Energy Technologies Area Lawrence Berkeley National Laboratory

Tracking the Sun 10

The Installed Price of Residential and Non-Residential Photovoltaic Systems in the United States

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— Report Summary —
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trackingthesun.lbl.gov

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Report Overview

Summarize trends in the installed price of grid-connected residential and non-residential PV systems in the United States

- **Focus on projects installed through 2016 with preliminary data for the first half of 2017**
- **Describe:**
  - Historical trends in national median prices
  - Variability in pricing across projects
- **Including:**
  - Key drivers for decline in median prices
  - Summary and comparison to other PV system price and cost benchmarks
  - Comparison to international markets
  - Installed price variation with system size and design, location, installer, and sector

***Tracking the Sun* public data file**

The full dataset developed for Tracking the Sun is available for download via NREL's Open PV website

(excluding data provided under confidentiality)

Related National Lab Research Products

***Tracking the Sun* is produced in conjunction with several related and ongoing research activities by LBNL and NREL**

- ***Utility-Scale Solar:*** LBNL annual report on utility-scale solar (PV and CSP) describing trends related to project characteristics, installed prices, operating costs, capacity factors, and PPA pricing
- ***The Open PV Project:*** Online data-visualization tool developed by NREL that hosts the public version of the dataset developed for *Tracking the Sun,* along with additional data.
- ***In-Depth Statistical Analyses*** of PV pricing data by researchers at LBNL, NREL, and several academic institutions examining PV pricing dynamics by applying more-advanced statistical techniques to the data in *Tracking the Sun*. These and other solar energy publications are available here.
- ***PV System Cost Benchmarks*** developed by NREL researchers, based on bottom-up engineering models of the overnight capital cost of residential, commercial, and utility-scale systems.

Outline

- **Data Sources, Methods, and Sample Description**
- **Historical Trends in Median Installed Prices**
- **Variation in Installed Prices**
- **Conclusions**

Key Definitions and Conventions

Installed price: The up-front $/W price paid by the PV system owner, prior to incentives (see next 2 slides for discussion of TPO and data limitations)

Customer Segments*:

- **Residential PV:** Single-family residences and, depending on the conventions of the data provider, also multi-family housing
- **Non-Residential PV:** Non-residential roof-mounted systems of any size, and non-residential ground-mounted systems up to 5 MW_{AC}
- **Utility-Scale PV** (**<u>not</u>** included in this report)**:** Ground-mounted ≥5 MW_{AC}

**These customer segment definitions are independent of whether systems are connected to the customer- or utility-side of the meter, and may differ from other market reports*

Units:

- Monetary values expressed in real 2016 dollars
- System size and capacity data expressed in DC units (module nameplate)

Data Sources and Limitations

Installed price trends are based on project-level data:

- Derived from state agencies and utilities that administer PV incentive programs, solar renewable energy credit registration systems, or interconnection processes
- To varying degrees, these data may already exist in the public domain (e.g., California's Currently Interconnected Dataset)

Key Data Limitations

- Self-reported by PV installers and therefore susceptible to inconsistent reporting practices
- Differs from the underlying cost borne by the developer or installer (price ≠ cost)
- Historical and therefore may not be representative of systems installed more recently or current quotes for prospective projects
- Excludes a sub-set of third-party owned (TPO) systems, for which reported prices represent appraised values (see next slide)

Data Cleaning and Standardization

- Standardize spellings of installer, module, and inverter names
- Assign attributes based on equipment data: module efficiency and type, building integrated vs. rack-mounted, module-level power electronics
- Infer system ownership (host-owned or TPO) if data not provided directly
- Remove systems from *final analysis sample* if:
  - Missing valid data for installed price or system size
  - Battery back-up
  - Self-installed
  - Integrated TPO systems (see below)

Treatment of Third-Party Owned (TPO) Systems in the Data Sample and Analysis

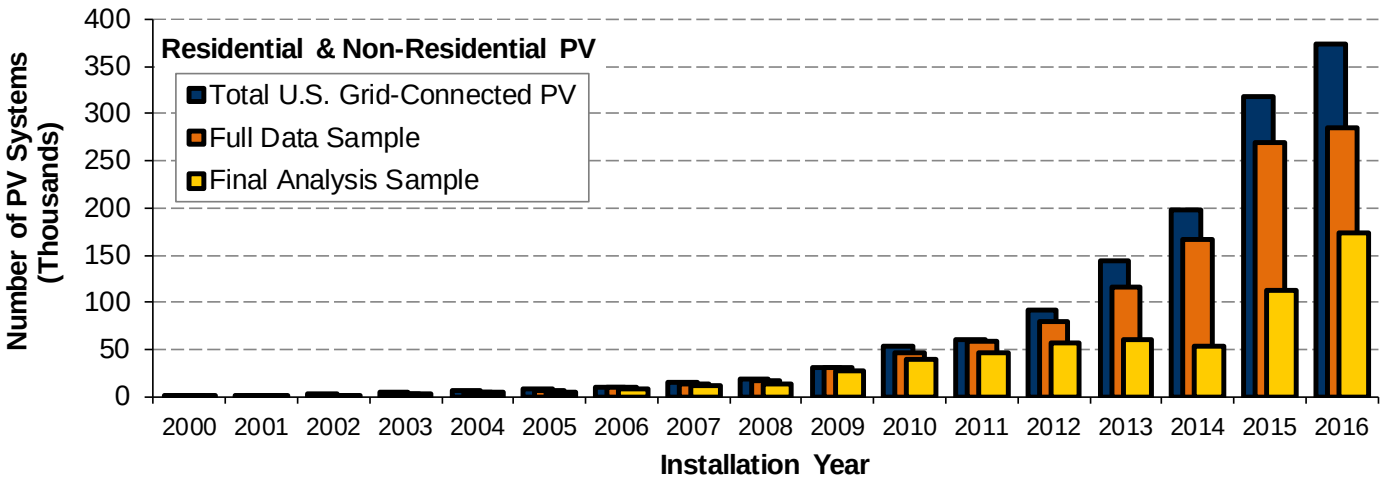
- **Integrated TPO.** A single company provides both the installation service and customer financing. Reported prices represent appraised values. ***Excluded from analysis***.
- **Non-Integrated TPO.** Customer finance provider purchases system from installation contractor. Reported prices represent sale price to customer finance provider. ***Retained in analysis***.

Sample Size Compared to Total U.S. Market

Full Data Sample:
*Prior to excluding integrated TPO and systems with missing data**

- ~1.1 million systems through 2016
- 83% of all U.S. PV systems; 76% of 2016 additions

** The basis for the public data file*



Total U.S. grid-connected PV system installations are based on data from IREC (Sherwood 2016) for all years through 2010 and data from GTM Research and SEIA (2017) for each year thereafter.

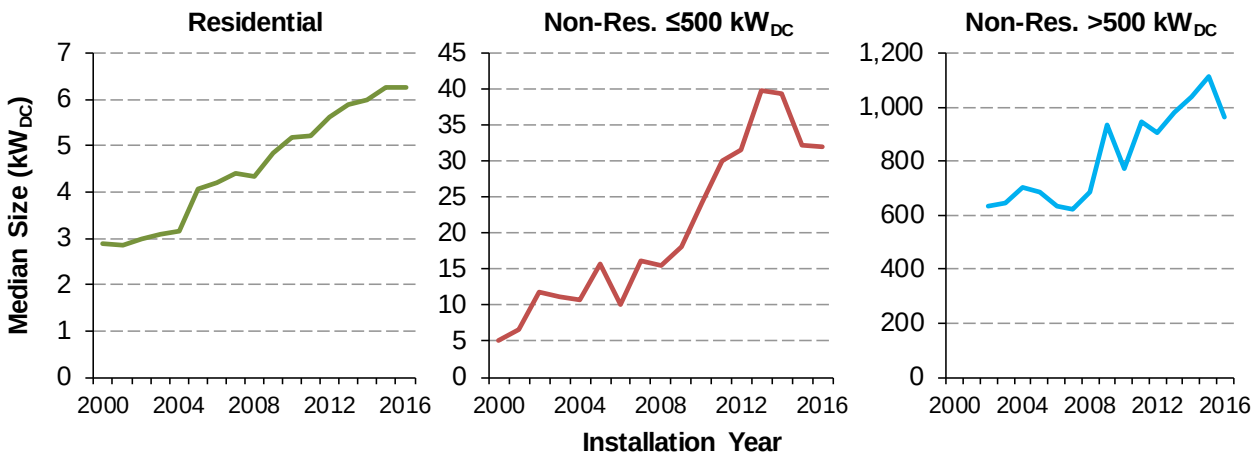
Final Analysis Sample*: Unless otherwise noted, this is the sample used in this analysis*

- ~630,000 systems installed through 2016 and 170,000 systems installed in 2016
- Gap between final sample and full data sample primarily reflects:
  - Removal of appraised-value TPO systems
  - Removal of systems with missing installed price data; most of those are in California and installed from 2013 to mid-2015, when data collection was under transition

Data Sample Characteristics:

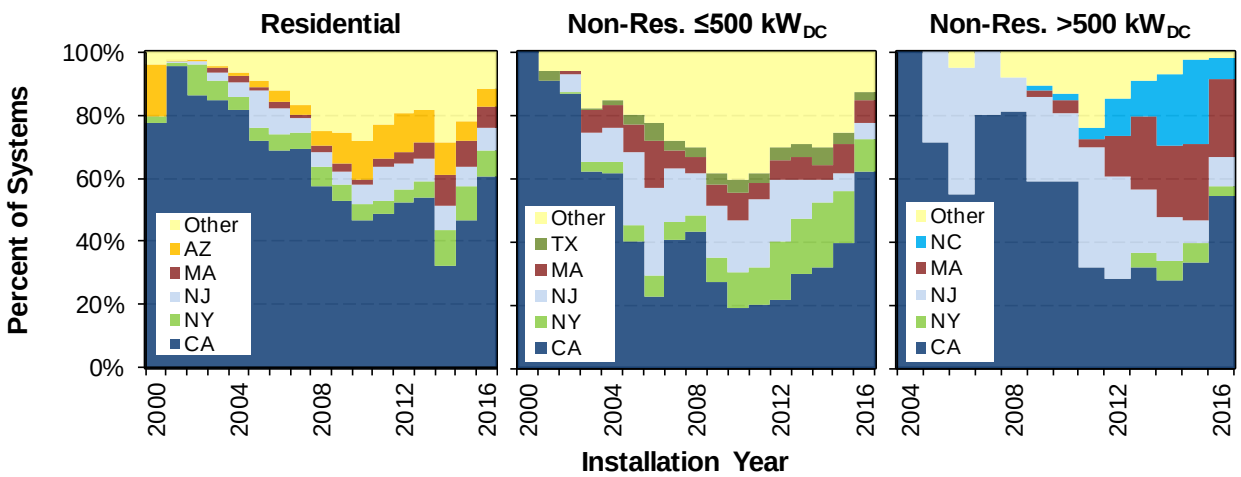
System size trends and distribution among states

