# Tracking the Sun

## Installed Price Trends for Distributed Photovoltaic Systems in the United States

## 2018 Edition

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**trackingthesun.lbl.gov**

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# Report Overview

**Summarizes installed prices and other trends among grid-connected, distributed solar photovoltaic (PV) systems in the United States**

- **Focuses on projects installed through 2017 with preliminary data for the first half of 2018**
- **Describes:**
  - **Project characteristics** related to system size and design, ownership, customer segmentation, and other attributes
  - **National median installed prices**, both long-term and recent trends
  - **Variability in pricing across projects** according to system size, state, installer, host-owned vs. third-party owned, residential new construction vs. retrofit, for-profit commercial vs. tax-exempt site host, module efficiency level, and rooftop vs. ground-mounted with or without tracking

**"Distributed PV"**

For the purpose of this report, includes residential and non-residential systems that are roof-mounted (of any size) or ground-mounted (up to 5 $MW_{AC}$)

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

The full dataset (excluding any confidential data) is available for download via trackingthesun.lbl.gov

# 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
- ***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
- ***The Open PV Project:*** Online data-visualization tool developed by NREL that incorporates the public version of the *Tracking the Sun* dataset 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*

# Data Sources, Methods, and Market Coverage

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# Key Definitions and Conventions

***"Installed Price" = The up-front $/W price paid by the PV system owner, prior to incentives***

## Units

- Real 2017 dollars
- Direct current (DC) Watts (W), unless otherwise noted

## Customer Segments

- **Residential:** Single-family residences and, depending on the conventions of the data provider, may also include multi-family housing
- **Non-Residential:** Non-residential roof-mounted systems of any size and ground-mounted systems up to 5 $MW_{AC}$ (ground-mounted systems >5 $MW_{AC}$ are considered utility-scale; are covered in LBNL's *Utility-Scale Solar* report)
  - Throughout much of the analysis, we further segment non-residential systems into "small" (≤500 kW) vs. "large" (>500 kW)

*Note that both 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*

# 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; 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

1. Standardize spellings of installer, module, and inverter names
2. Assign attributes based on equipment spec sheet data: module efficiency and technology type (mono vs. poly vs. other), building integrated module vs. rack-mounted, module-level power electronics
3. Remove systems from analysis sample if:
   - Missing data for installed price or system size
   - Battery back-up
   - Self-installed
   - Reported price is likely an “appraised value” rather than an actual transaction price (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***.

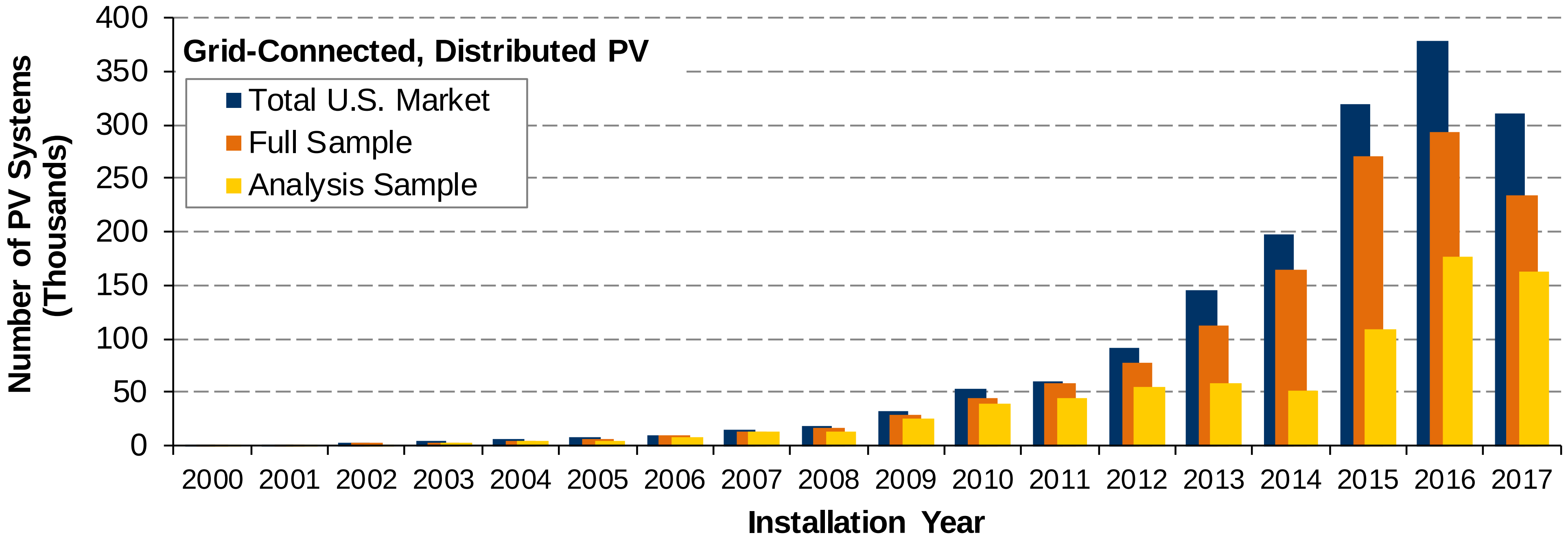
# Sample Size Relative to Total U.S. Market

**Full Sample** *(prior to removing systems from the dataset)*

- **1.3 million** systems through 2017 (81% of U.S. market)
- 230,000 systems installed in 2017 (75% of U.S. market)

**Analysis Sample** *(used for analysis of installed price trends)*

- **770,000** systems through 2017
- 160,000 installed in 2017



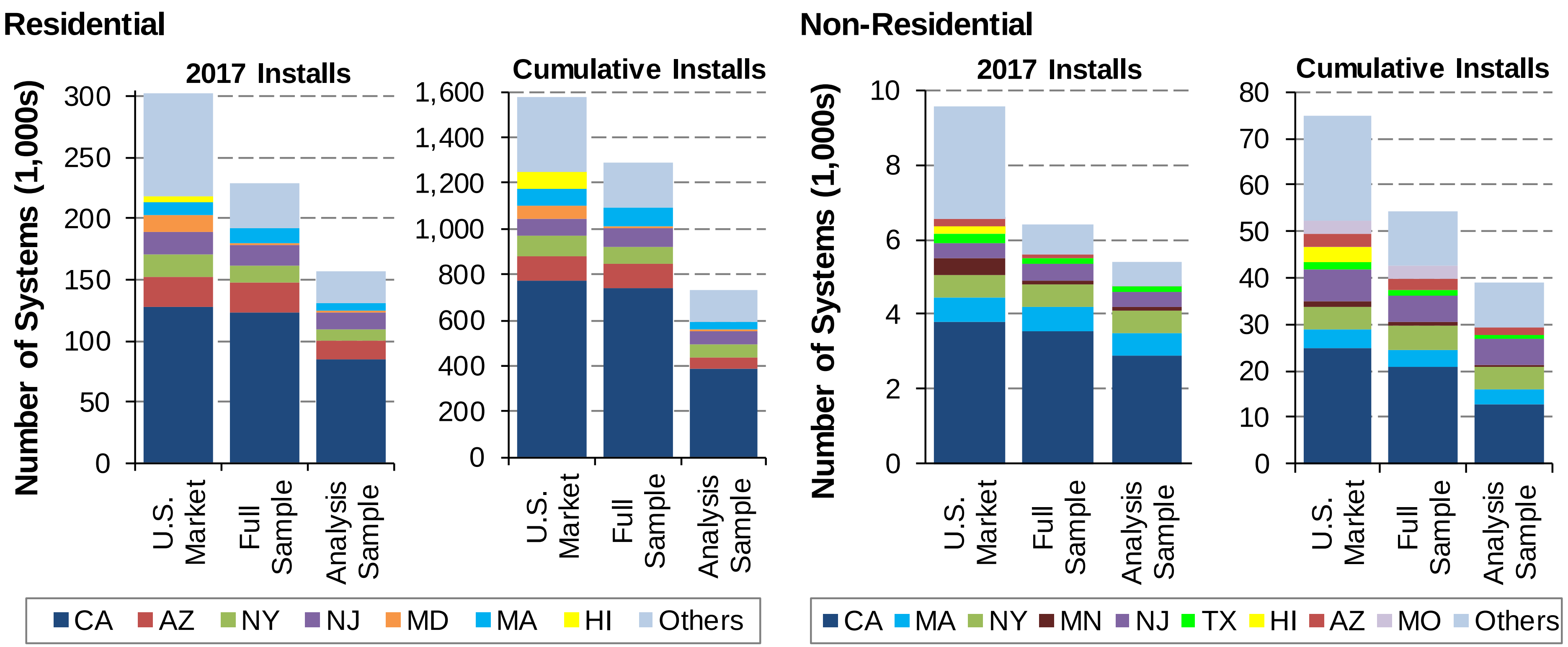

*Notes: Total U.S. distributed PV installations are based on data from IREC (Sherwood 2016) for all years through 2010 and from GTM Research and SEIA (2018) for each year thereafter.*

**Gap between Full Sample and U.S. Market:** Associated mostly with smaller and mid-sized state markets either missing or under-represented in the sample; see next slide

**Gap between Analysis Sample and Full Sample:** Primarily appraised-value systems and systems missing installed price data; larger gaps in 2013-2016 due to transitional issues in CA

# State-Level Sample Distribution and Market Coverage

- 29 states in full sample, 25 in the analysis sample (no price data for 4 states)
- CA dominates the sample, as in the larger U.S. market
- Coverage in larger markets is strong, with a few exceptions: HI, MD (res), MN (non-res)
- Smaller state markets somewhat under-represented in the sample (denoted as “Others”)
- Better coverage for the residential than non-residential market (though comparisons for the latter are imperfect, due to definitional differences—see figure notes)




*Notes: Data for total U.S. market are from GTM Research and SEIA (2018), which defines non-residential systems based on the off-taker (any entity other than a homeowner or utility) rather than based on the site-host and system size, as we define it for our analysis. The figure explicitly identifies states that are among the top-5 in each segment in terms of either 2017 installations or cumulative installations, in either the U.S. market or data sample.*

