Energy Technologies Area Lawrence Berkeley National Laboratory

Tracking the Sun IX

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

Galen Barbose and Naïm Darghouth

Lawrence Berkeley National Laboratory

— 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 2015 with preliminary data for the first half of 2016**
- **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

New this year

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

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 2015 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 primarily from state agencies and utilities that administer PV incentive programs, solar renewable energy credit registration systems, or interconnection processes (~60 entities in total)
- Supplemented with data from other public sources (FERC Form 1, U.S. Treasury Department's Section 1603 Grant Program, trade press, etc.)

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

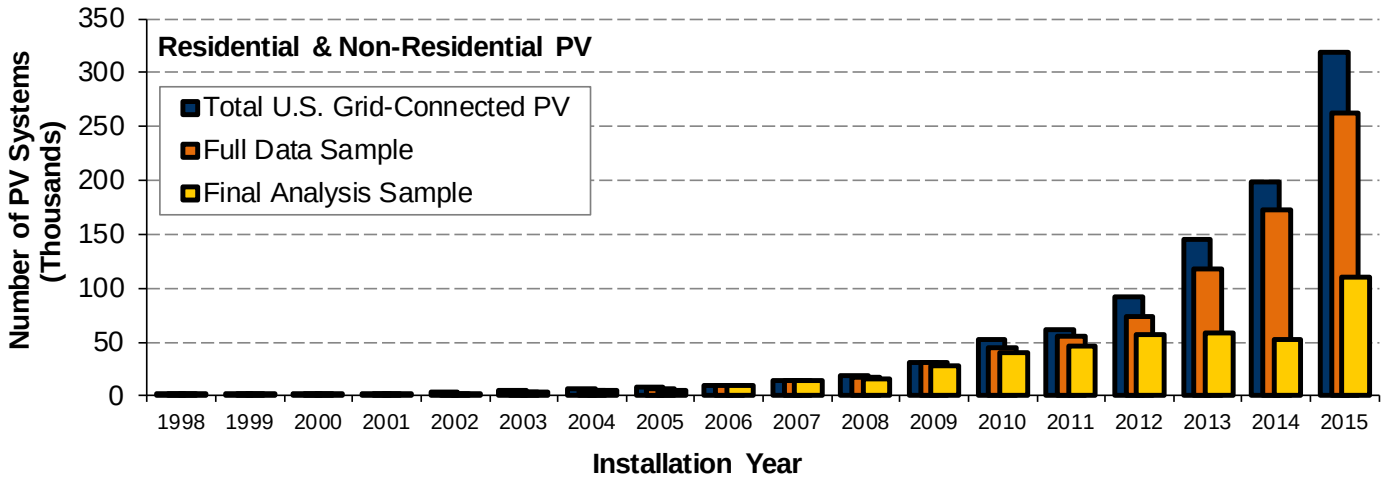
- **Integrated TPO.** A single company provides both the installation service and customer financing. Reported prices represent appraised values. ***Excluded from analysis***.
- **Non-Integrated TPO.** Customer finance provider purchases system from installation contractor. Reported prices represent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

- ~820,000 systems through 2015
- 85% of all U.S. PV systems; 82% of 2015 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 (2016) for each year thereafter.

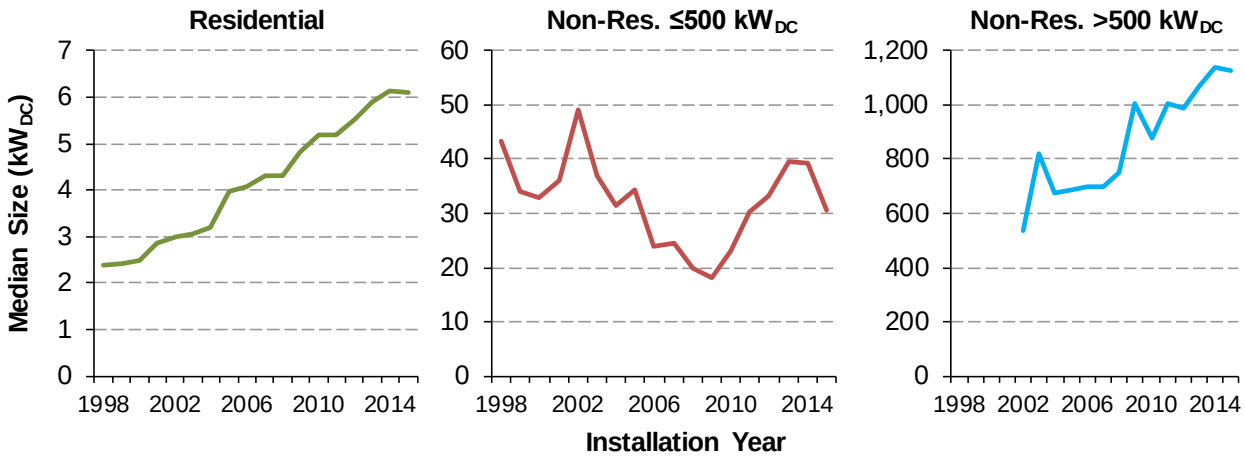
Final Analysis Sample*: Unless otherwise noted, this is the sample used in this analysis*