System Size Trends



- System sizes growing steadily over time
- Median sizes in 2016:
  - Residential = 6.2 kW
  - Non-Res ≤500 kW = 32 kW
  - Non-Res >500 kW = 965 kW
- Non-Res. systems in the sub-500 kW class are generally small (20-40 kW)

Sample Distribution Across States



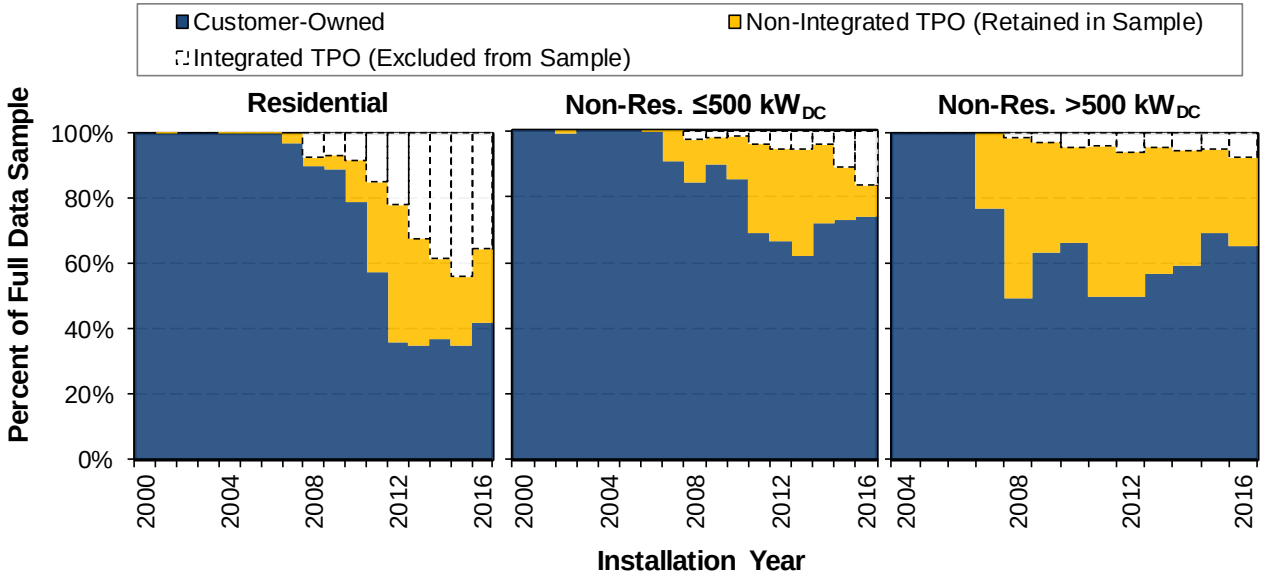
- Sample spans 25 states, though heavily weighted toward CA , MA, NY, NJ, AZ, TX, NC
- CA proportion rose sharply in 2016 due to greater data availability

Data Sample Characteristics:
Distribution by system ownership

Residential:

- Total TPO share grew to ~65% of sample by 2012, remaining near that level through 2015
- Integrated TPO shares grew with greater market consolidation → increasing portion of systems excluded from final analysis sample
- TPO share dropped to 58% in 2016, reflecting broader market trends back toward customer ownership

Sample Distribution by System Ownership



Notes: This figure is based on the full data sample in order to show explicitly how exclusion of integrated TPO systems impacts the final data sample used for analysis; unless otherwise indicated, all other figures are based on the final data sample.

Non-Residential:

- Overall TPO percentages are considerably lower than residential: 26% of non-res. systems ≤500 kW and 34% of non-res. systems >500 kW in 2016
- Negligible presence of integrated TPO

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- Data Sources, Methods, and Sample Description
- **Historical Trends in Median Installed Prices**
- Variation in Installed Prices
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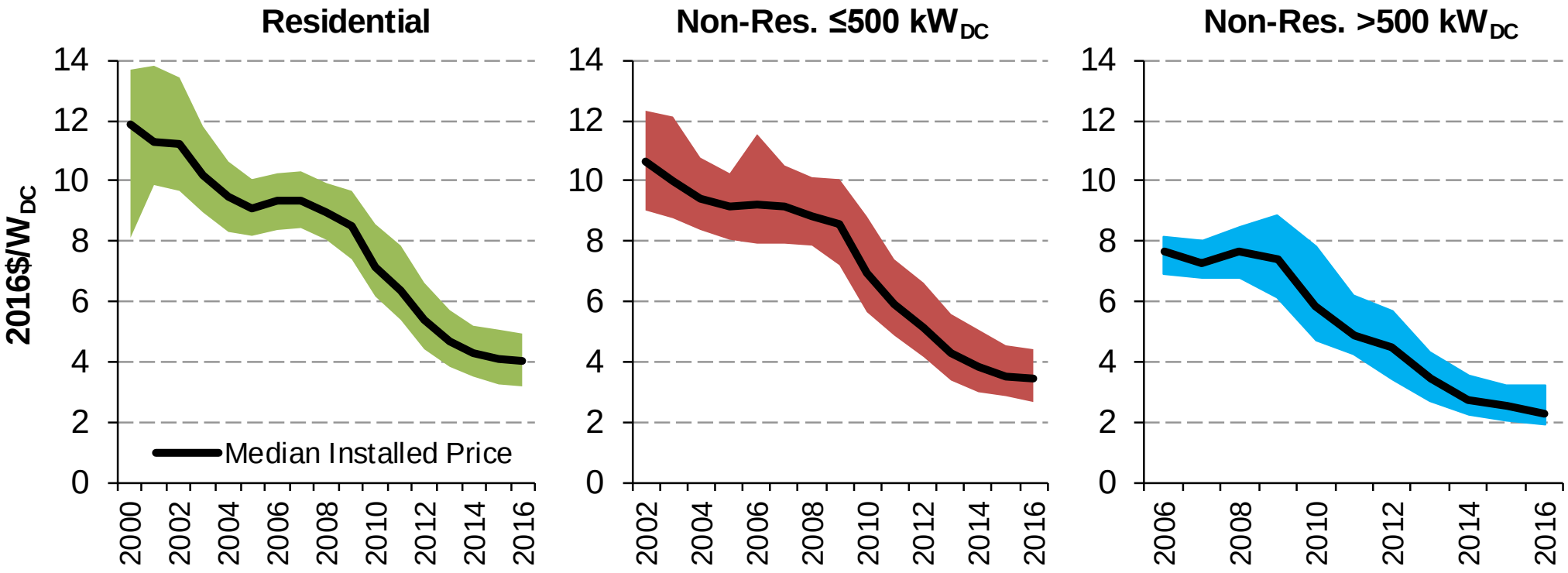
Installed prices continued to fall in 2016, albeit at the slowest rate since 2009

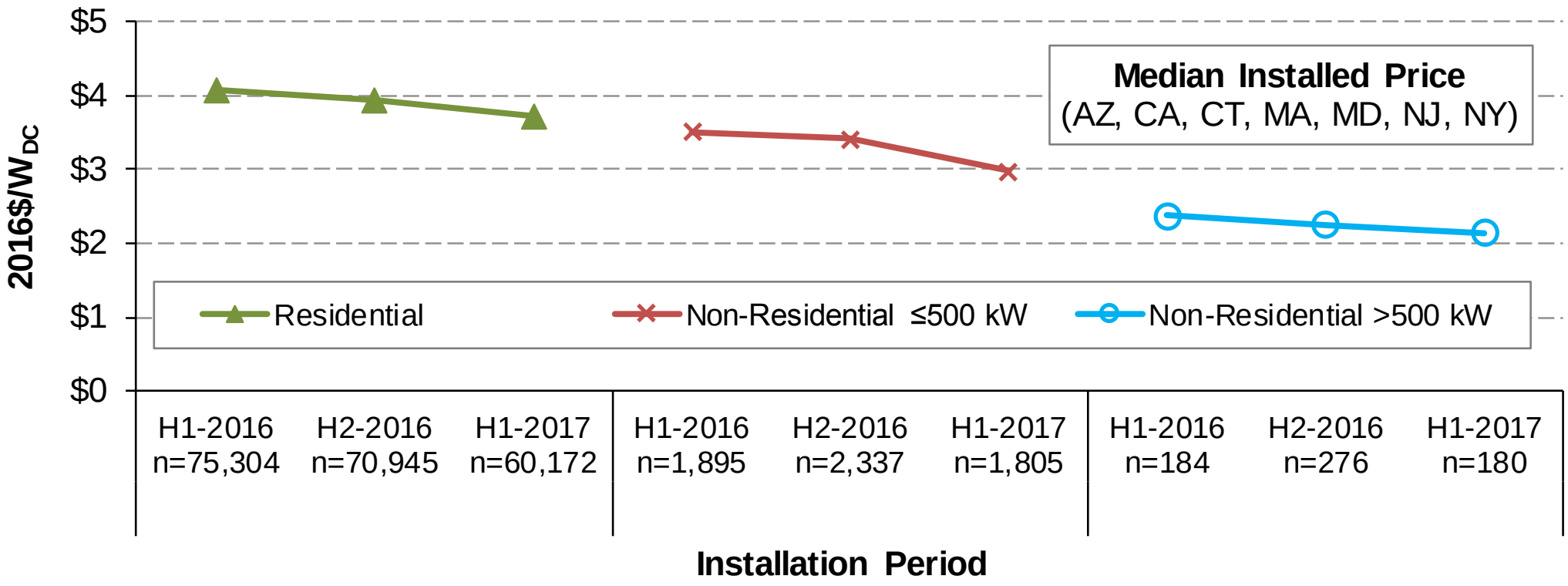
National median installed prices in 2016 declined YoY by $0.1/W (2%) for residential systems, by $0.1/W (3%) for non-residential systems ≤500 kW, and by $0.2/W (8%) for non-residential systems >500 kW



Notes: Solid lines represent median prices, while shaded areas show 20th-to-80th percentile range. Summary statistics shown only if at least 20 observations are available for a given year and customer segment.

