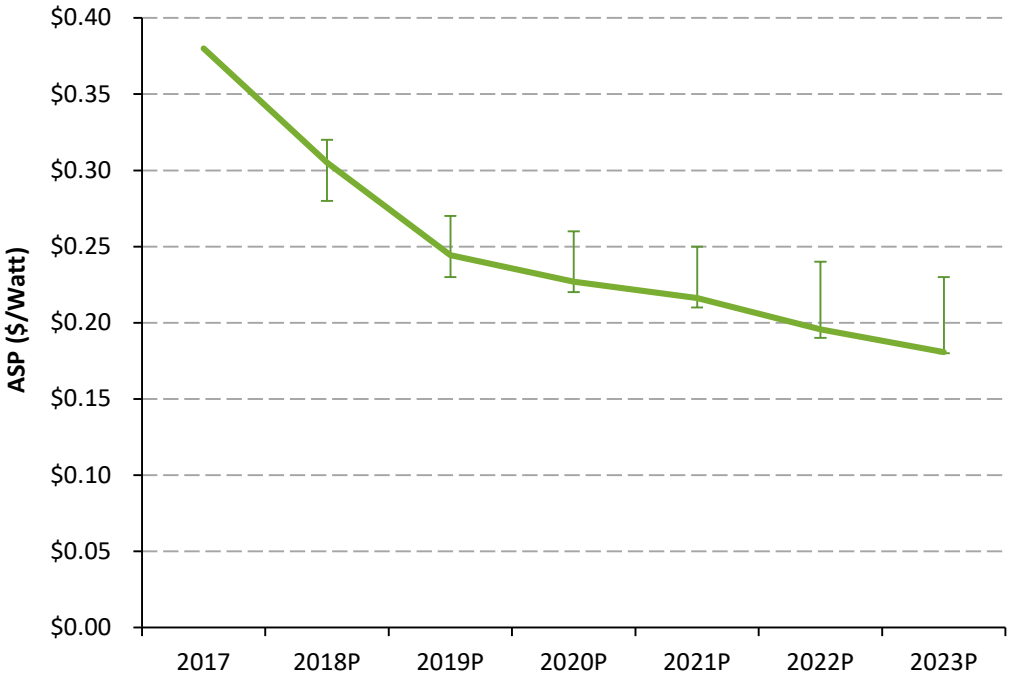
Commercial inverter prices dropped approximately $0.01/W in Q2 2018, down 30% y/y.

- Residential and utility-scale inverter prices have dropped 7% and 17% y/y respectively.




**Source**. Wood Mackenzie Power & Renewables/SEIA.

# Near-Term Global Module Price/Cost Projections

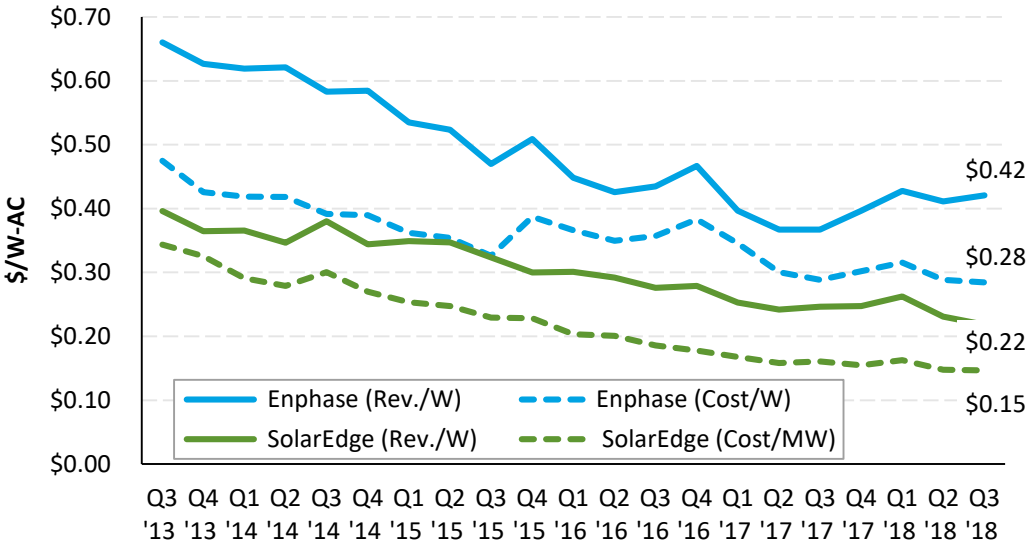



- Recent analysts' reports indicate global module prices are expected to continue to drop in the next few years, falling to below $0.20/W in the next five years.
- Regional module preferences and tariffs could impact actual pricing in the United States, Europe, India, and elsewhere.