- ~450,000 systems installed through 2015 and 110,000 systems installed in 2015
- 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:

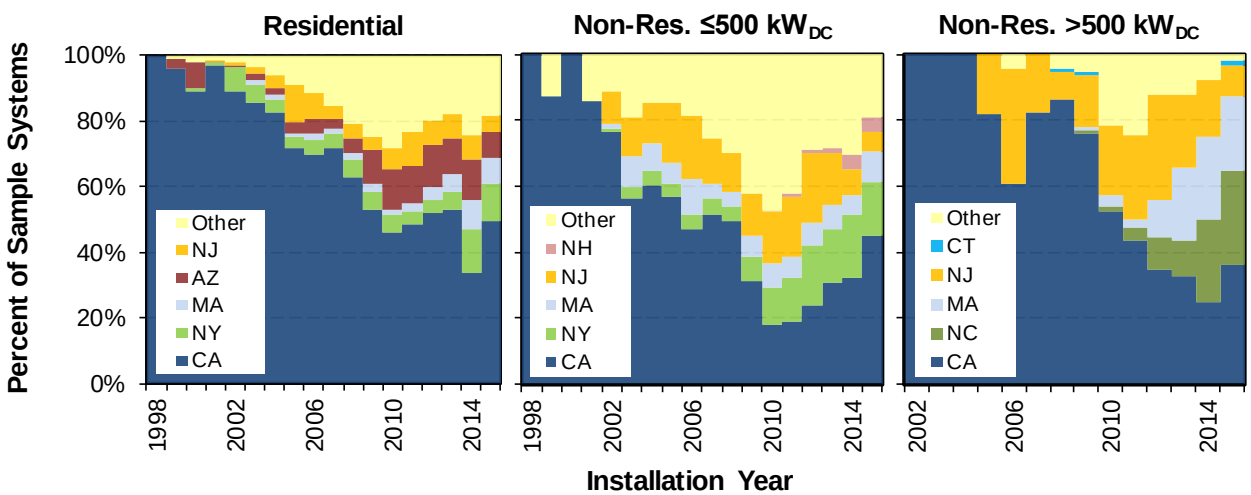
System size trends and distribution among states

System Size Trends



- Residential system sizes growing steadily over time (6.1 kW in 2015)
- Non-Res. systems in the sub-500 kW class are generally small (20-40 kW)
- Non-Res. systems >500 kW also growing in size (1,100 MW in 2015)