Preliminary data for the first half of 2017 suggest that price reductions are picking back up

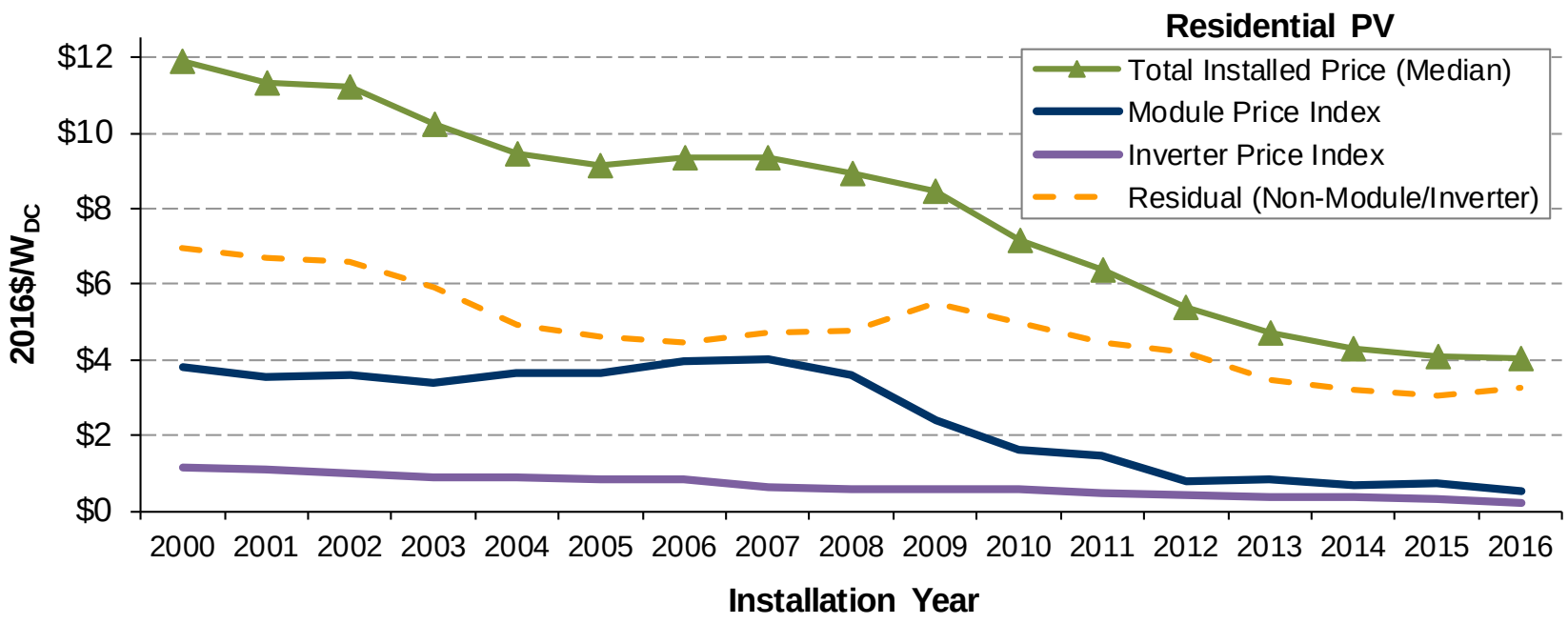
Extrapolated over a full year, installed price declines in the first half of 2017 would yield an 11% year-over-year decline for residential, 25% for small non-residential, and 10% for large non-residential systems



Notes: The figure is based on data from only a subset of programs from the larger dataset, and therefore cannot be directly compared to other figures in the slide deck.

Recent installed price drop driven by hardware costs; sizeable soft-cost declines over long-term

- Installed price decline from 2015 to 2016 driven primarily by falling hardware component prices, lagging behind hardware price declines
- Since 2000, roughly 53% of the total decline in residential system installed prices attributed to falling module and inverter prices, while the remaining 47% is associated primarily with reductions in the aggregate set of soft costs

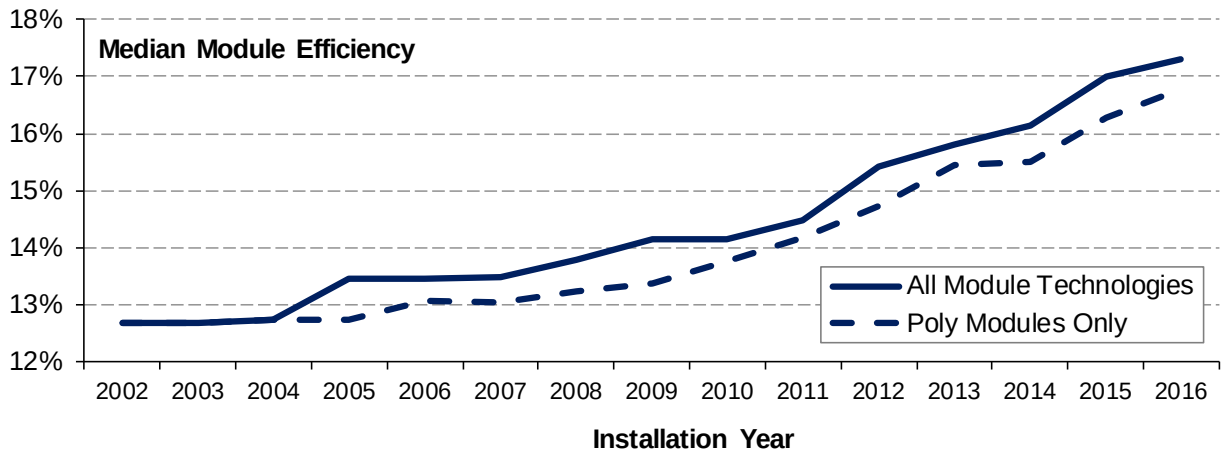


Notes: The Module Price Index is the global module price index for large quantity buyers, published by SPV Market Research (2017). The Inverter Price Index is a weighted average of residential string inverter and microinverter prices published by GTM Research and SEIA (2017); that price series begins in 2010, and we extend it backwards in time using inverter costs reported for individual systems within the LBNL data sample. The Residual term is calculated as the Total Installed Price minus the Module Price Index and Inverter Price Index.

Increasing module efficiencies and system sizes contribute to installed price declines

- Increased module efficiencies and system sizes help to reduce those costs that are either fixed in nature or scale with the physical dimensions of the system
  - Median module efficiencies grew from 12.7% to 17.3% from 2002 to 2016
  - Median residential system sizes more than doubled over time (from 2.9 kW in 2000 to 6.2 kW in 2016, as previously shown)

Increasing module efficiencies and system sizes are together responsible for roughly a **$1.0/W** reduction in residential system costs over the long-term (12% of the total decline in residential installed prices)



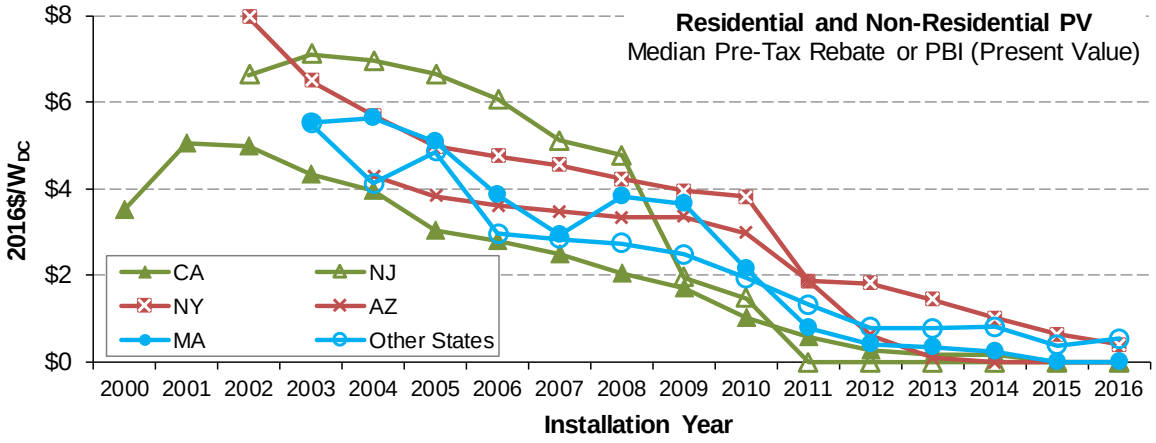
Notes: "All Systems" is based on all residential systems in the data sample, regardless of module technology, while "Poly Systems" is based on only those systems with poly-crystalline modules.