**Sources:** Lines represent the median estimates, and error bars represent the maximum and minimum, ASP and costs for Jinko Solar and industry averages from the following analysts: BNEF (August 2018); Credit Suisse (June 2018); Goldman Sachs (June 2018); Wood Mackenzie Power and Renewables (December 2017).

# Enphase Microinverters and SolarEdge DC-Optimized Inverter Systems

- In Q3 2018, SolarEdge and Enphase costs, per watt, were at record low levels, down a penny, y/y.
  - Since Q3 2013, SolarEdge and Enphase costs have decreased 57% and 40% respectively.

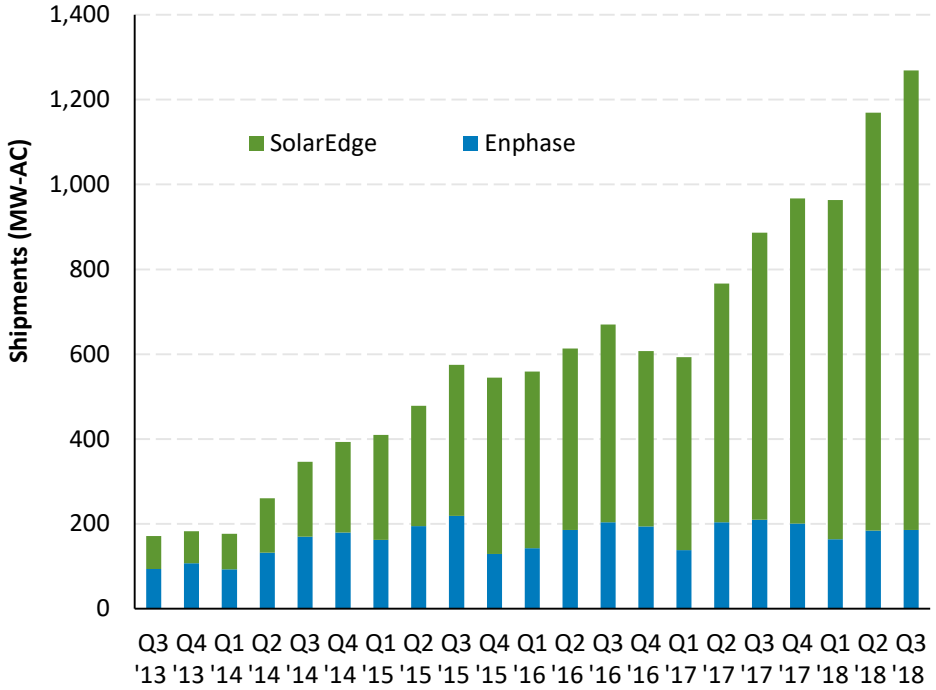



- In Q3 2018, the SolarEdge price per watt was at a record low level, down 11% y/y and 45% in the past five years.
- Enphase pricing has increased over the past year as the company has focused on increasing margins and new product offerings, such as batteries.
  - Enphase has shipped over 25 MWh of batteries since 2016.
  - SolarEdge is also pursuing storage products as they acquired the top-five battery manufacturer, Kokam, in October 2018.

**Note:** Starting in Q2 2017 Enphase switched reporting shipments from W-AC to W-DC; we adjust these values using an ILR of 1.1.

**Sources:** Corporate filings.

# Enphase Microinverters and SolarEdge DC-Optimized Inverter Systems




In the first nine months of 2018, Enphase shipments were down 3% y/y, while SolarEdge shipments grew 69% y/y, recording its highest quarter ever in Q3 2018.

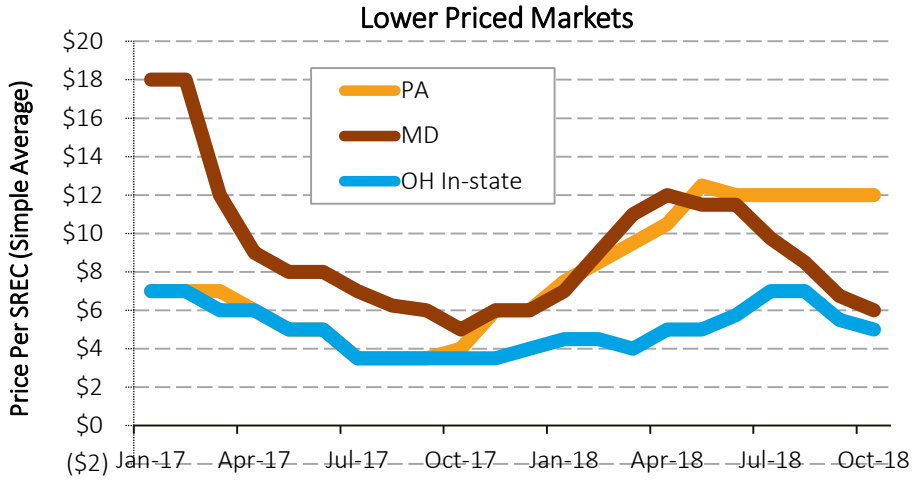
**Sources:** Corporate filings.