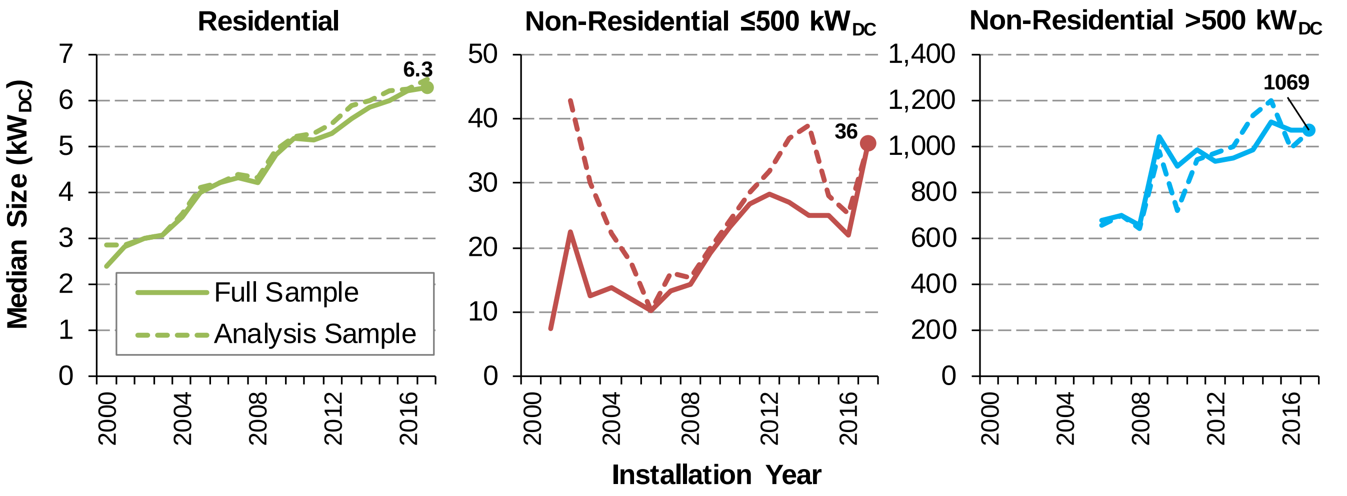
# Sample Characteristics

*Based on Full Sample, unless otherwise noted*

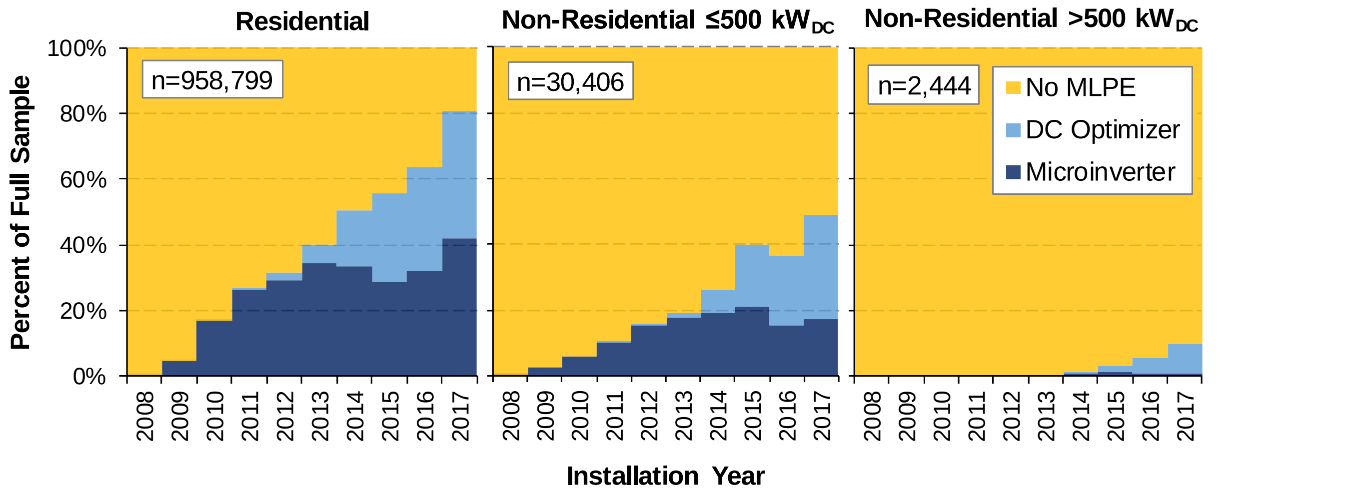
# Technical Characteristics

## System size, module efficiency/technology, MLPEs, and mounting configuration

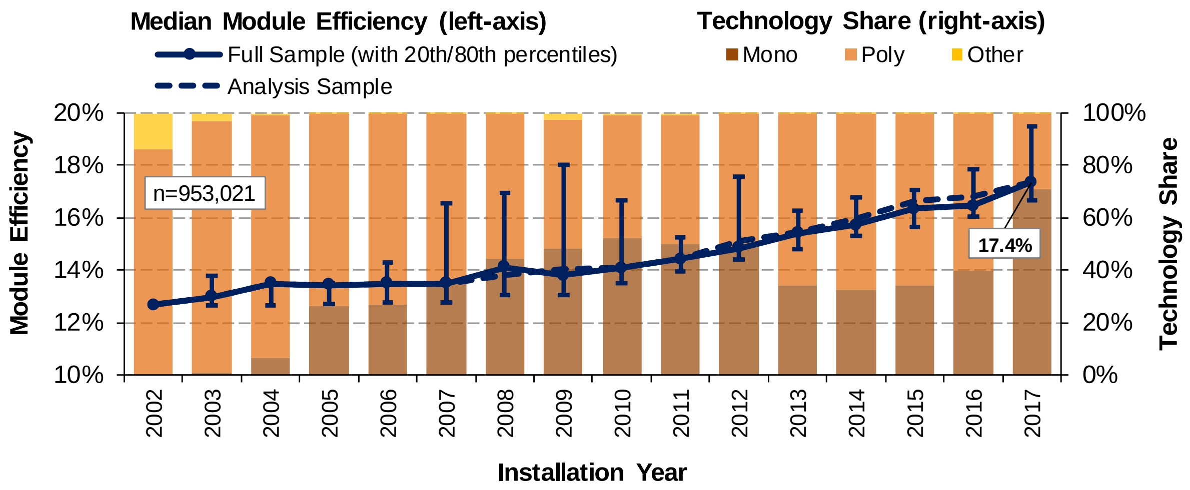
### System Size Trends



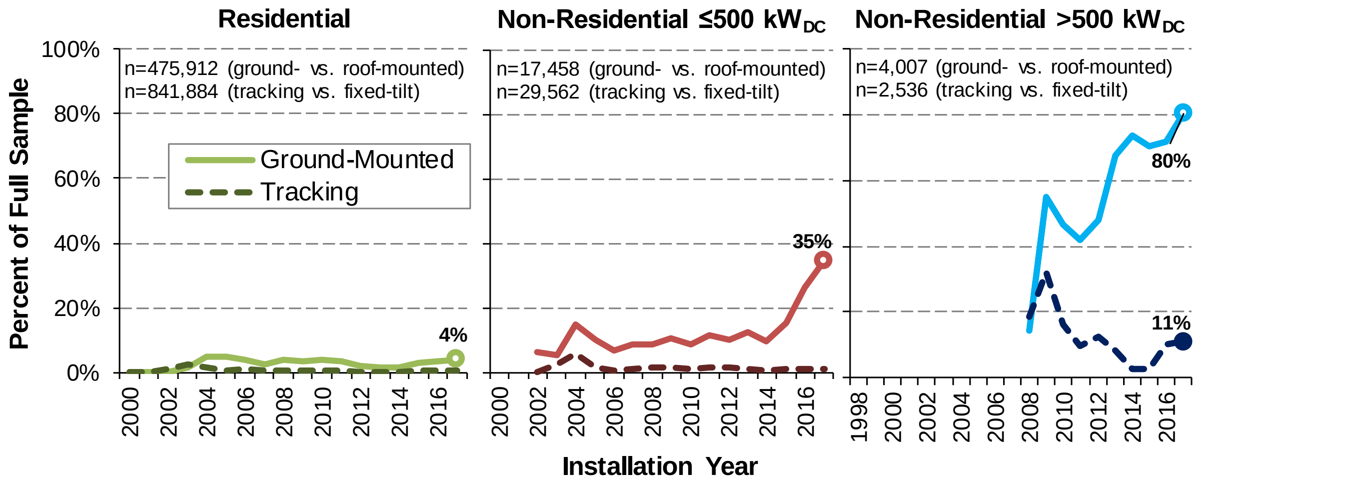

### Module-Level Power Electronics (MLPEs)




### Module Efficiency and Technology Trends

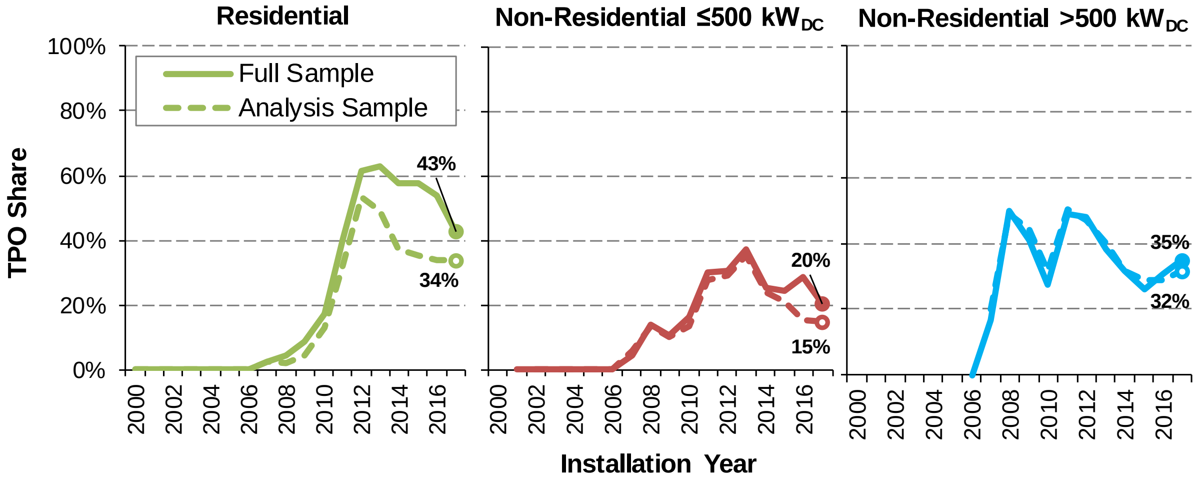



### Mounting Configuration

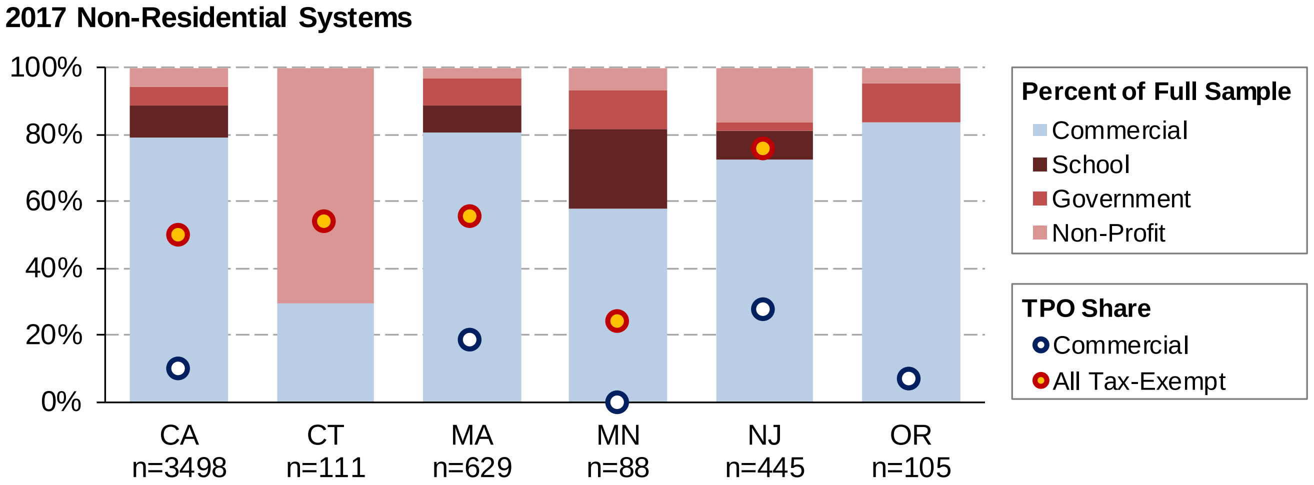


# Third-Party Ownership and Customer Segmentation

## Third-Party Ownership




## Non-Residential Customer Segmentation




- Data sample reflects the growth, and more recent decline, of third-party ownership (TPO)
  - TPO Share lower in Analysis Sample than in Full Sample, largely due to removal of integrated TPO systems
  - Somewhat lower TPO shares for non-residential than for residential systems
- Roughly 20% of non-residential systems in 2017 installed at tax-exempt customer sites (schools, government, non-profits)
- TPO in non-residential sector more prevalent among tax-exempt site hosts (~50% of such systems in 2017), as such entities are otherwise generally unable to fully monetize tax benefits

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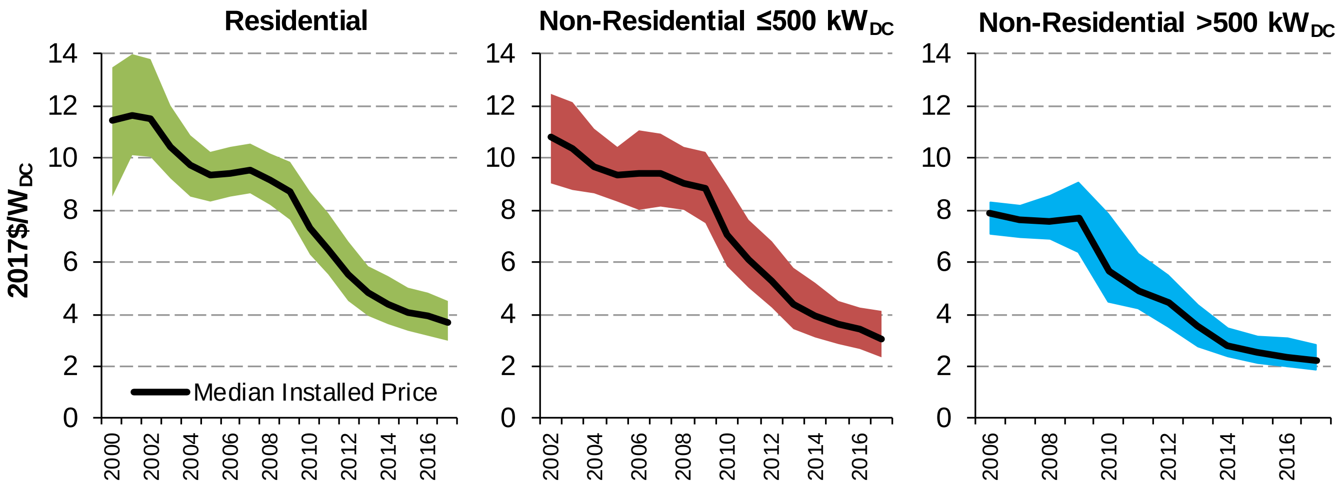
# Historical Trends in Median Installed Prices

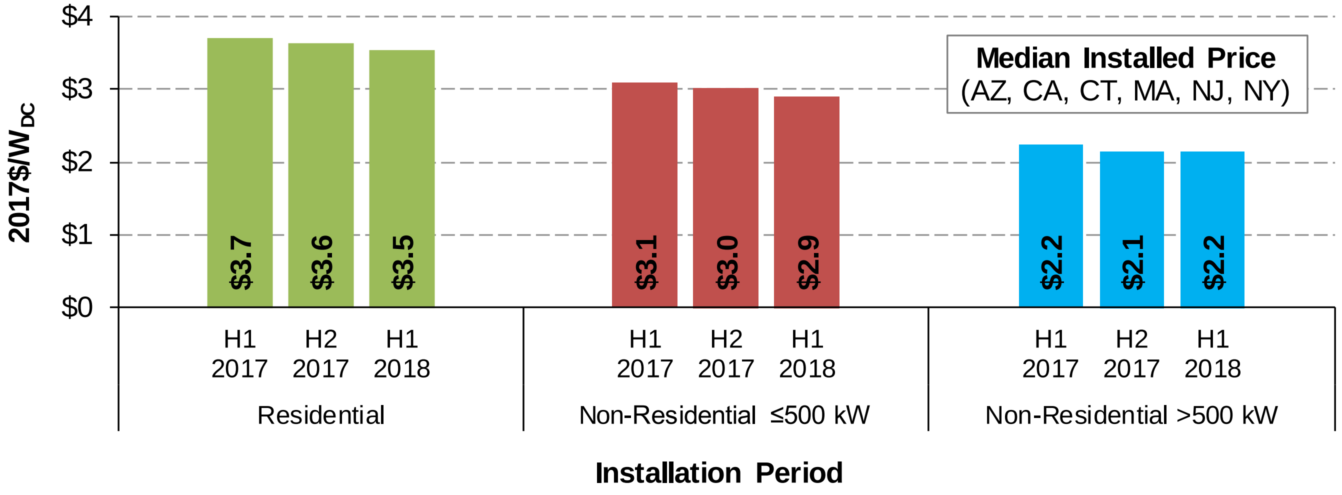
# Installed Prices Continued to Decline through 2017 and into 2018

## National Median Installed Prices: 2000-2017




*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.*

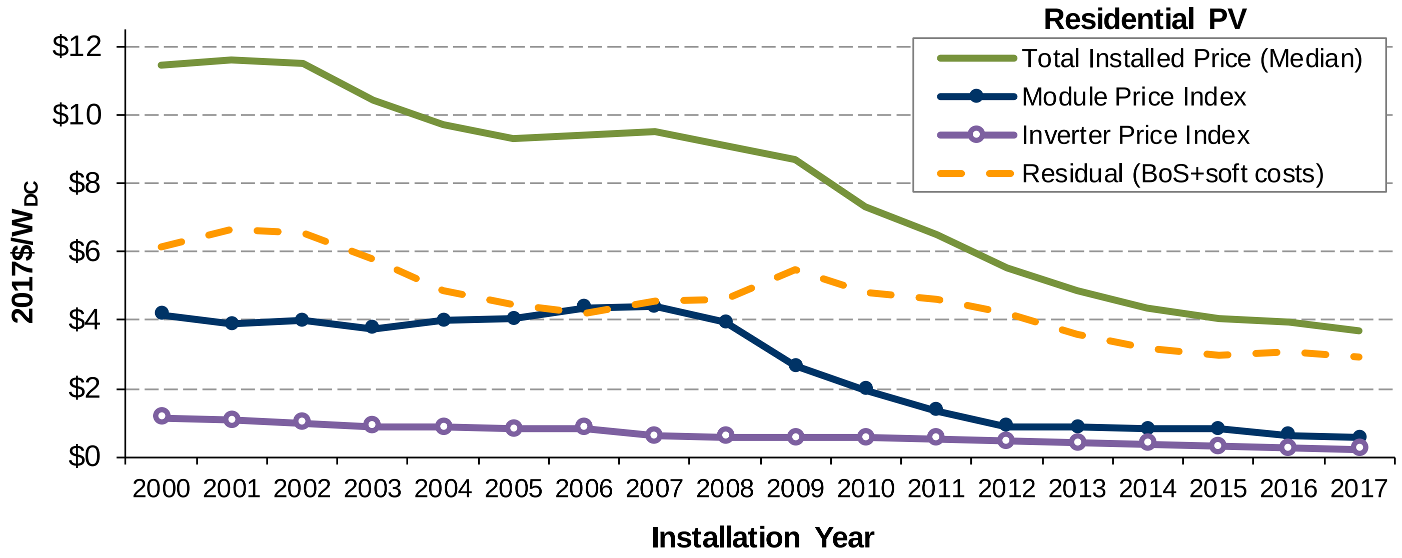