- Soft cost reductions also associated with broad policy trends:
  - Widespread policy and industry R&D efforts aimed at reducing soft costs
  - Steady reductions in incentives (next slide)

Installed price declines have been partially offset by falling state and utility incentives

- Rebates and performance-based incentives (PBIs) have declined from $4-8/W at their peak to less than $1/W (or zero) in most major markets
- Incentive reductions partly a response to installed price declines and the emergence of other forms of incentives (SRECs, ITC, improved monetization of tax benefits)
- Ratcheting down of incentives also a deliberate strategy in some states to induce cost reductions

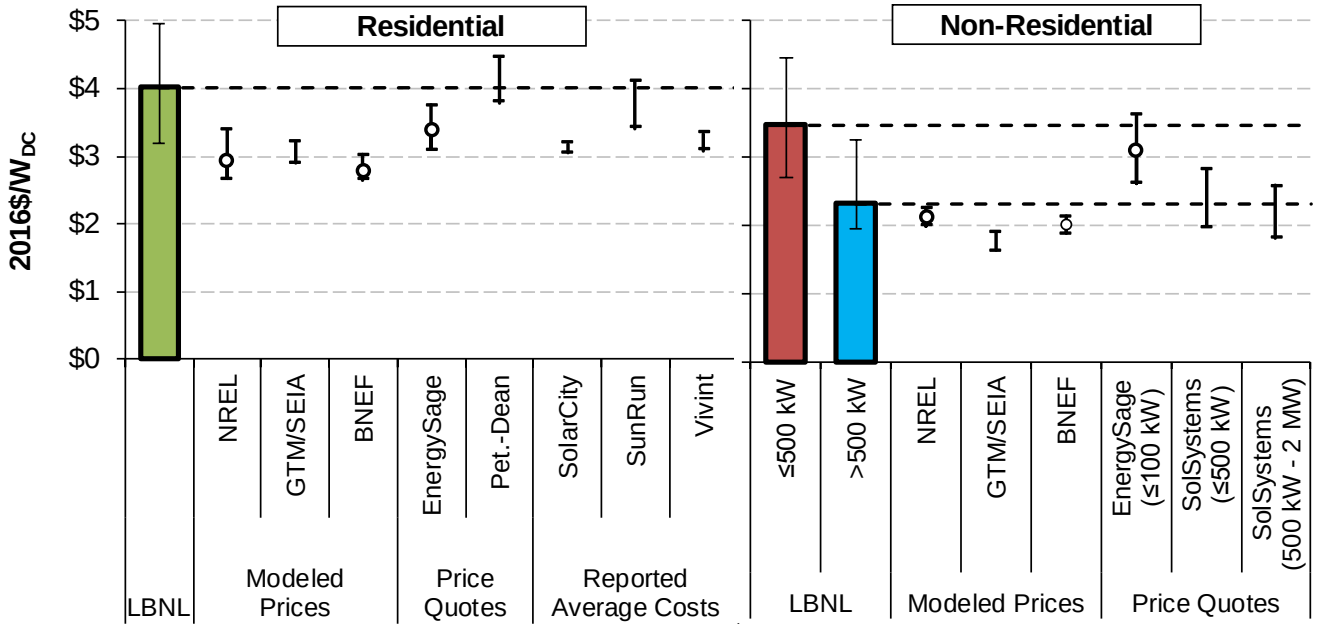
Reductions in rebates and PBIs since their peak equate to 70% to 120% of the corresponding drop in installed prices



Notes: The figure depicts the pre-tax value of rebates and PBI payments (calculated on a present-value basis) provided through state/utility PV incentive programs, among only those systems that received such incentives. Although not shown in the figure, a growing portion of the sample received no direct cash incentive. Also note that the data are organized according to the year of installation, not the year in which incentives were reserved.

National median installed prices are relatively high compared to other recent benchmarks

National median prices for systems installed in 2016: $4.0/W (res.), **$3.4/W** (sm. non-res.), **$2.3/W** (lg. non-res.)



Notes: **LBNL** data are the median and 20th and 80th percentile values among projects installed in 2016. **NREL** data represent modeled turnkey costs in Q1 2016 for a 5.6 kW residential system (range across system configuration and installer type, with weighted average) and a 200 kW commercial system (range across states and national average) (Fu et al. 2016). **GTM/SEIA** data are modeled turnkey prices for Q1 and Q4 2016; their residential price is for a 5-10 kW system with standard crystalline modules, while the commercial price is for a 300 kW flat-roof system (GTM Research and SEIA 2017). **BNEF** data are estimated PV capex with developer margin in 2016 (US averages and range across states/regions) (Serota and Bromley 2016). **EnergySage** data are the median and 20th and 80th percentile range among price quotes issued in 2016, calculated by Berkeley Lab from data provided by EnergySage; quote data for non-residential systems are predominantly from small (<100 kW) projects. **Petersen-Dean** data are the minimum and maximum values from a series of online price quotes for turnkey systems across a range of sizes (3.4 to 8.4 kW) and states (CA and TX), queried from the company website by Berkeley Lab in June 2016. **SolarCity**, **SunRun**, and **Vivint** data are the companies' reported average costs, inclusive of general administrative and sales costs, for Q1 and Q4 2016 (or Q3 2016 for SolarCity). **SolSystems** data are averages of the 25th and 75th percentile values of "developer all-in asking prices" published in the company's monthly Sol Project Finance Journal reports throughout 2016.

Medians differ from other benchmarks due to:

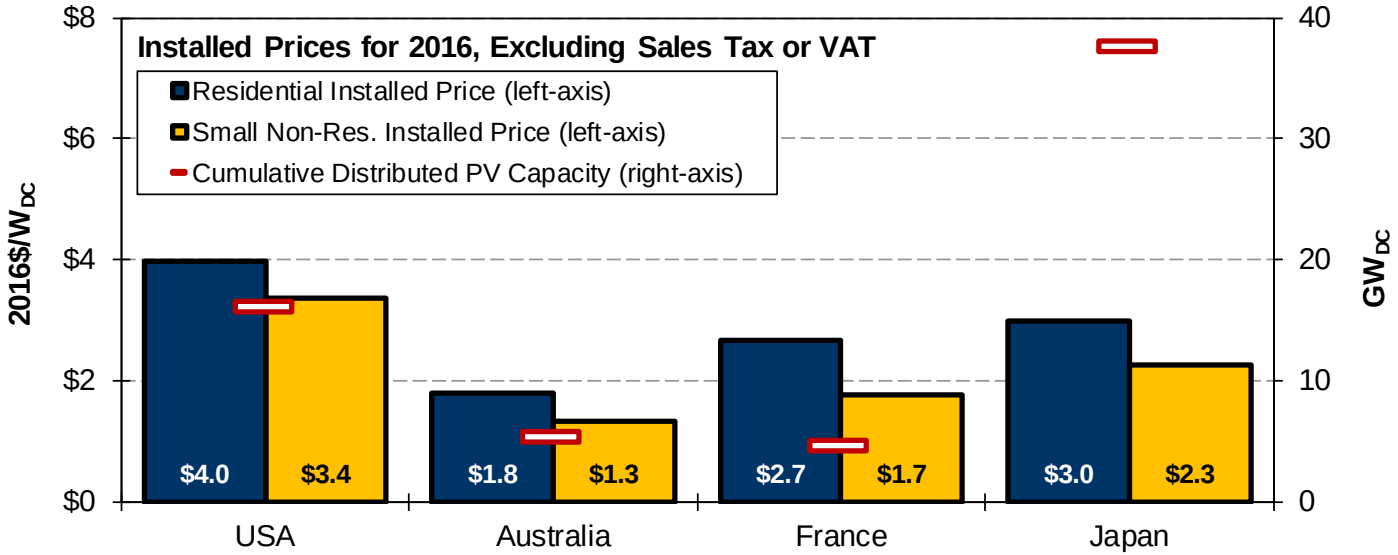
- Timing/vintage
- Location
- Price vs. cost
- Value-based pricing
- System size & components
- Scope of costs included
- Installer characteristics

Other benchmarks align more closely with the 20th percentile values in the LBNL dataset

Installed prices in the United States are higher than in other national PV markets

Among the countries shown here, the starkest differences are compared to Australia, where typical residential pricing in 2016 was less than half of U.S. median prices

- Hardware costs are largely (though not entirely) uniform across countries
- Installed prices thus differ largely due to soft costs
- Soft cost differences driven partly by deployment scale



Notes: Data for Australia, France, and Japan are based on each country's respective IEA Photovoltaic Power Systems Programme's (PVPS) 2016 National Survey Report (Johnston and Egan 2017, L'Epine 2017, and Yamada and Ikki 2017).

- Yet smaller prices reported for smaller national markets suggest that other factors also likely contribute (e.g., solar industry business models, customer awareness, incentive levels and incentive design, building architecture, systems sizing and design, interconnection standards, labor wages, and permitting and interconnection processes).

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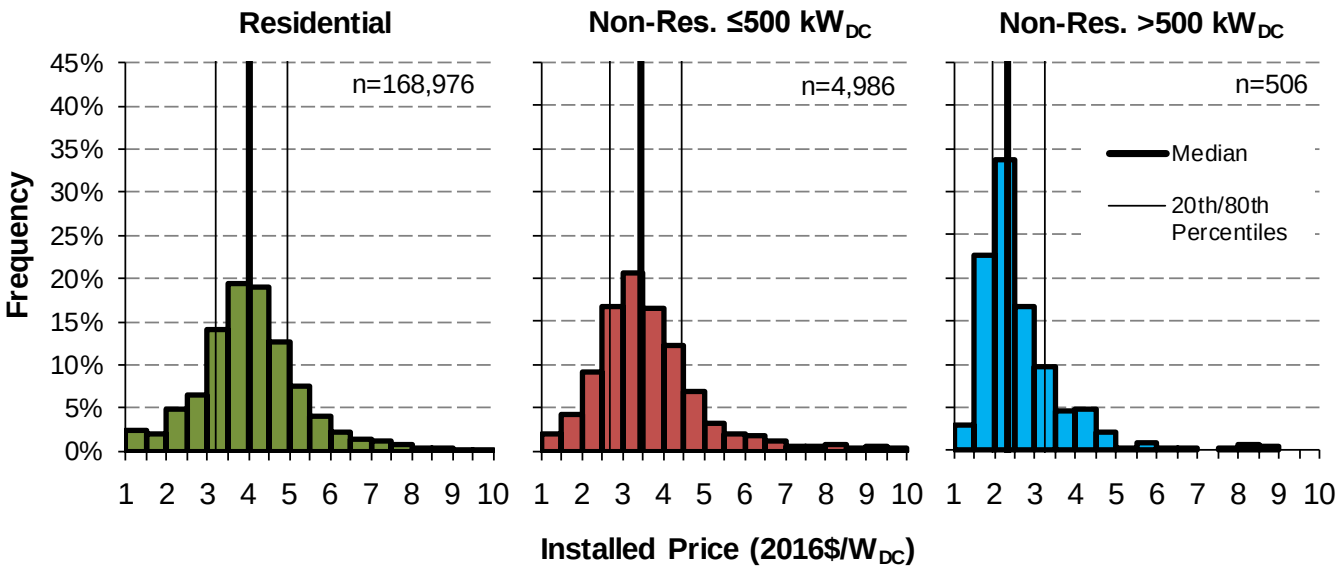
Installed prices vary widely across projects

Persistent over time, despite market maturation

Installed Price Distributions for Systems Installed in 2016



Among 2016 systems, 20th-to-80th percentile prices range from:

$3.2-5.0/W (res.)