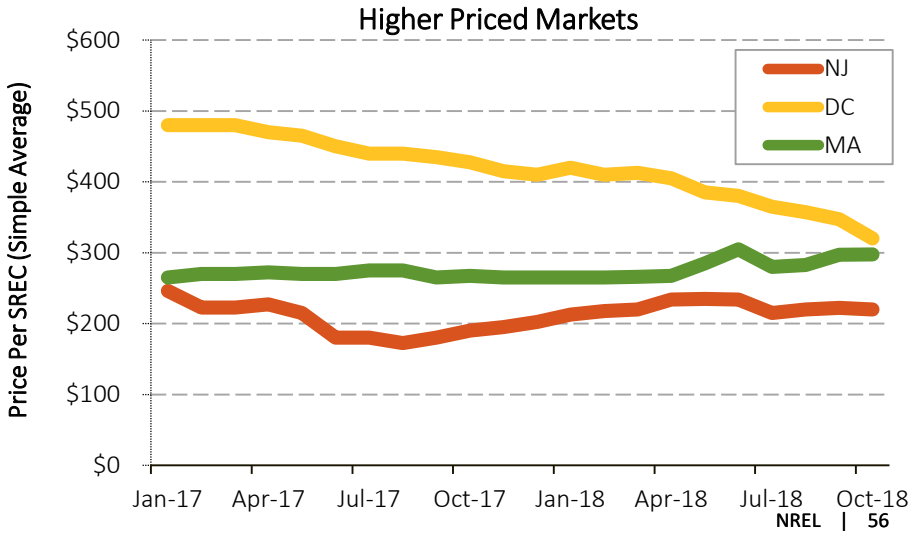
- **Despite (or perhaps because of) recent changes to their states' solar policies, SREC market pricing in New Jersey and Massachusetts remain steady, while SREC pricing in Washington, D.C. has lowered due to a reduction in demand.**
- **At the end of October 2018, solar stocks were down 30% for the year, compared to 5% for the broader market.**

# SREC Pricing

- SREC pricing in Washington, D.C. has declined due to a reduction in demand.
  - Electric suppliers, with contracts before October 2016, are able to pay a lower SACP ($300) rather than the current SACP of $500.

- Despite (or perhaps because of) recent changes to their states' solar policies, SREC market pricing in New Jersey and Massachusetts remain steady.
  - In May 2018, New Jersey increased its RPS solar carve-out to 5.1% and decreased its SACP.
  - Massachusetts approved the successor to its SREC program, though SREC applications are still open.