Distribution Across States



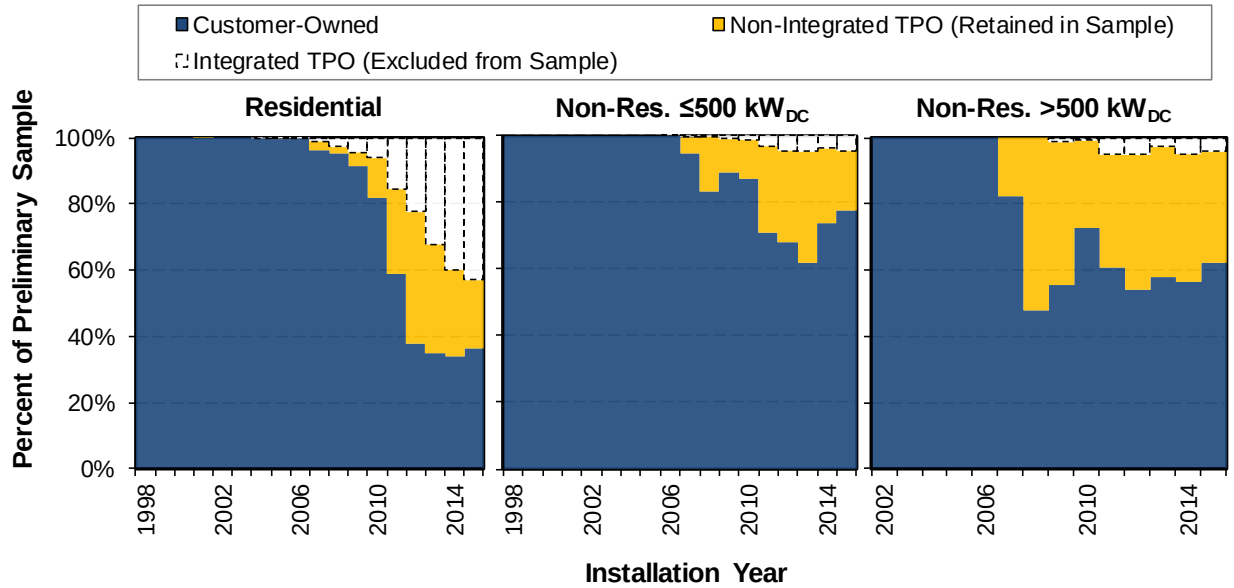
- Sample spans 33 states, though heavily weighted toward CA , MA, NY, NJ, AZ, NC
- Dominance of CA has fallen long term, but rose sharply in 2015 (for res)

Data Sample Characteristics:
Distribution by system ownership

Residential:

- Total TPO shares grew to ~60% of sample by 2012, remaining near that level through 2015
- Much higher TPO shares of sample for some states (80-90% in AZ, NJ)
- Integrated TPO shares have continued to grow; increasing percentage of systems excluded from final data sample
- Most pronounced for AZ and MA (60% of 2015 residential sample is integrated TPO)

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:

- TPO emerged somewhat earlier than residential, but plateaued at lower level
- 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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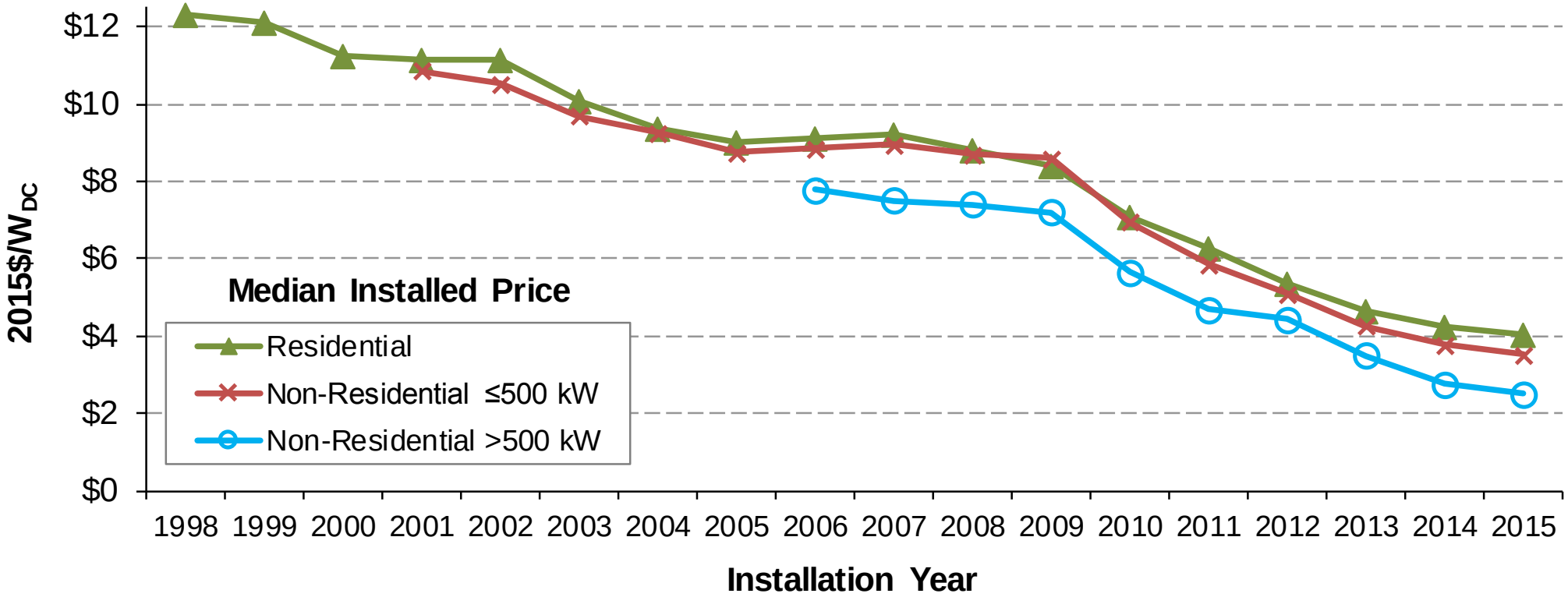
Installed Prices Continued to Fall in 2015, but at a Somewhat Slower Pace Than in Recent Years