$2.7-4.4/W (sm. non-res.)

$1.9-3.2/W (lg. non-res.)

- Potential underlying causes of pricing variability include differences in project characteristics, installers, and local market or regulatory conditions
  - The remainder of this document explores some of these drivers; see also the growing body of studies noted on the next slide
- Wide pricing distributions also serve to demonstrate potential for low-cost systems
  - For example, more than 15,000 residential systems installed in 2016 (9%) were priced below $2.5/W, and 8,000 (5%) were below $2.0/W

A variety of statistical analyses shed light on installed pricing dynamics for residential PV

Studies conducted by LBNL, NREL, and academic partners (Yale, U. of Wisconsin, U. of Texas) have applied more-sophisticated statistical and econometric methods to explain PV pricing dynamics within the *Tracking the Sun* dataset

Nemet et al. (2017) analyzes price dispersion in U.S. residential PV installations, finding that factors that increase consumer access to information—such as neighbors who have recently installed PV and the availability of third-party quotes—are associated with less price dispersion

O'Shaughnessy (2016) developed a new approach to delineating solar PV market boundaries based on the spatial distribution of installer firms (instead of the more-typical approach using political boundaries, such as county or zip code)

Nemet et al. (2016a) and **Nemet et al. (2016b)** examined the characteristics of low-priced systems (within the lowest 10th percentile), showing, among other things, that high consumer incentives for solar tend to increase installed prices as a general matter, yet the lowest-priced systems are also associated with relatively high consumer incentives

Gillingham et al. (2014) estimated the effects of a broad set of drivers on residential PV pricing, including variation in system size ($1.5/W effect), density of installers ($0.5/W effect), consumer value of incentives and electricity bill savings ($0.4/W effect), and installer experience ($0.2/W effect)

Dong and Wiser (2013) found installed price differences of $0.3/W to $0.8/W between cities in California with the least- and most-onerous permitting practices

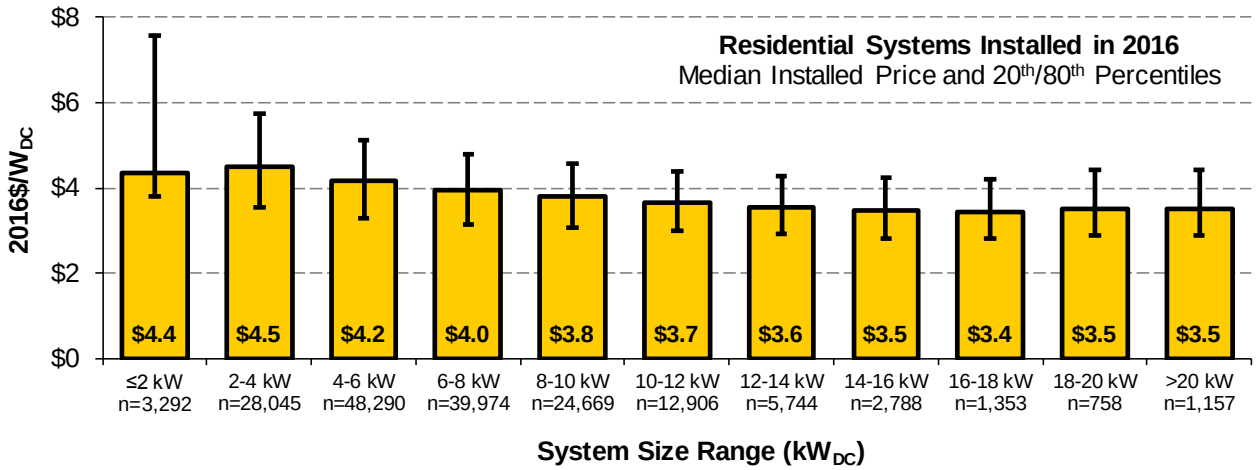
Burkhardt et al. (2014) found that local permitting procedures alone impact installed prices by $0.2/W, while the combination of permitting and other local regulatory procedures impacts prices by $0.6-0.9/W

Dong et al. (2014) found that, historically, 95% to 99% of rebates in California were passed through to consumers, rather than retained as increased installer margins

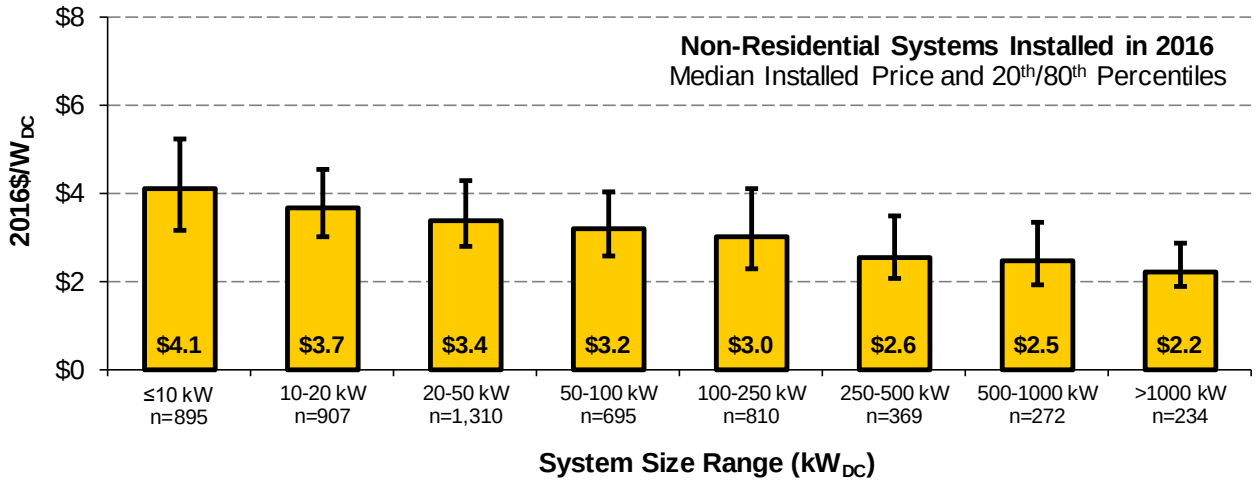
Studies available at http://emp.lbl.gov/projects/solar

Strong economies of scale exist among both residential and non-residential systems

Residential Systems



Non-Residential Systems



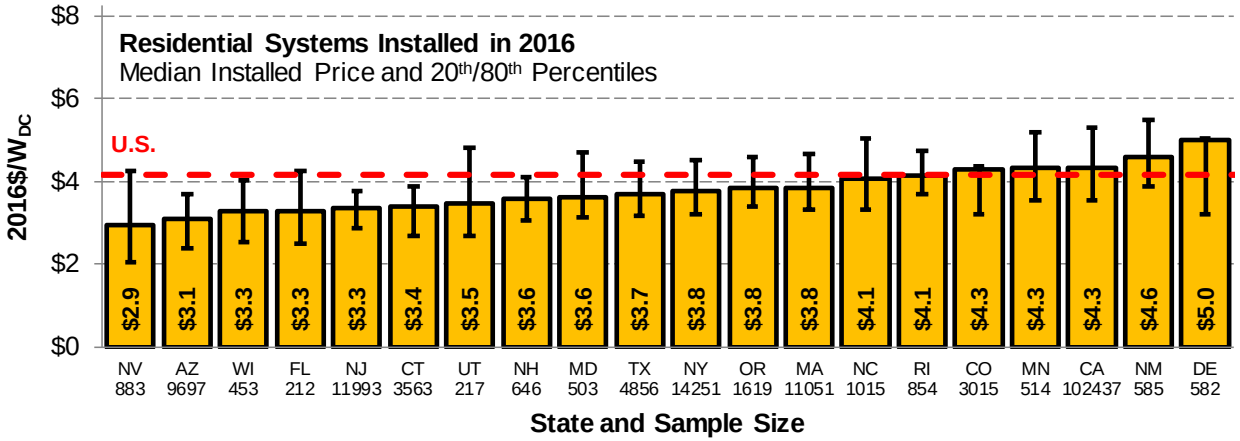
- For residential systems installed in 2016, median prices were roughly 19% lower for 10-12 kW systems than for 2-4 kW systems
- Among non-res. systems installed in 2016, median installed prices were 46% lower for the largest (>1,000 kW) than for the smallest (≤10 kW) non-res. systems
- Even greater economies of scale arise when progressing to utility-scale systems, which are outside the scope of this report

Installed prices vary widely among states

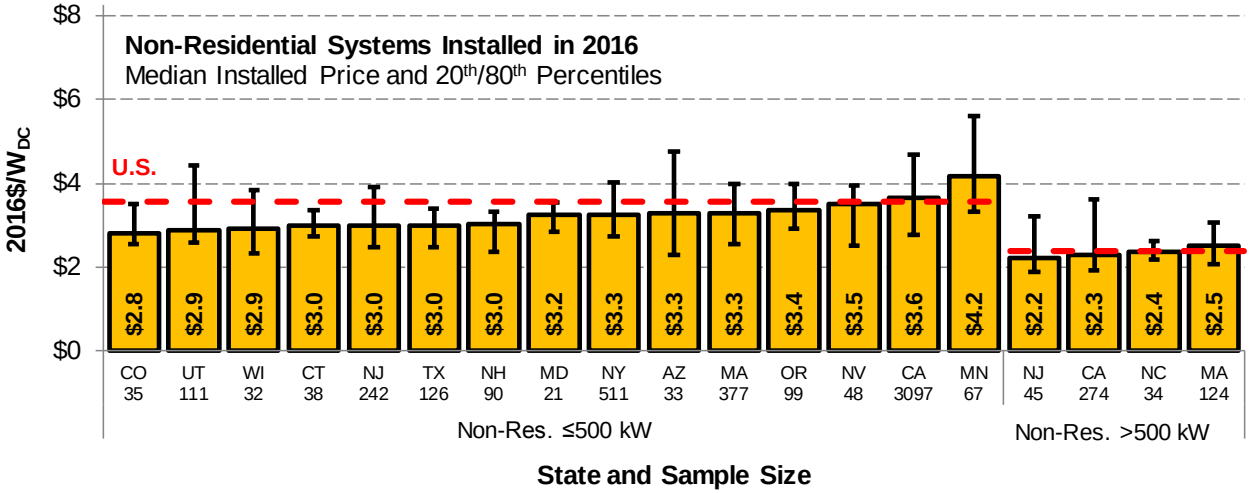
Relatively high prices in some large state markets