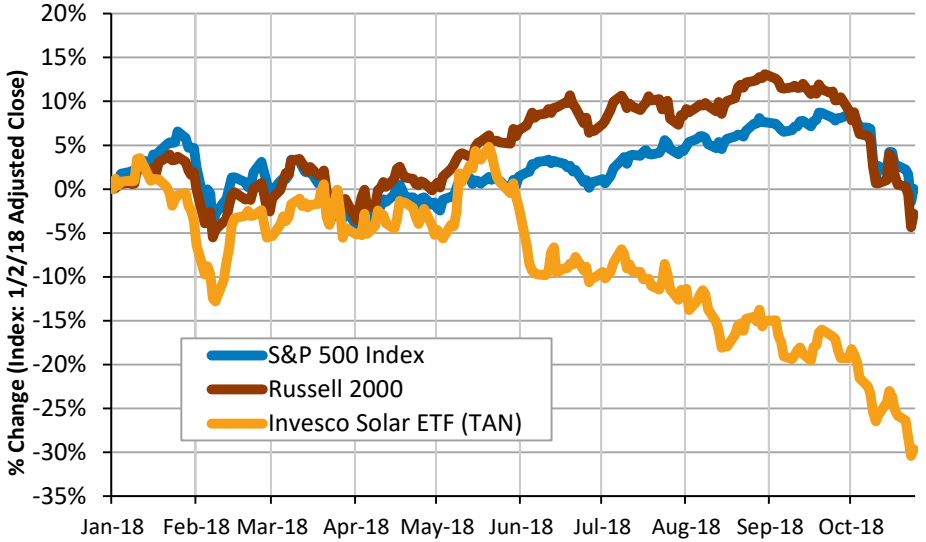


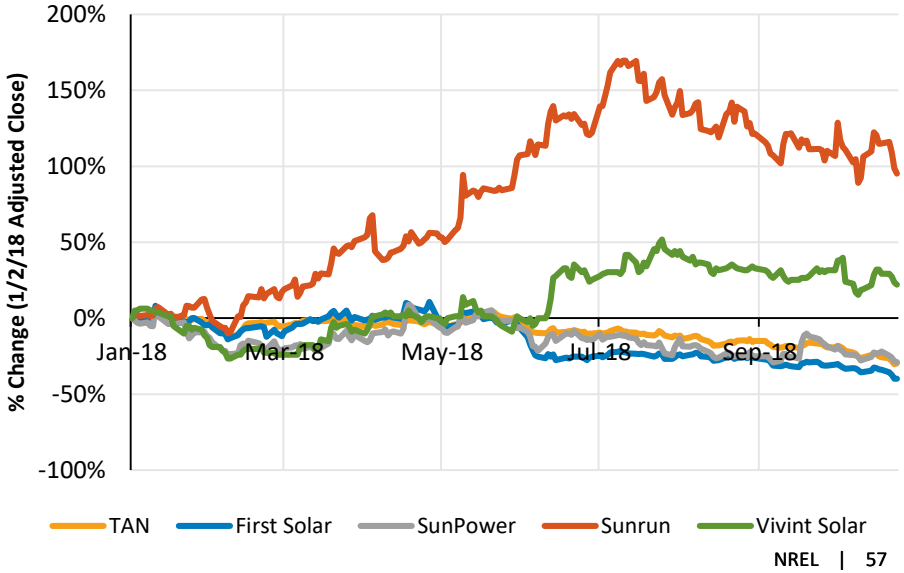




**Sources**: SRECTrade, www.srectrade.com, accessed 10/25/18.

# Stock Market Activity

- At the end of October 2018, solar stocks were down 30% for the year, compared to 5% for the broader market.
  - Solar prices have plummeted since the Chinese announcement in late May of a decrease in subsidies, causing an oversupply in the marketplace.
- As to be expected, the Chinese announcement is a negative for module manufacturers but a positive for developers (e.g., Sunrun and Vivint) outside China.




**Source**: Stock market: Yahoo Finance (10/25/18).

# Thank You

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***Special thanks to Galen Barbose (LBNL), Mark Bolinger (LBNL), David Burton (Mayer Brown), Naim Darghouth (LBNL), Anna Ebers (DOE), Ran Fu (NREL), Parthiv Kurup (NREL), Ashwin Ramdas (NREL), Jo Seel (LBNL).***

# List of Acronyms and Abbreviations

| | |
|---|---|
| AC | alternating current |
| AD+CVD | anti-dumping and countervailing duties |
| ASP | average selling price |
| B | billion |
| BNEF | Bloomberg New Energy Finance |
| BoS | balance of system |
| C-Si | crystalline silicon |
| CdTe | cadmium telluride |
| CIGS | copper indium gallium selenide |
| CSP | concentrating solar power |
| DC | direct current |
| DG | distributed generation |
| DPV | distributed PV |
| EIA | U.S. Energy Information Administration |
| ETF | exchange traded fund |
| FIT | feed-in-tariff |
| G&A | general and administrative expenses |
| GW | gigawatt |
| GW-th | gigawatt-thermal |
| GWh | gigawatt-hour |
| ILR | inverter loading ratio |
| IRS | Internal Revenue Service |
| ITC | investment tax credit |
| kg | kilogram |
| kW | kilowatt |
| kWh | kilowatt-hour |
| MLPE | module-level power electronics |
| MM | million |
| MT | metric ton |
| MW | megawatt |
| MWh | megawatt-hour |
| NEM | net energy metering |
| PBI | performance based incentive |
| PPA | power purchase agreement |
| PSC | public service commission |
| PV | photovoltaic |
| Q | quarter |
| ROW | rest of the world |
| RPS | renewable portfolio standards |
| S&P | Standard and Poor's |
| SACP | solar alternative compliance payment |
| SEIA | Solar Energy Industries Association |
| SETO | Department of Energy Solar Technology Office |
| SG&A | selling, general, and administrative expenses |
| SREC | solar renewable energy certificate |
| TAN | Invesco Solar ETF |
| TPO | third-party owner |
| UPV | utility-scale PV |
| W | watt |
| y/y | year over year |
| YTD | year to date |