## Preliminary Data for H1 2018




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

- National median installed prices in 2017 were $3.7/W for residential systems, $3.1/W for "small" non-residential systems ≤500 kW, and $2.2/W for "large" non-residential systems >500 kW
- From 2016-2017, national median prices fell by $0.2/W (6%) for residential, $0.4/W (11%) for small non-residential, and $0.1/W (5%) for large non-residential systems; similar rates of decline observed among most major state markets and are driven primarily by trends among host-owned systems
- Recent trends consistent with the pace of price declines since 2014, and mark a slowing from the years immediately preceding (2009-2013) when prices fell by roughly $1/W per yr. (mostly due to module price declines)

# Installed Price Declines Reflect Reductions in Both Hardware and Soft Costs




*The Module Price Index is the U.S. module price index published by SPV Market Research (2018). The Inverter Price Index is a weighted average of residential string inverter and microinverter prices published by GTM Research and SEIA (2018), extended backwards in time using inverter costs reported for systems in the LBNL data sample. The Residual term is calculated as the Total Installed Price minus the Module Price Index and Inverter Price Index.*

## The Impact of System Sizes and Module Efficiency

- Steady growth in residential system sizes and module efficiencies have helped to fuel long-term reductions in BoS and soft costs
- Spreads fixed costs over greater number of watts, and reduces area-related costs
- ~40% of the long-term decline in BoS+soft costs estimated as attributable to these two inter-related factors (system size being the more significant)