- Some of the largest markets (CA, MA, NY) are relatively high-priced, pulling overall U.S. median prices upward
- 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
- High degree of variability also occurs *within* states

Residential Systems



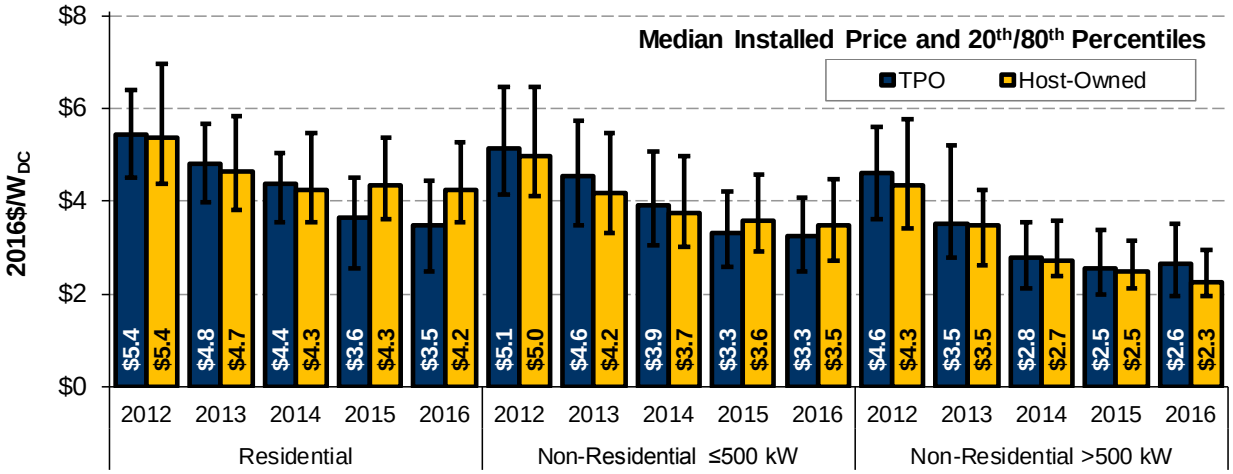
Non-Residential Systems

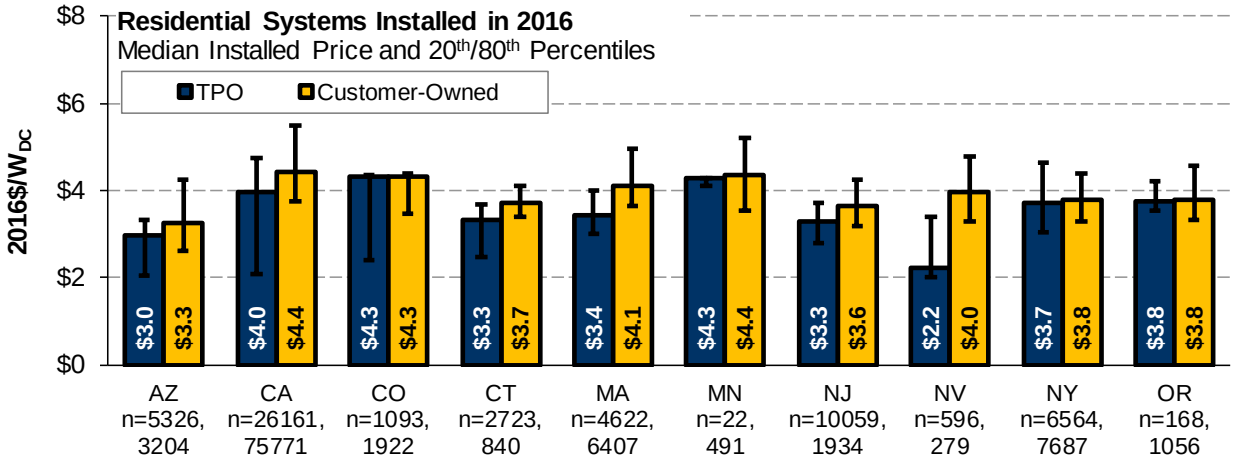


Note: Results shown only if 20 or more observations are available for the state

Residential TPO systems were significantly lower-priced than host-owned systems in 2016

- Median price was $0.7/W lower for TPO than for host-owned residential systems in 2015 and 2016 (top figure)
- TPO systems also lower-priced than host-owned in most states (bottom figure)
- May reflect a combination of:
  - Loan origination fees included in the price of some host-owned systems
  - Cust. acquisition sometimes performed by TPO financiers
  - Negotiating power of TPO financiers
  - More-standardized design of TPO systems

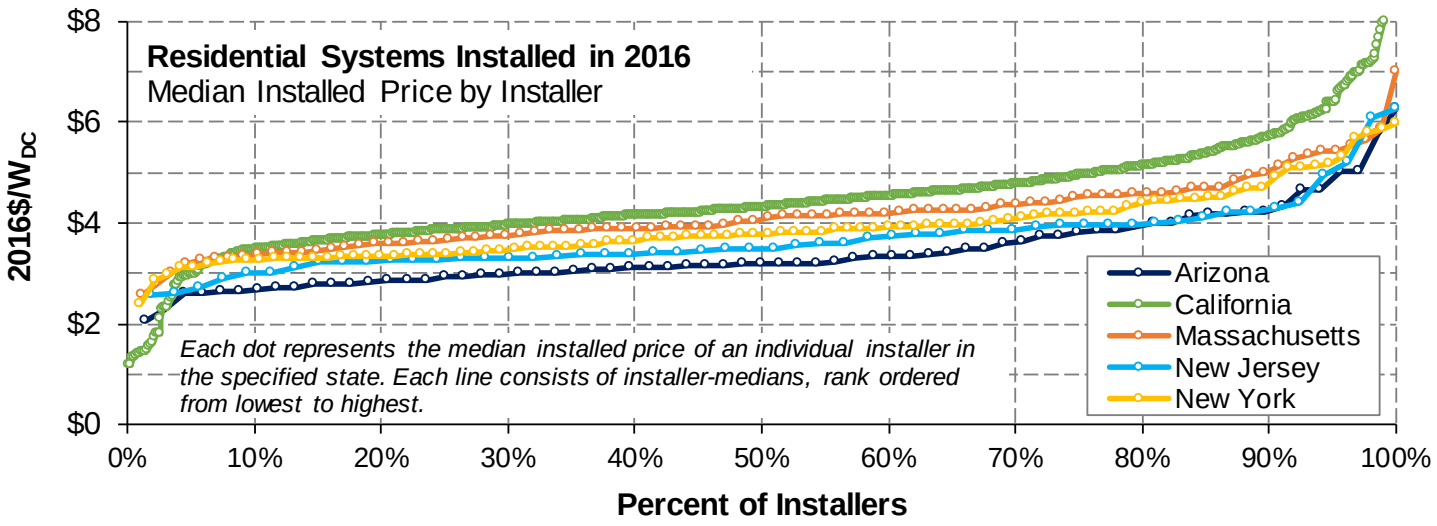




Notes: The values shown here for TPO systems are based on systems financed by non-integrated TPO providers, for which installed price data represent the sale price between the installation contractor and customer finance provider.

Prices vary considerably across installers

Within each of the five states shown, ***installer-level median prices*** differ by $0.7/W to $1.4/W between the 20th & 80th percentiles (and by more across the full set of installers)

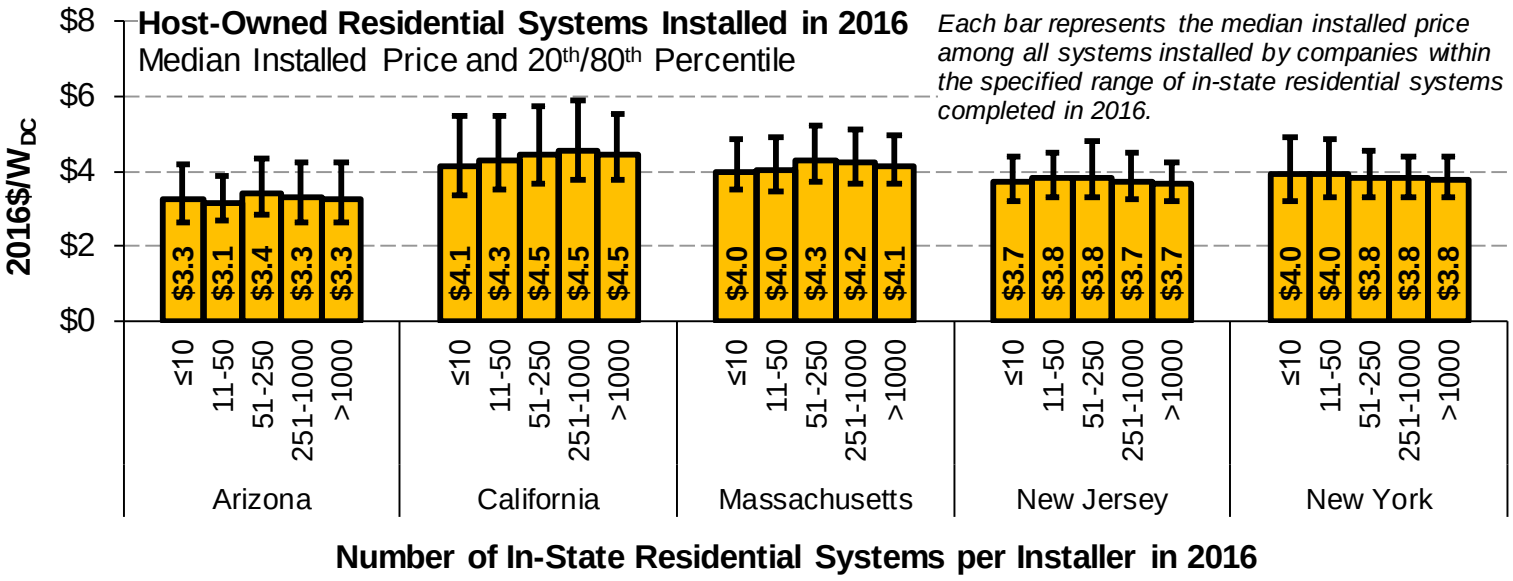


Notes: Each line includes only installers that completed at least 10 residential systems in the given state in 2016.