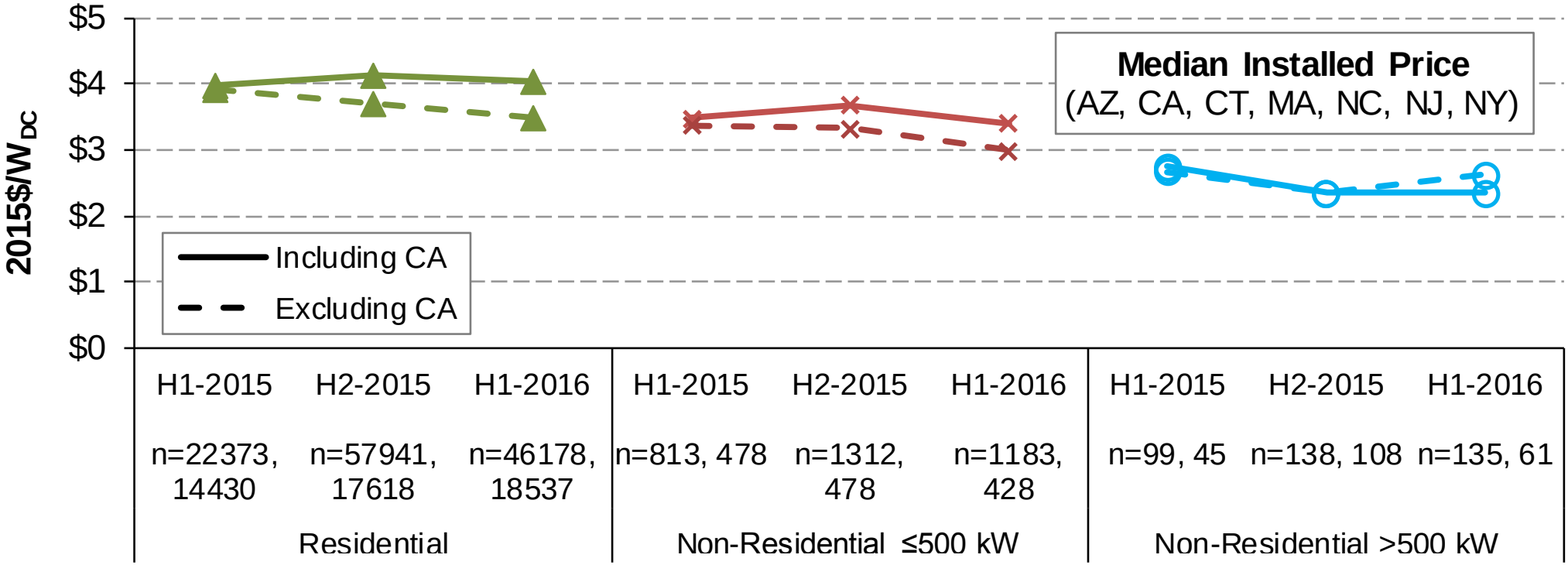
National median installed prices in 2015 declined YoY by $0.2/W (5%) for residential systems, by $0.3/W (7%) for non-residential systems ≤500 kW, and by $0.3/W (9%) for non-residential systems >500 kW



Notes: Median installed prices are shown only if 20 or more observations are available for a given year and customer segment.