**Of the total $8/W long-term decline in median residential system prices…**

- ~46% associated with falling module prices, ~12% with falling inverter prices, and the remaining 42% with the collective assortment of balance of systems (BoS) and soft costs—i.e., the residual term in the figure
- Soft costs: customer acquisition, installation labor, installer margins, loan fees, and other business process costs

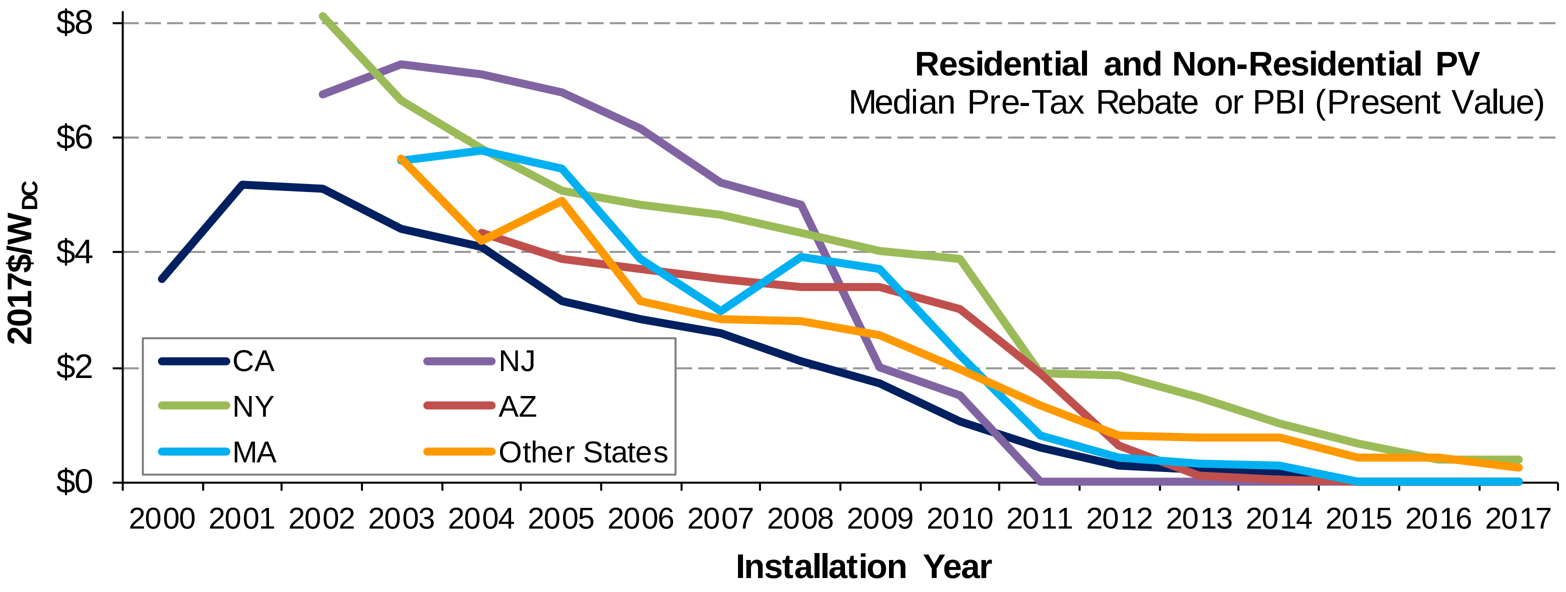
**Over the last year of the analysis period…**

- Residential hardware costs fell by ~$0.1/W in total, equivalent to about half the drop in median installed prices

# Installed Price Declines Have Been Partially Offset by Falling Incentives

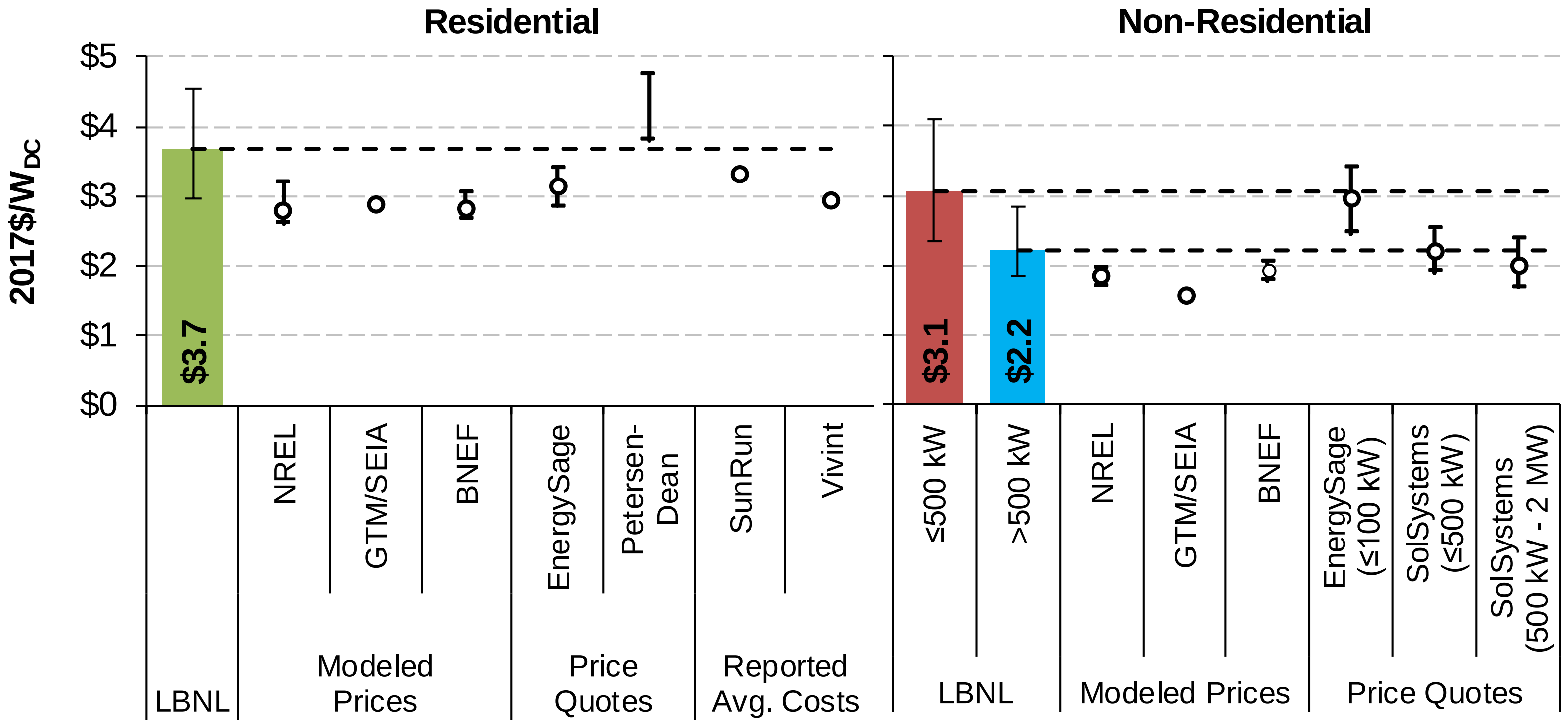
- Various types of incentives have been offered to distributed PV, depending on the state and timeframe
  - Tax credits, RECs, net metering, rebates, performance-based incentives (PBIs), etc.
- Focusing here just on direct cash incentives provided in the form of rebates and PBIs…
  - At their peak, many programs were offering incentives of $4-8/W
  - These incentives have been largely phased-out over time, or have diminished to below $0.5/W
  - Partly a response to installed price declines, the emergence of other incentives, and increasing penetration

**Long-term drop in rebates and PBIs equates to 67% to 100% of the installed price decline among larger state markets**




*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.*

# National Median Installed Prices Are Relatively High Compared to Other Recent Benchmarks



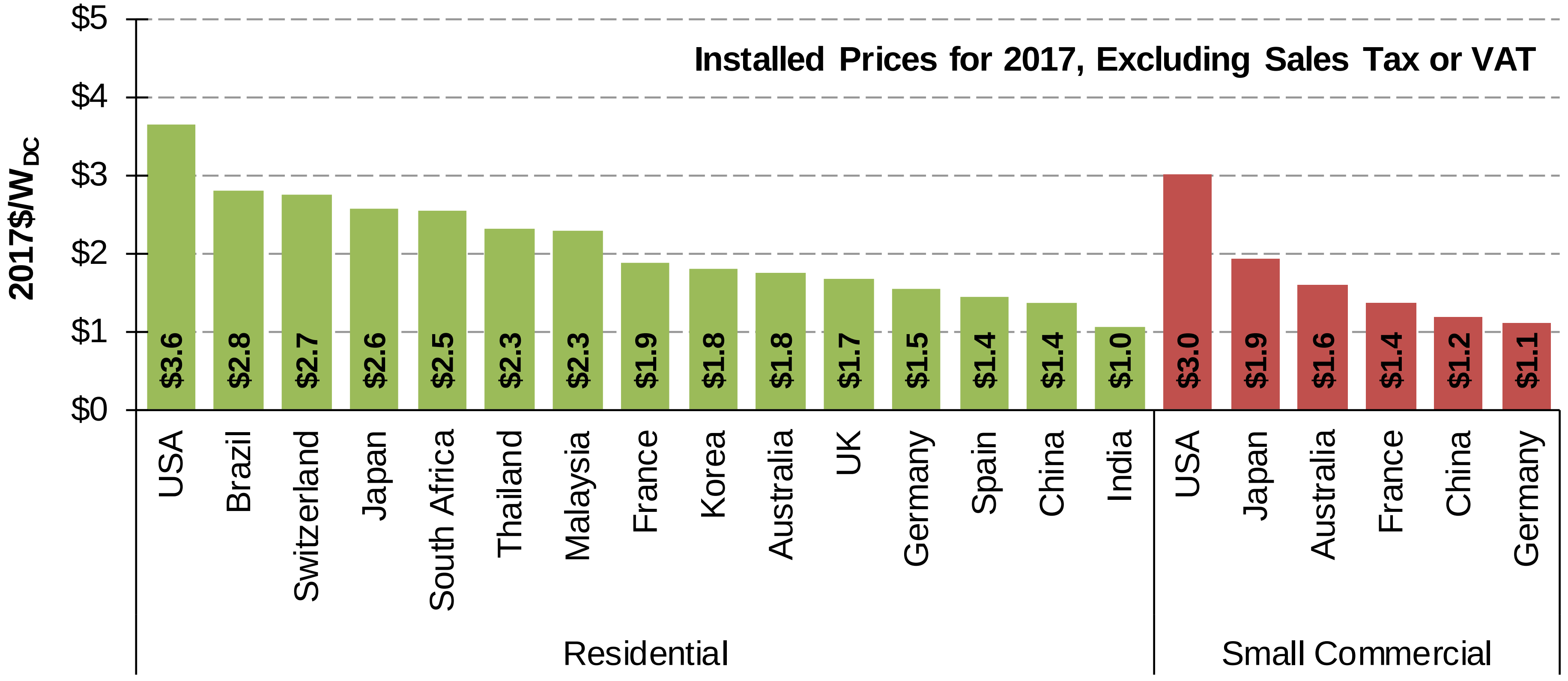

*Notes: **LBNL** data are the median and 20th and 80th percentile values among projects installed in 2017. **NREL** data represent modeled turnkey costs in Q1 2017 for a 5.7 kW residential system (range across system configuration and installer type, with weighted average) and a 200 kW commercial system (range across states and national average) (Fu et al. 2017). **GTM/SEIA** data are modeled turnkey prices for Q1 and Q4 2017; 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 2018). **BNEF** data are estimated PV capex with developer margin in 2017 (US averages and range across states/regions) (BNEF 2018). **EnergySage** data are the median and 20th and 80th percentile range among price quotes issued in 2017, 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 online price quotes for 3.4 to 8.4 kW systems in CA, queried from the company website by Berkeley Lab in May 2017. **SunRun** and **Vivint** data are the companies' reported average costs (in the case of SunRun, for cash-sale systems only), inclusive of general administrative and sales costs, for Q1 and Q4 2017. **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 2017.*