- "Low-price leaders" provide a benchmark for what may be achievable in terms of near-term installed price reductions within the broader market (e.g., 20% of installers in New York have median prices below $3.3/W)
- High-priced installers may specialize in "premium" systems or may include in their reported prices additional items beyond what is typically counted as part of the PV system (e.g., loan origination fees, re-roofing costs, etc.)

No clear relationship between installer-level pricing and installer volume

In general, little difference and no consistent directional trend based on installer-volume (with the possible exception of CA, which seems to show lower prices for high-volume installers)



Notes: Installer volumes are calculated from the full data sample, and therefore include integrated TPO systems and other excluded systems that are not used for the purpose of calculating installed price statistics.

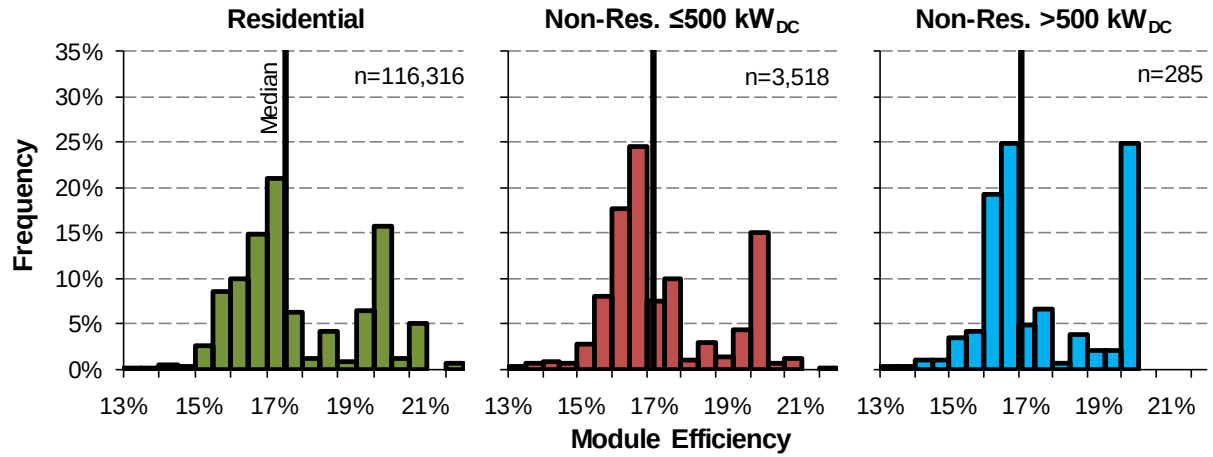
Potentially competing dynamics at play

- Higher-volume installers have economies of scale and greater efficiencies as a result of accumulated experience
- But high-volume installers may also enjoy a certain degree of market power or reputational advantages, and also have higher customer acquisition costs

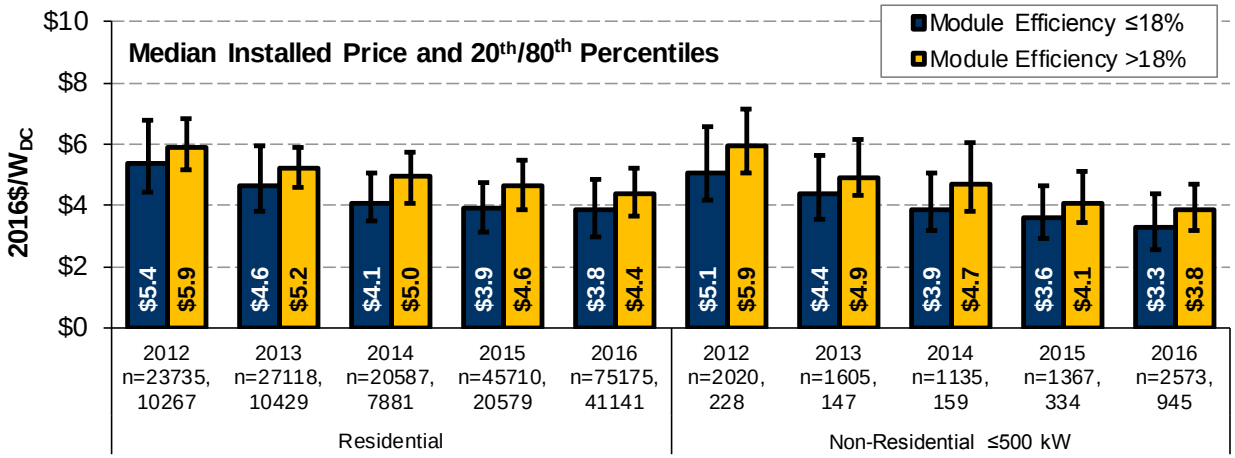
Installed prices are substantially higher for systems with premium efficiency modules

- Roughly 35% of 2016 residential systems in the sample have module efficiencies >18%
- Median installed prices $0.5/W higher for systems with high-efficiency modules in 2016, compared to standard efficiency
- Cost premium for high-efficiency modules appears to outweigh any reduction in BOS costs (though tradeoffs between module technologies entail a broader set of considerations)

Module Efficiency Distributions for Systems Installed in 2016

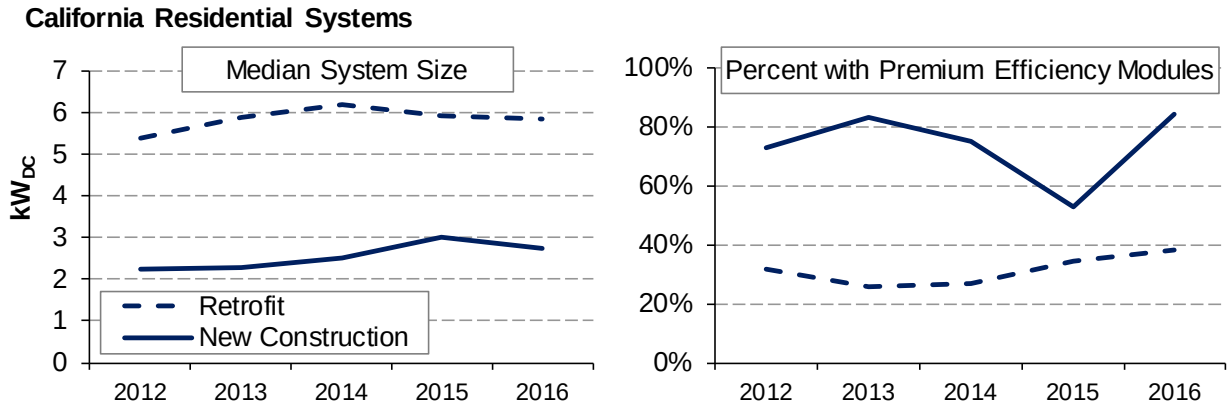


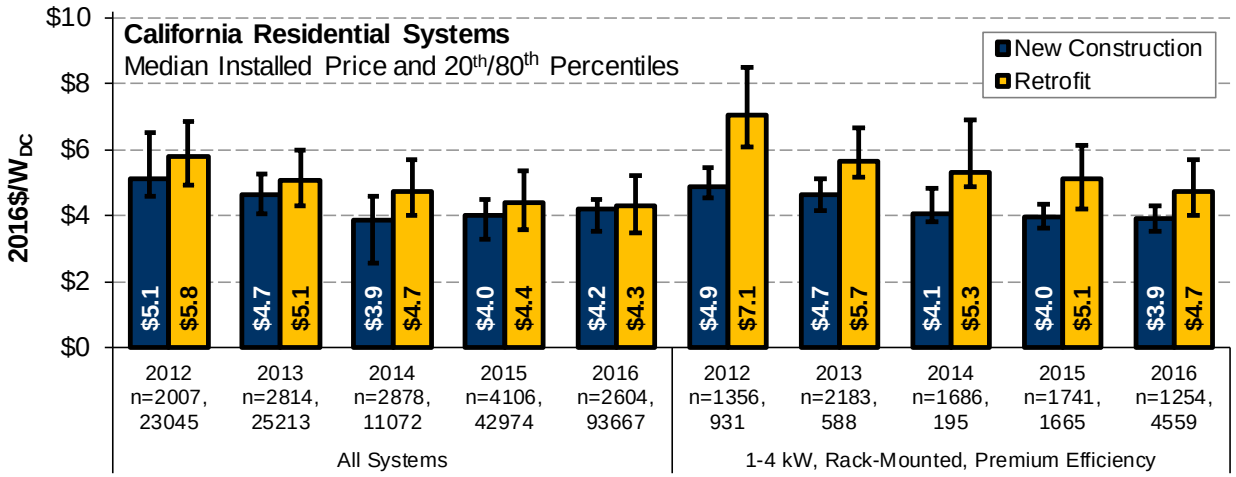
Installed Price Differences Based on Module Efficiency



Residential new construction offers significant installed price advantages compared to retrofits

- PV systems installed in new construction tend to be small and have high incidence of premium modules (top chart)
- Nevertheless, residential new construction systems in CA are consistently lower priced than retrofits (bottom chart)
- Price advantage even greater if comparing among 1-4 kW systems with premium efficiency modules
- Illustrates economies of scale and scope in new construction (particularly for large housing developments)