Preliminary Data for 2016 Are Mixed in Terms of Near-Term Installed Price Trajectory

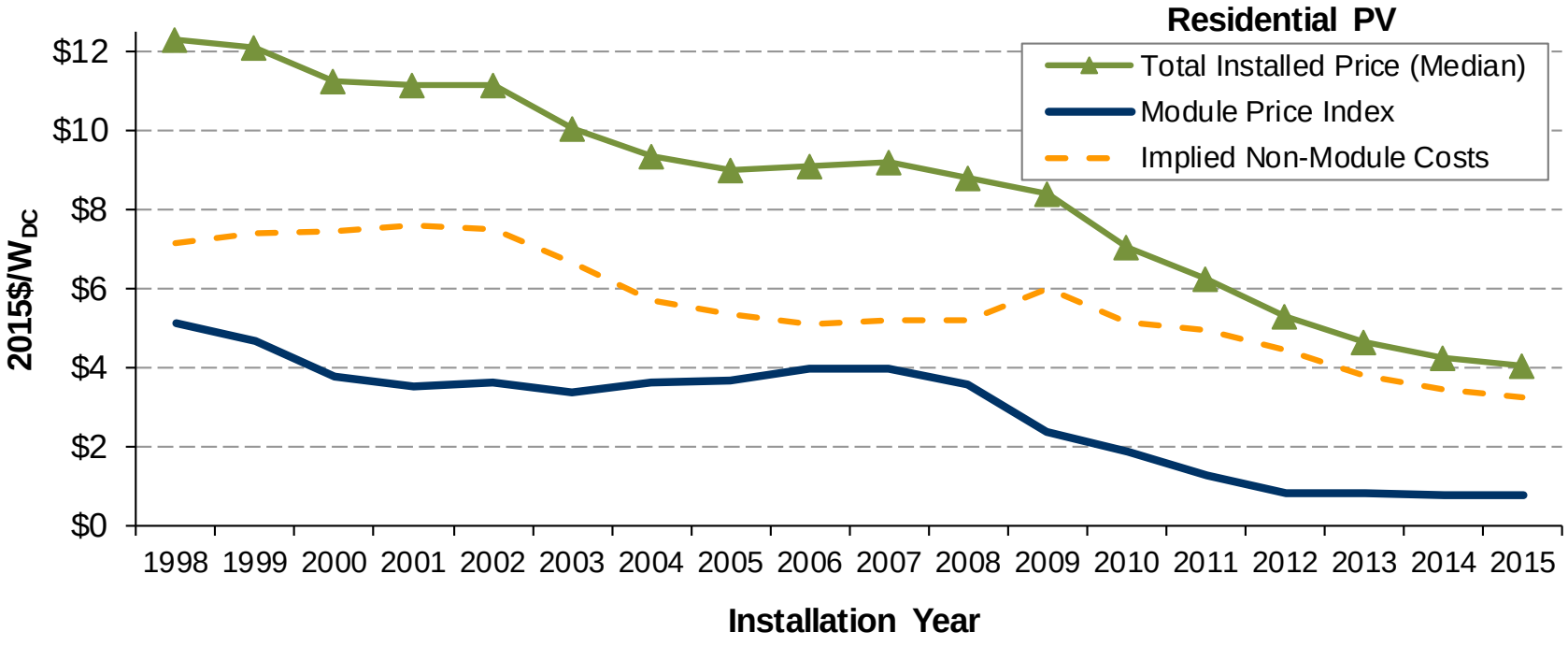
National trends are complicated by growing CA-share in data sample; excluding CA systems, residential and small non-res. installed prices fell in the first half of 2016, while large non-res. shows slight uptick



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. Within the residential sample, the California-share grows from 36% in H1-2015 to 70% in H2-2015 and 60% in H1-2016. For the sample of smaller non-residential systems, the progression is 41%, 64%, 64%. For the larger non-residential systems, the California-share progresses from 55% to 22% to 55%.