- Other benchmarks include bottom-modeled prices, price quotes, and average costs reported by several large installers
- Divergence from LBNL national median reflects differences in underlying data, methods, conventions

  E.g., related to timing/vintage, location, price vs. cost, value-based pricing, system size and design, scope of costs included, installer characteristics)
- Other benchmarks align more closely with the 20th percentile values in the LBNL dataset and may be more reflective of "best in class" or "turnkey" systems and/or relatively low cost markets

# Installed Prices in the United States Are Higher than in Most Other Major National PV Markets

- Differences are quite large, with median U.S. prices double (or more) than a number of other well-developed markets (e.g., Australia, Germany)
- Installed price differences primarily due to soft costs (as differences in hardware costs are much smaller than the installed price gaps shown here)
- Lower soft costs in other countries reflect differences in, for example: solar industry business models, market maturity, permitting and interconnection processes, and labor rates, among other factors

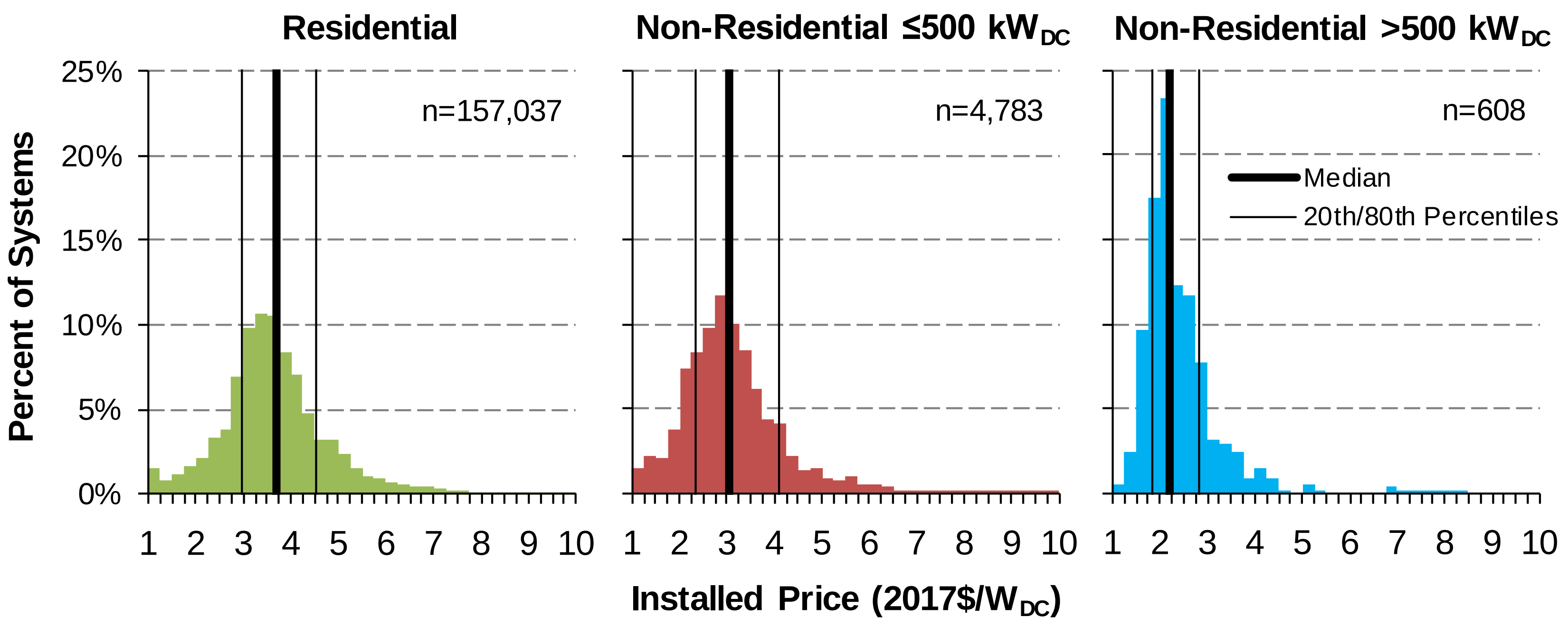



*Notes: Installed prices for countries other than the United States are primarily from IRENA (2018) and refer to average prices in either Q1 or Q2 2017; the one exception is the value reported for small commercial systems in France, which comes from de L'Epine-Hespul (2018) and is an annual number for all of 2017.*

# Variation in Installed Prices

# Installed Prices Vary Widely Across Individual Projects

## Installed Price Distribution for Systems Installed in 2017




**20th-to-80th Percentile Bands for Systems Installed in 2017**

- $3.0/W - $4.5/W (residential)
- $2.4/W - $4.1/W (small non-residential)
- $1.8/W - $2.8/W (large non-residential)

- Wide pricing variability has persisted over time, despite continuing maturation of the U.S. PV market
- Reflects underlying differences in:
  - Project characteristics
  - Installer attributes
  - Broader market, policy, and regulatory environment (competition, incentive levels, electricity rates, permitting and interconnection processes, labor wages, taxes, etc.)
- The drivers above partially explored through the remainder of this report, as well as through a series of more in-depth statistical analyses

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# 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

**O'Shaughnessy (2018)** found that PV prices tend to be lower in markets where experienced installers hold higher market shares, but increase again if those installers hold very high market shares, suggesting that learning effects can be offset by a lack of competition

**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

**Nemet et al. (2016a)** and **Nemet et al. (2016b)** examined the characteristics of low-priced systems (within the lowest $10^{th}$ 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)

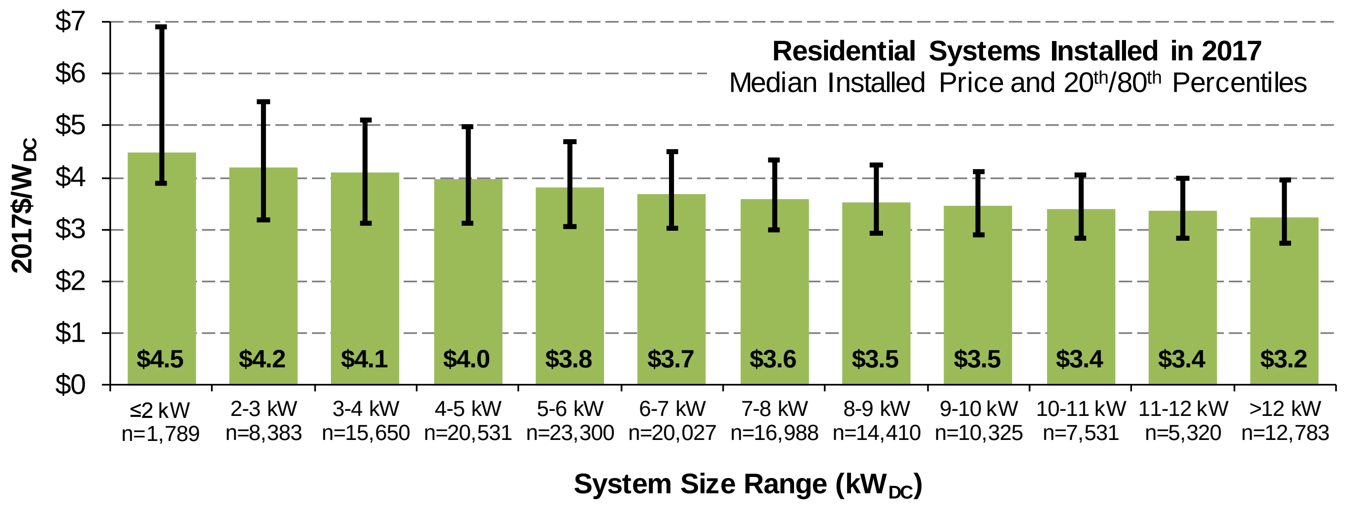
**Dong and Wiser (2013)** found installed price differences of $0.3/W to $0.8/W between cities in California with the least- and most-onerous permitting practices