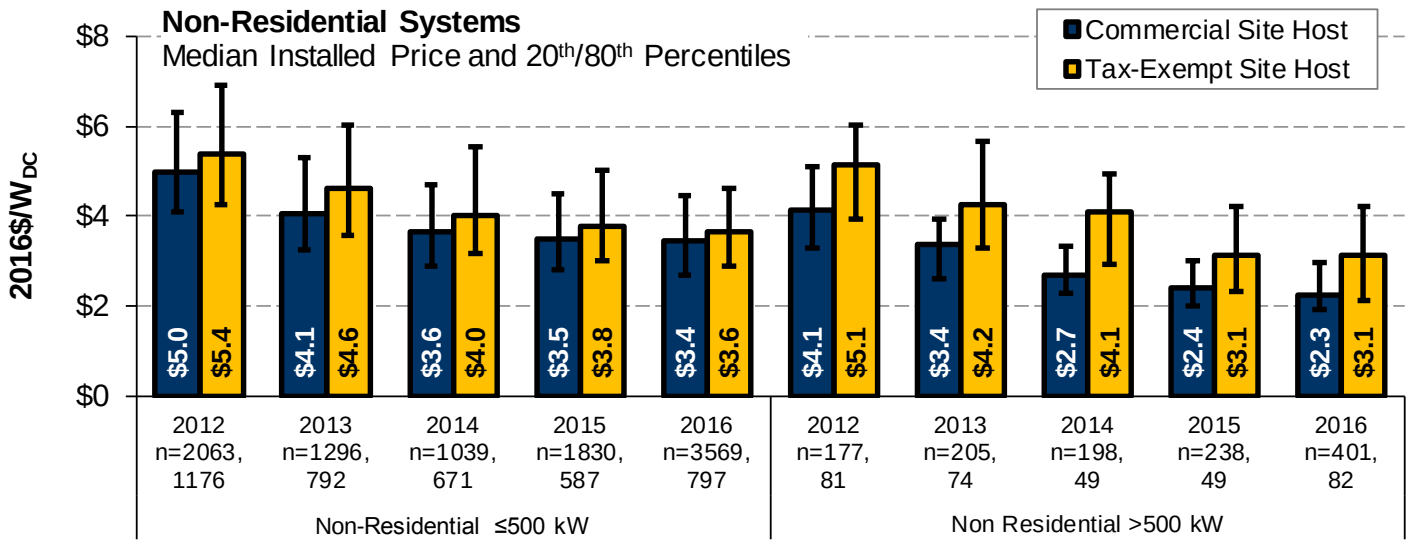




Installed prices are higher for systems at tax-exempt customer sites than at for-profit commercial sites

Tax-exempt customers

- Schools, government facilities, non-profits, religious organizations
- Represent 18% of small and 27% of large non-res. systems in 2016 sample

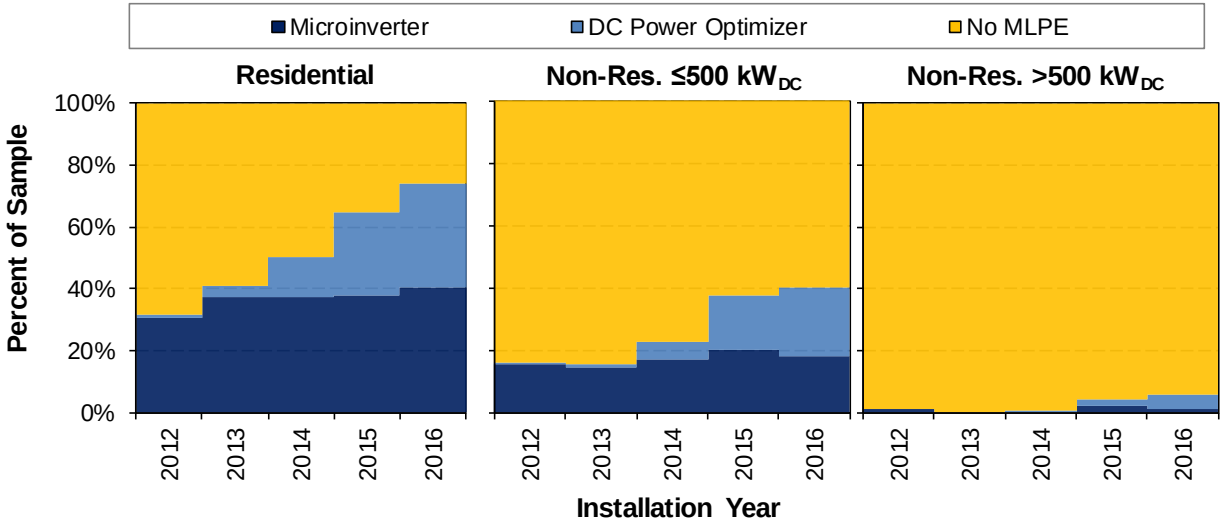


Compared to systems installed at for-profit commercial sites

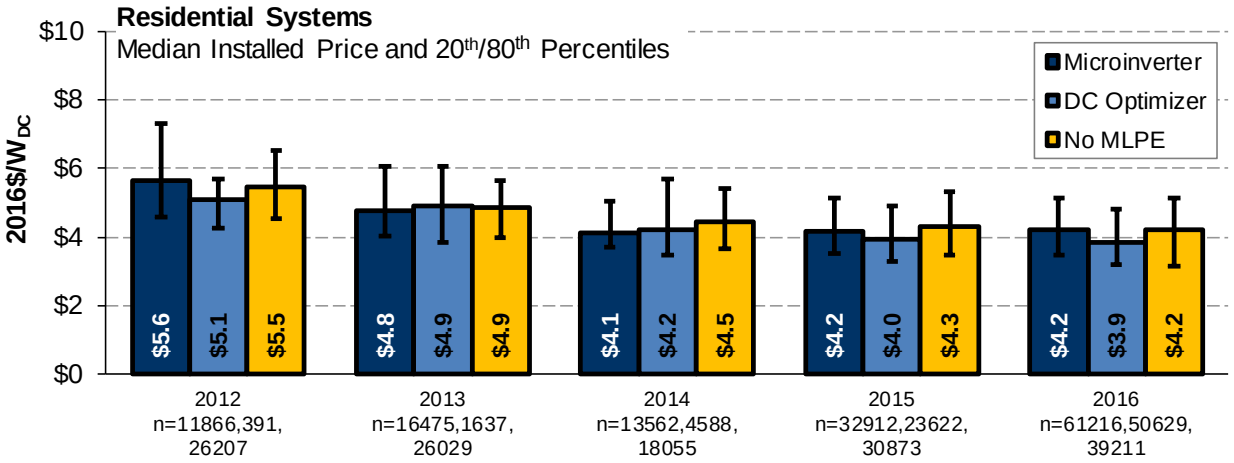
- Median prices at tax-exempt sites in 2016 were $0.2/W higher for systems ≤500 kW and $0.8/W higher for systems >500 kW
- May reflect less-stringent financial criteria; more onerous permitting and procurement processes; and higher incidence of prevailing wage/union labor requirements, domestically manufactured components, and shade or parking structures

Module-level power electronics have a seemingly small effect on installed prices

- Penetration of module-level power electronics (MLPE) has grown substantially among residential and smaller non-residential systems (top chart)
- Despite additional hardware costs, differential in total system prices relative to systems without MLPE has generally been small, or even negative (bottom chart)
- Suggest that MLPE devices may offer some offsetting reductions in other BOS and soft costs

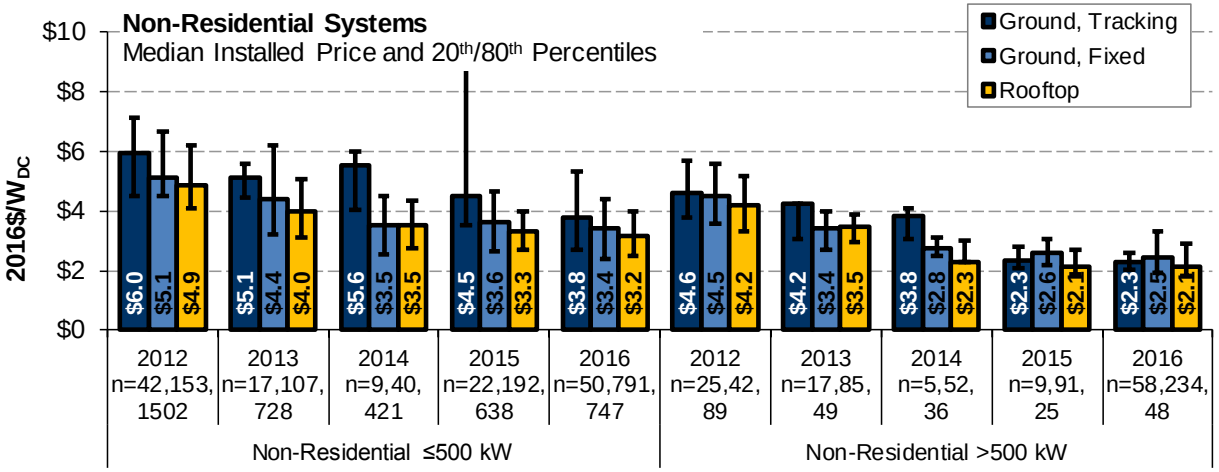


Notes: The DC power optimizer share includes only systems using SolarEdge inverters, and thus likely understates the actual share of DC power optimizers in the data sample.



Ground-mounted non-residential systems are generally higher priced than rooftop systems

- Most of the large (>500 kW) non-residential systems in the data sample are ground-mounted (86% in 2016), often with tracking (17% in 2016)
- A smaller but still significant portion of non-res. systems <500 kW are ground-mounted, some with tracking



Notes: The figure is derived from the relatively small subsample of systems for which data were available indicating both whether the system is roof- or ground-mounted and whether or not it has tracking.

- Among both small and large non-res. systems, the median price was $0.3/W higher for fixed, ground-mounted systems than for rooftop systems in 2016.
- Tracking equipment adds additional costs, though this is not always readily or precisely discernible with the installed price data
  - Among small non-res. systems in 2016, median price was about $0.4/W higher for systems with tracking than for fixed, ground-mounted systems
  - For large non-res. systems in 2016, prices were actually lower for those with tracking than those without it (a function of small sample sizes, idiosyncratic variability)

Outline

- Data Sources, Methods, and Sample Description
- Historical Trends in Median Installed Prices
- Variation in Installed Prices
- **Conclusions**

Conclusions

- Installed prices for distributed PV have fallen dramatically over time, with reductions attributable to declines in both hardware and soft costs
- Suggests that recent efforts by industry and policymakers to target soft costs have begun to bear fruit
- Significant further reductions in soft costs will be needed to sustain continued declines in PV system pricing
- Lower installed prices in other major national PV markets and in some U.S. states, as well as the high degree of variability in U.S. system pricing, suggests that deeper reductions in soft costs are possible in the near term
- Achieving dramatic reductions in soft cost may accompany market scale, but also likely requires targeted policies aimed at specific soft costs, as well as R&D to identify barriers to and opportunities for further reducing soft costs

For more information

Download the report along with a briefing and summary data tables:

trackingthesun.lbl.gov

Download the "Public Data File" with project-level data

https://openpv.nrel.gov/search

Search other renewable energy publications and join our mailing list to receive notice of future publications:

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