Installed Price Declines Have Continued Despite Flat Module Prices

- Steep reductions in module prices were the primary driver for installed price reductions from 2008 to 2012 (~80% of the total installed price decline)
- Since 2012, however, module prices have remained relatively flat, and installed price declines have been driven primarily by reductions in non-module costs (including installer margins)

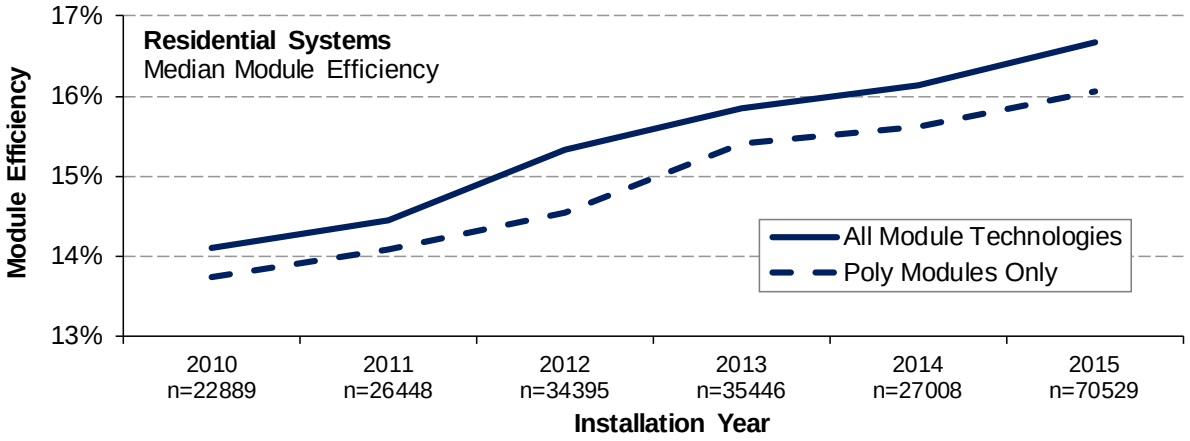


Notes: The Module Price Index is the U.S. module price index published by SPV Market Research (Mints 2015). Implied Non-Module Costs are calculated as the Total Installed Price minus the Module Price Index, and therefore include installer profit margin.

Recent Non-Module Cost Reductions Are Associated Primarily with Declining Soft Costs

Non-module cost have fallen by $1.9/W since 2010, roughly $0.4/W per year on average, with a $0.2/W drop from 2014 to 2015

- Inverters and racking prices have fallen significantly in recent years, representing 20% of non-module cost reductions since 2010 (GTM Research and SEIA 2016)
- Remainder is attributable mostly to soft costs reductions, stemming partly from technical factors (that can be readily quantified):
  - Increasing module efficiency (~8% of non-module cost reductions since 2010)
  - Increasing system size (~10% of total non-module cost reduction since 2010)
- Soft cost reductions also associated with:
  - Widespread policy and industry efforts aimed at reducing soft costs
  - Steady reductions in incentives (next slide)

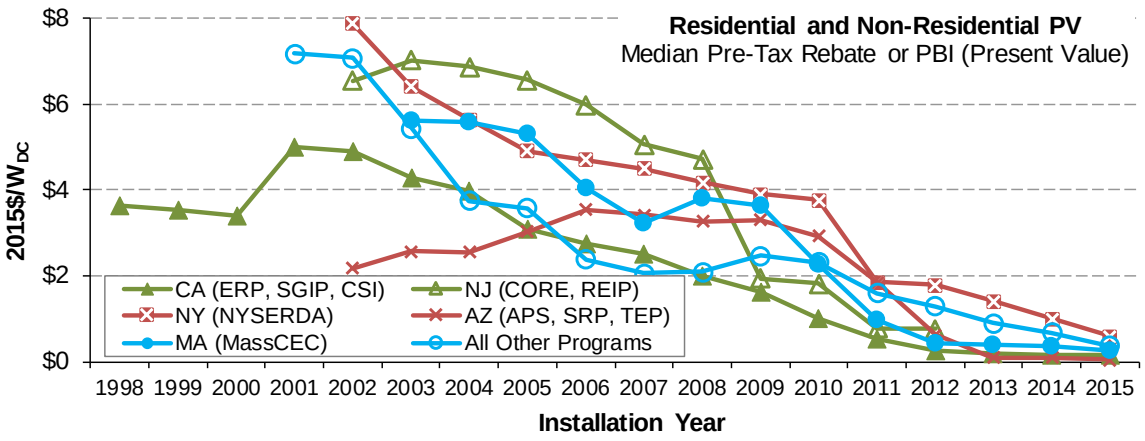


Notes: "All Systems" is based on all residential systems in the data sample, regardless of module technology, while "Poly Systems" is based on only those systems with poly-crystalline modules.