**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

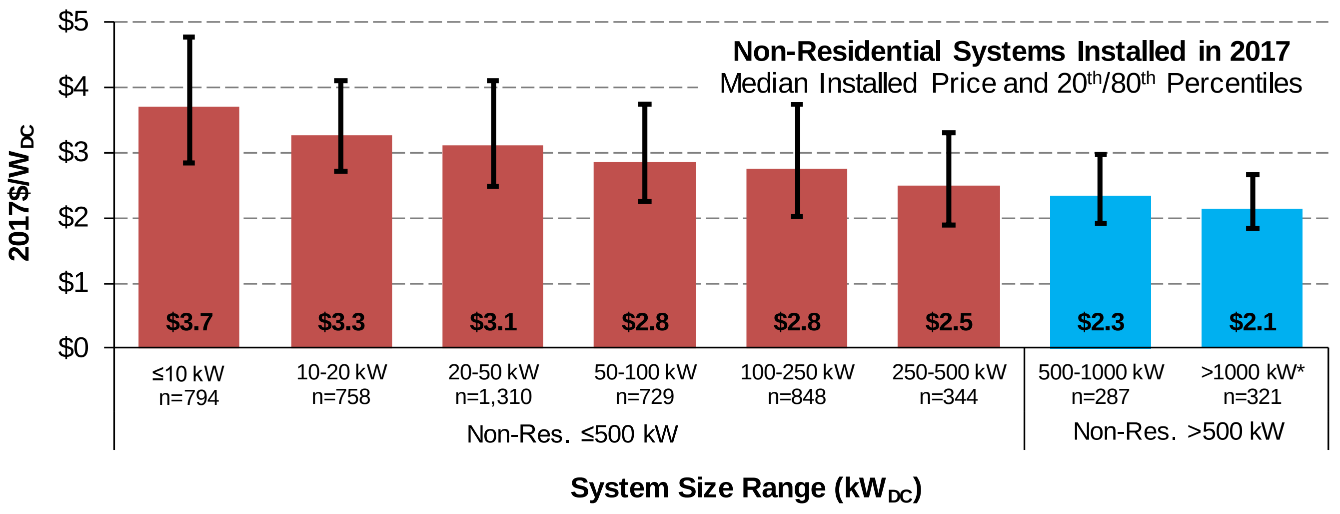
**Dong et al. (2014)** found that, historically, 95% to 99% of rebates in California were passed through to consumers, rather than retained as increased installer margins

# Clear Economies of Scale Exist Among Both Residential and Non-Residential Systems

## Residential Systems



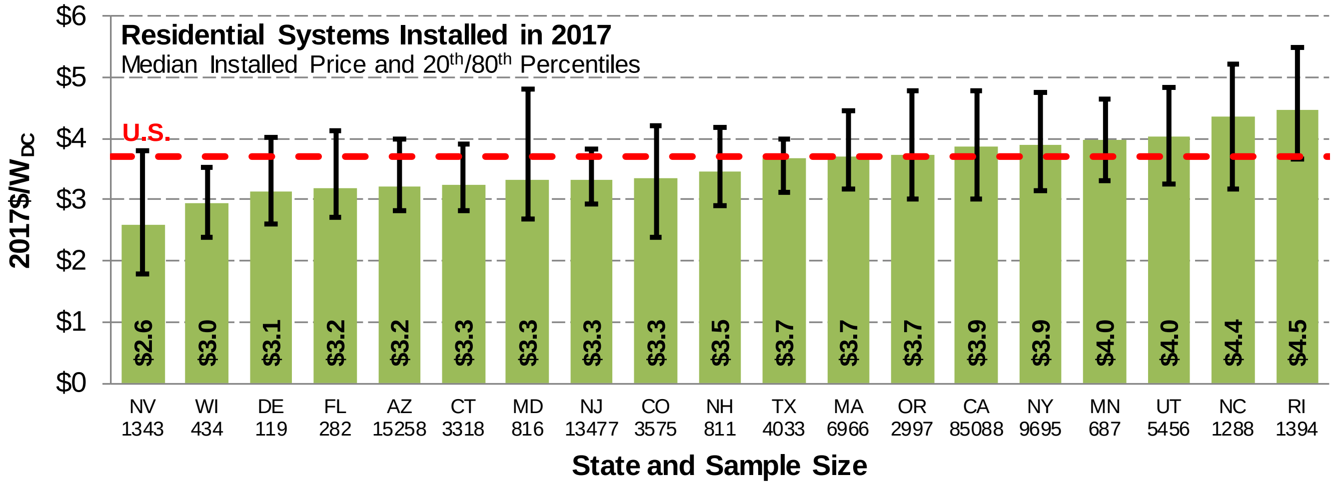

## Non-Residential Systems




- Among residential systems installed in 2017, median prices were roughly $1.3/W lower for the largest (>12 kW) systems compared to the smallest (≤2 kW) systems
- Among non-residential systems, which span an even wider size range, median prices were $1.6/W lower for systems >1,000 kW, compared to the smallest non-residential systems ≤10 kW (keeping in mind that ground-mounted systems in this report are capped at 5 MW$_{AC}$)
- Diminishing returns to scale are also evident—e.g., for residential, pace of price declines slows beyond 8-9 kW

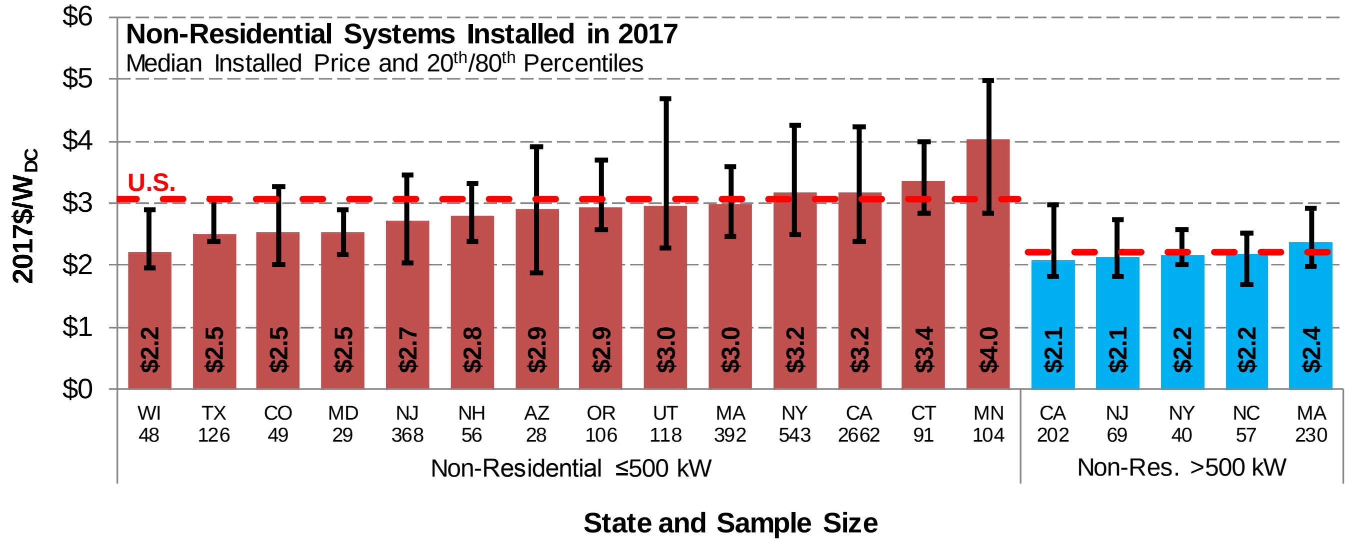
# Installed Prices Vary Widely Among States, with Relatively High Prices in Some Large State Markets

## Residential Systems




*Notes: Data shown only if at least 20 observations are available for a given state.*

## Non-Residential Systems




- Some of the largest markets (CA, MA, NY) are relatively high-priced, pulling overall U.S. median prices upward, but ***pricing in most states is below the national median***
- Cross-state pricing differences reflect both idiosyncratic features of particular states (a single large installer with anomalous prices) as well as more-fundamental differences in market and policy conditions, such as those noted as apply to price variability more generally

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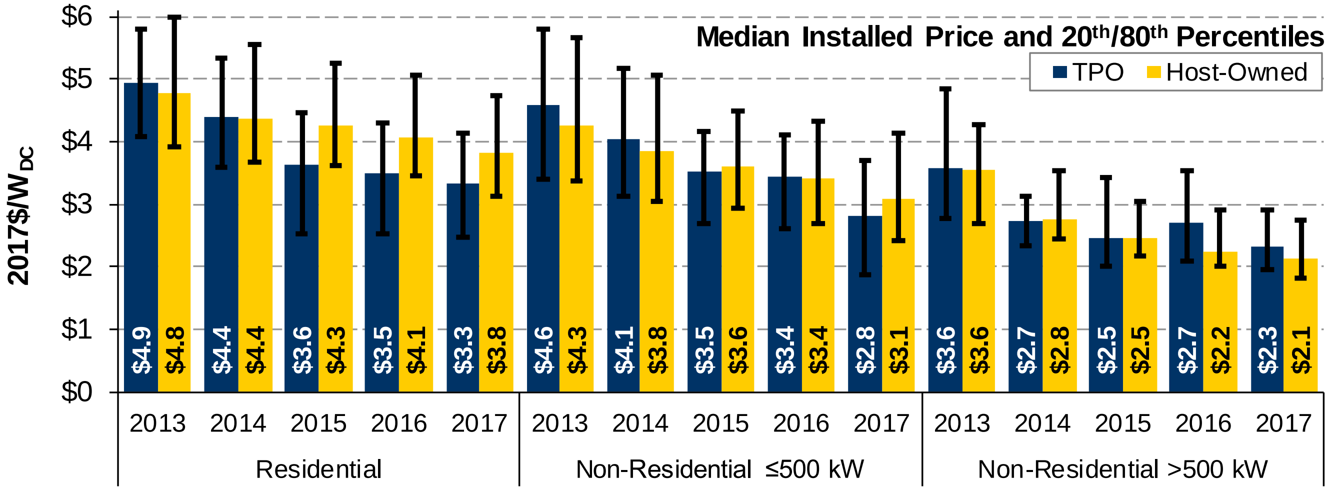
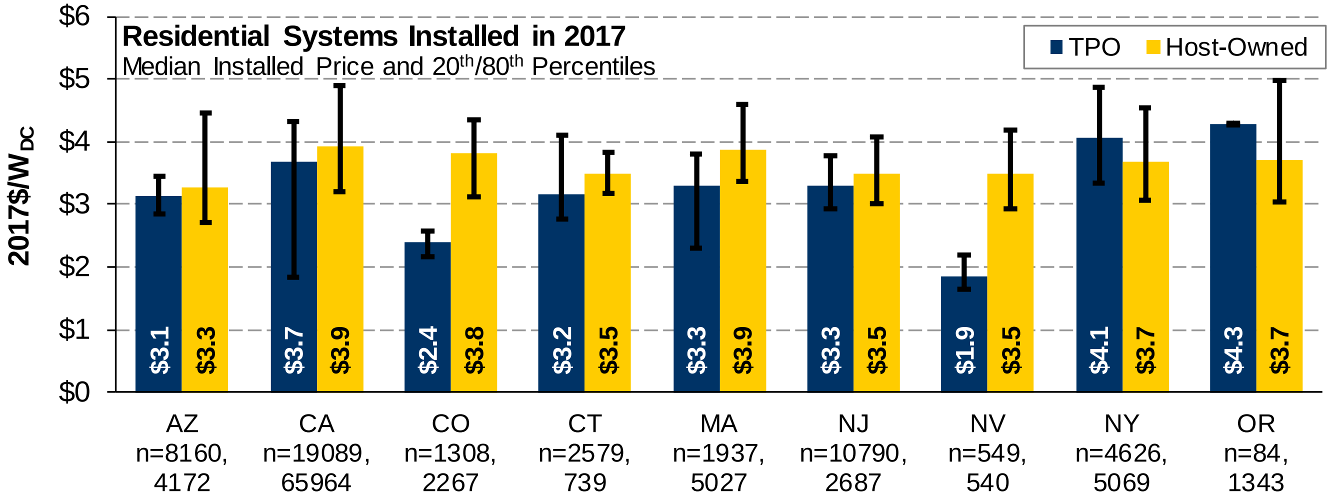
# Prices that Installers Receive for Third-Party Owned Residential Systems Tend to Be Lower than for Host-Owned Systems

## TPO vs. Host-Owned over Time and by Sector




## Residential TPO vs. Host-Owned by State

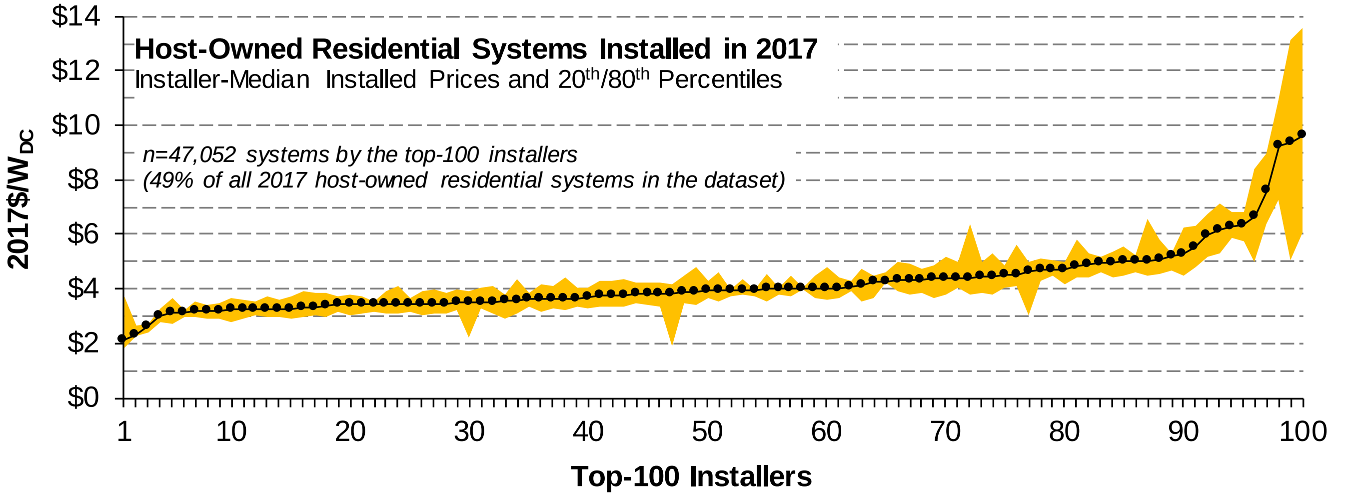



*Notes: The values shown here for TPO systems are based on systems financed by non-integrated TPO providers, for which installed price data represent the sale price between the installation contractor and customer finance provider.*

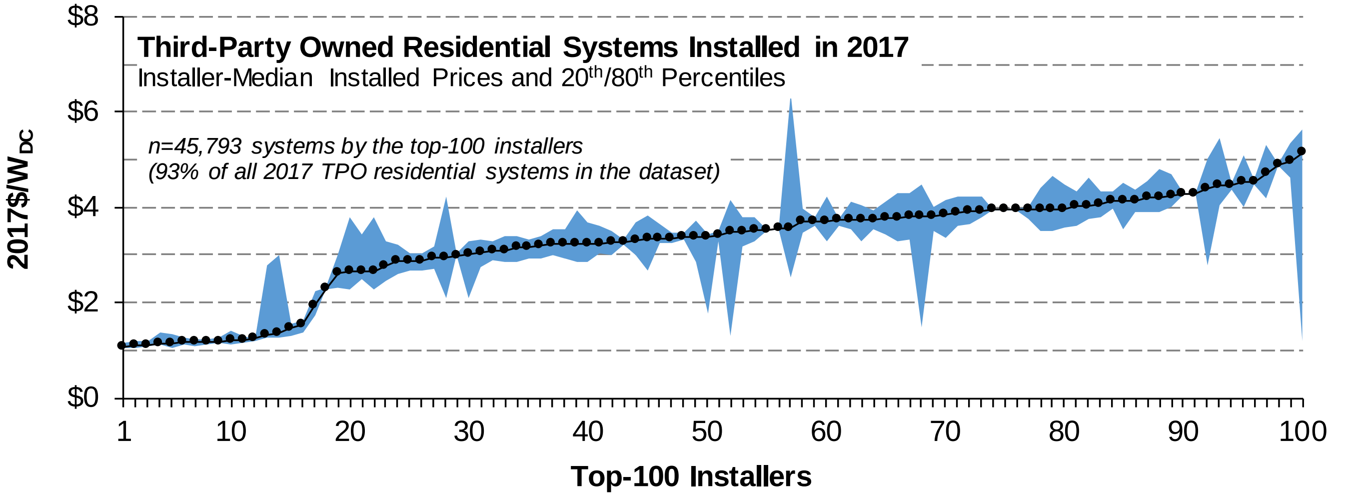
- In the residential sector, installed prices for TPO systems generally have been less than for host-owned systems, at least over the last several years and in most states; no clear trend for non-residential systems, however
- Trends in the residential sector likely reflect some combination of: greater buying power on the part of third-party financiers, more-standardized or turnkey installations in the TPO segment, customer acquisition managed or performed by the financier, and loan-financing fees rolled into the prices reported for many host-owned systems

# Wide Pricing Variability Exists Across Major Residential Installers

## Top-100 Host-Owned Residential Installers




## Top-100 TPO Residential Installers

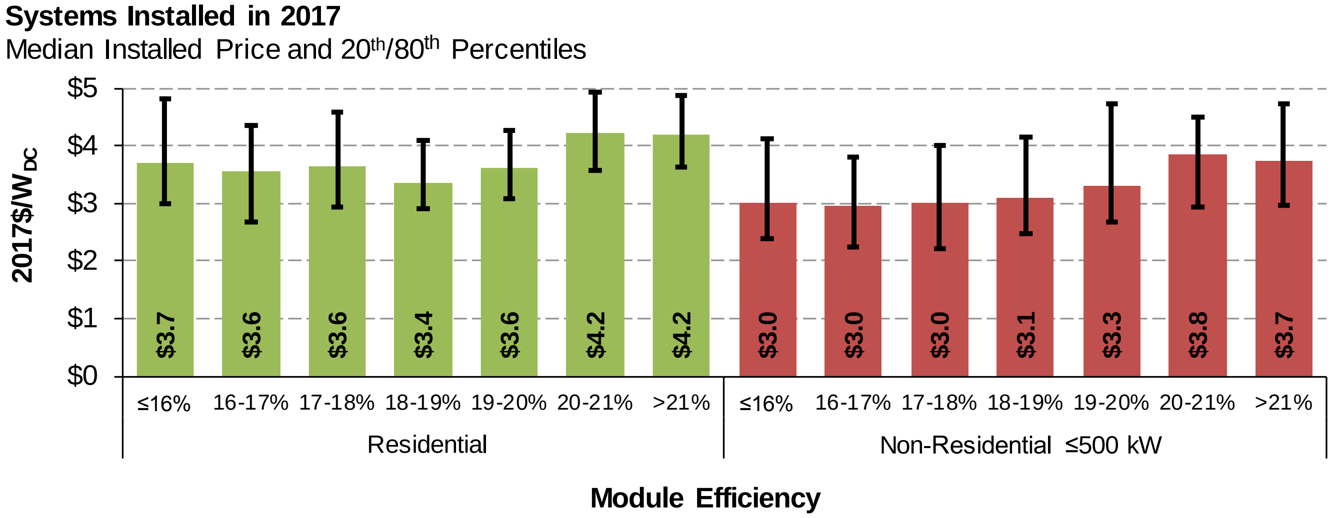



*Notes: Each dot represents the median installed price of an individual installer, ranked from lowest to highest, while the shaded band shows the 20th to 80th percentile range for that installer.*

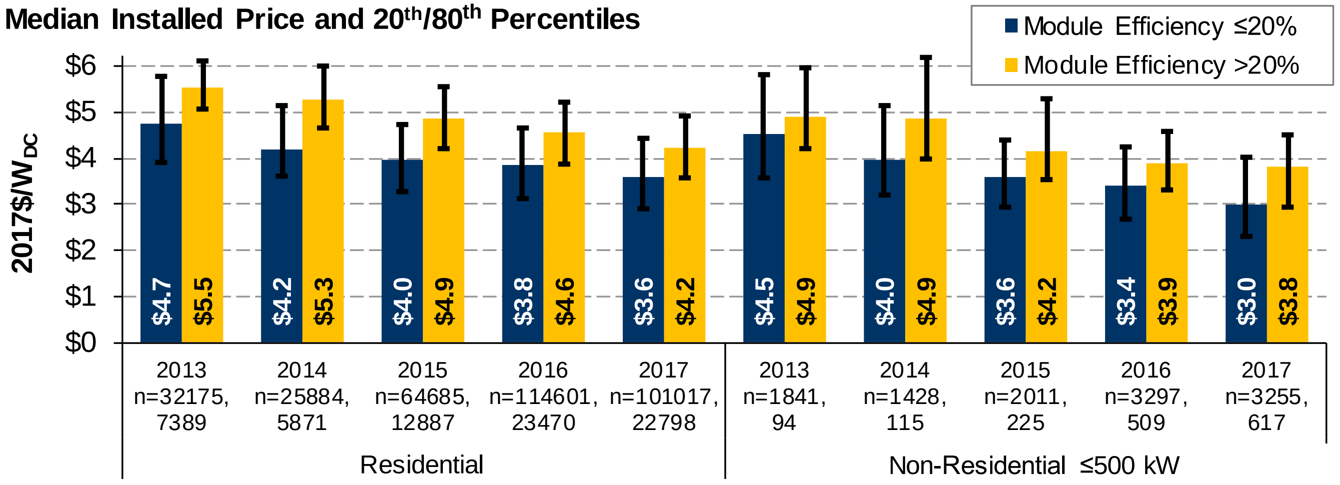
- Installer-level median prices ranged from $2.1/W to $9.6/W across the top-100 host-owned residential installers in 2017, and from $1.1/W to $5.5/W across the top-100 TPO installers (though the upper bound for host-owned systems and the lower-bound for TPO systems likely reflect anomalous price reporting)
- Differences across installers reflect both firm attributes (size, experience, level of training, business strategy and model) as well as features of the markets in which each installer operates (labor costs, permitting and interconnection costs, competition)

# Installed Prices Are Substantially Higher for Systems with “Premium Efficiency” Modules

## Installed Price Variation with Module Efficiency (2017)




## Installed Price Variation with Module Efficiency over Time




- Median installed prices are fairly level up until module efficiency levels of 19-20%, but jump up significantly for systems with “premium efficiency” modules above 20%; consistently higher installed prices over time
- Installed price differential driven by higher underlying module costs for premium efficiency products, more than offsetting any BoS cost savings associated with smaller project footprint
- Important to recognize, however, that premium efficiency modules may also offer performance advantages and longer warrantees, also relevant to any complete economic comparison

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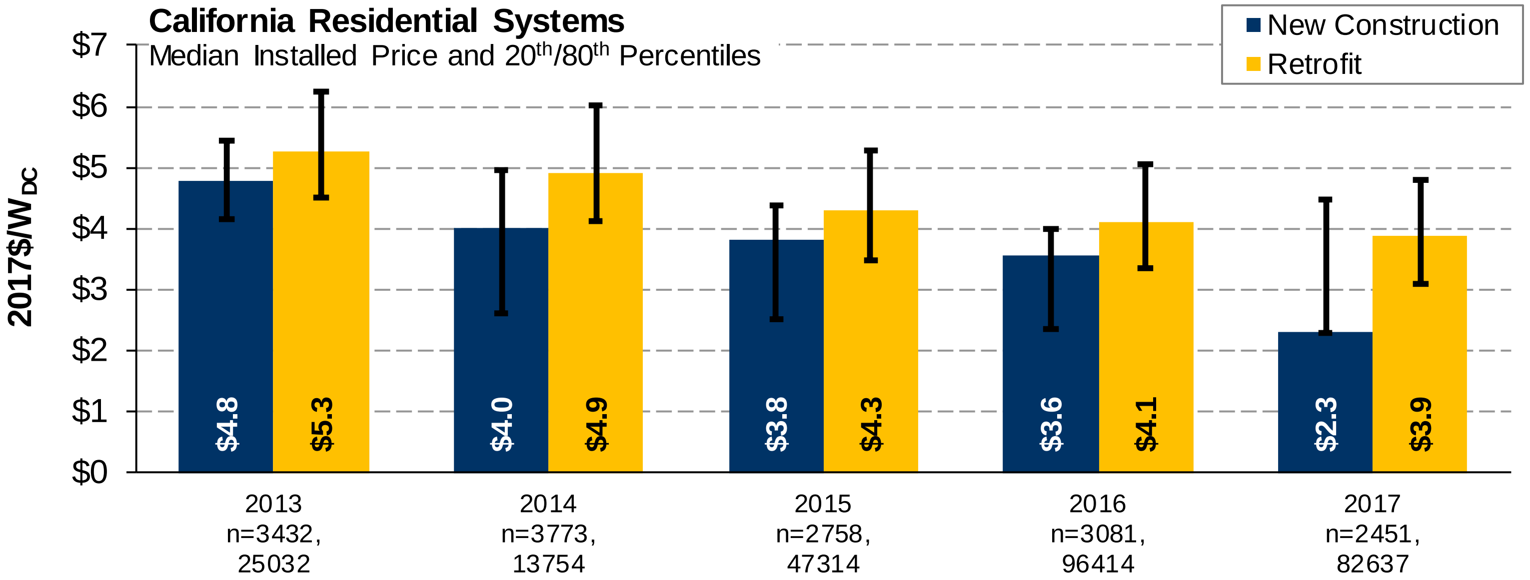
# Residential New Construction Offers Significant Installed Price Advantages Compared to Retrofit Applications

- In California, residential systems installed in new construction have been consistently lower-priced than those installed on existing homes
- Disparity in 2017 exaggerated due to several installers with large numbers of especially low-priced systems; earlier years suggest a difference of closer to $0.5/W
- Price advantage for systems installed in new construction reflects some combination of economies of scale, economies of scope, and lower customer acquisition costs
- Trends are particularly notable given that PV systems in new construction are generally quite small (a median size of 3.0 kW in 2017, compared to 6.1 kW for residential retrofits in California in that year)

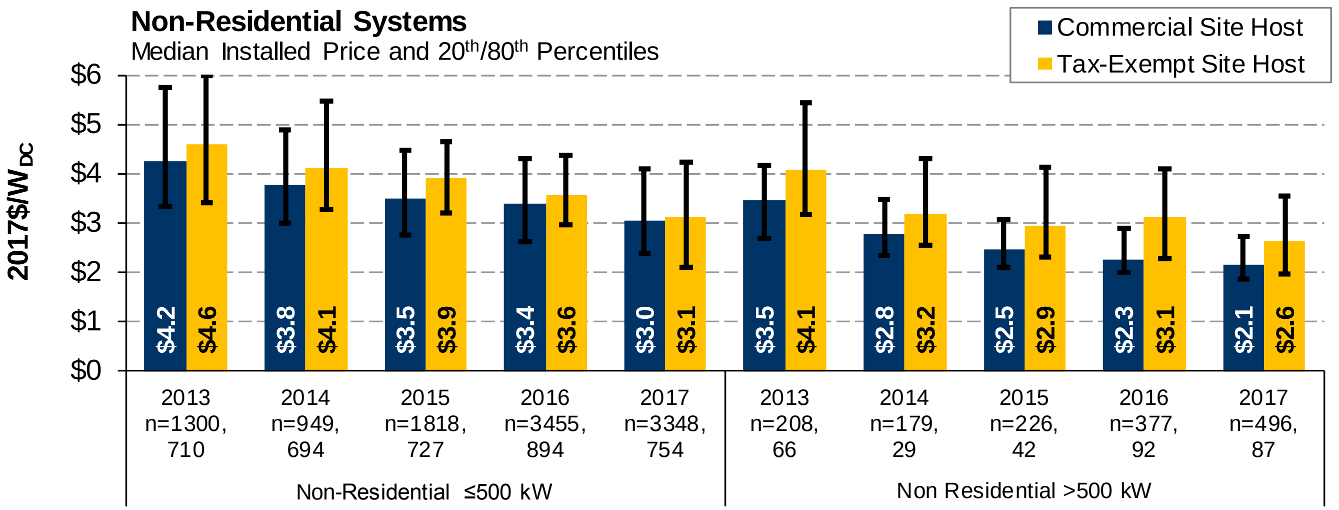
## Residential New Construction vs. Retrofits in California



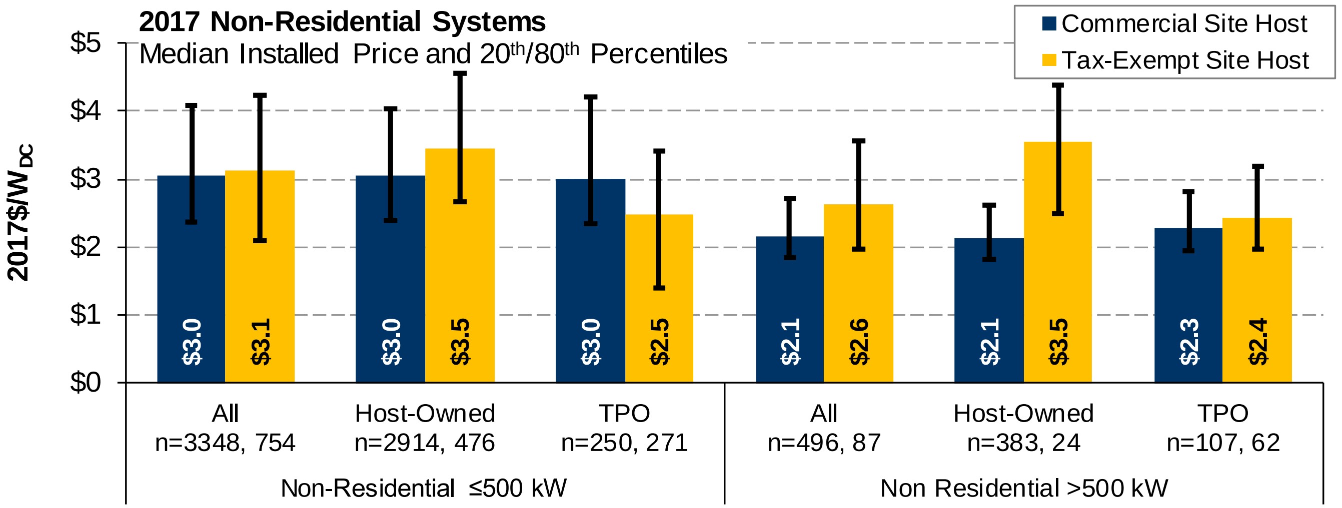

*Notes: We focus here on California as relatively few other states provide data indicating which PV systems were installed on new construction. Several issues with the installed price data for new construction systems are worth noting. First, we commonly observe that identical prices are reported for all systems within a given development, presumably because the developer purchases the set of systems as a bulk order. This is a smaller scale issue than what we observe in the 2017 dataset, where several large installers report all or most of their systems at the same price. Second, to the extent that certain costs are shared between the PV installation and other aspects of home construction (e.g., roofing and electrical work), the entities reporting installed-price data may have some discretion in terms of how those shared costs are allocated to the PV system, which can create difficulties in making a true apples-to-apples comparison with retrofit systems.*

# Installed Prices Are Generally Higher for Systems at Tax-Exempt Customer Sites than for Systems at Commercial Sites

## Commercial vs. Tax-Exempt Site Hosts over Time




## Commercial vs. Tax-Exempt Site Hosts by PV Ownership




- Differences are most pronounced among the larger class of >500 kW non-residential systems, and are greatest when comparing specifically among host-owned systems (results for TPO systems are more erratic)
- Higher prices at tax-exempt customer sites potentially reflect higher incidence of prevailing wage/union labor requirements, domestically manufactured components, and shade or parking structures; tax-exempt customers may also have lower borrowing costs (enabling higher-priced systems to pencil-out)

# Conclusions

- Installed prices for distributed PV have fallen dramatically over time, with reductions attributable to declines in both hardware and soft costs
- Continued reductions in soft costs will be essential to sustaining PV system price declines, given the limits to further hardware cost savings
- 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, suggest that deeper reductions in soft costs are possible
- Achieving dramatic reductions in soft cost may accompany market scale, but also likely requires targeted R&D aimed at specific soft costs and at supporting efficient and competitive PV markets

# For more information

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