Installed Price Declines Have Been Partially Offset by Falling State and Utility Incentives

- Rebates and performance-based incentives (PBIs) have declined from $3-8/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 by some states to induce cost reductions

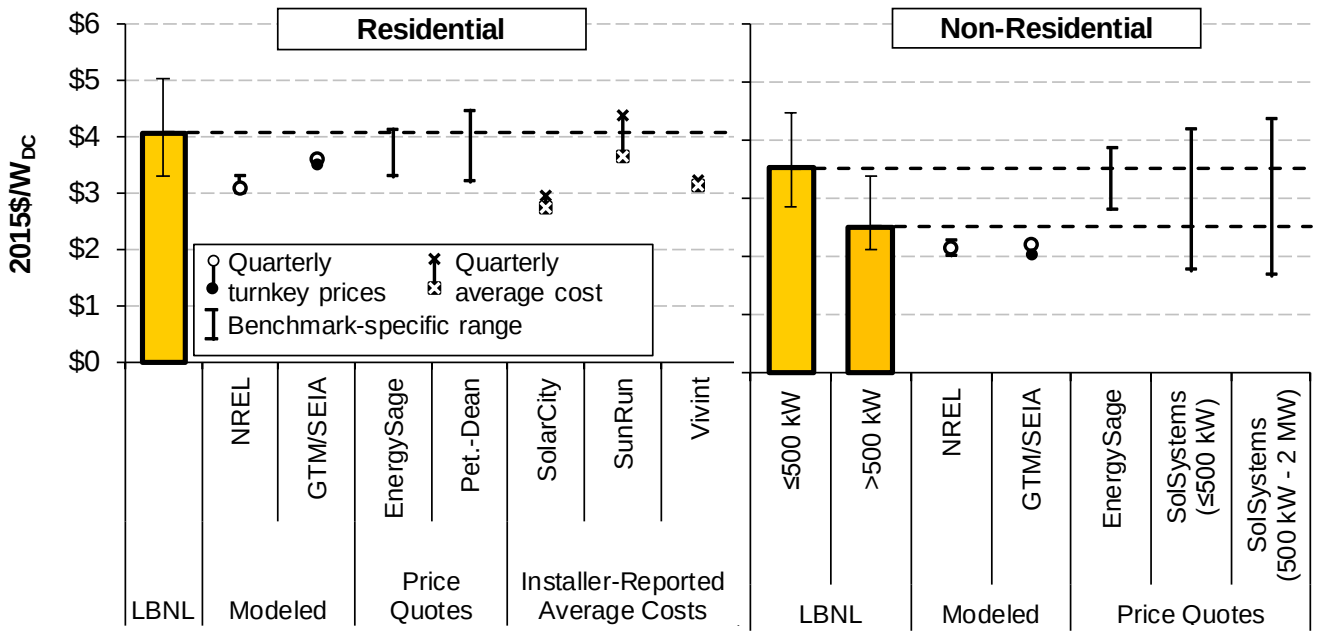
Reductions in rebates and PBIs since their peak equate to 60% to 120% of the corresponding drop in installed prices



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 2015: $4.1/W (res.), **$3.5 /W** (sm. non-res.), **$2.5/W** (lg. non-res.)



*Notes: **LBNL** data are the median and 20thand 80th percentile values among projects installed in 2015. **NREL** data represent the national average and range in statewide average modeled turnkey costs, not including installer profit, for 5.2 kW residential and 200 kW commercial systems, representative of bids issued circa Q1 2015 (Chung et al. 2015). **GTM/SEIA** data are modeled turnkey prices for Q1 and Q4 2015; residential price is for 5-10 kW system with standard crystalline modules, while commercial price is for a 300 kW "minimalist" flat-roof system, with further details available from the reference source (GTM Research and SEIA 2016). **EnergySage** data are the 20thand 80th percentile range among price quotes issued in 2015, calculated by LBNL from data provided by EnergySage. **Petersen-Dean** data are the minimum and maximum values from a series of online price quotes for turnkey systems across a range of sizes (3.3 to 8.3 kW) and states (AZ, CA, and TX), queried from the company website by LBNL in May 2015. **SolarCity**, **SunRun**, and **Vivint** data are the companies' reported average costs, inclusive of general administrative and sales costs, for Q1 and Q4 2015. **SolSystems** data are the lowest and highest "developer all-in asking prices" among the company's monthly Sol Project Finance Journal reports issued in 2015.*

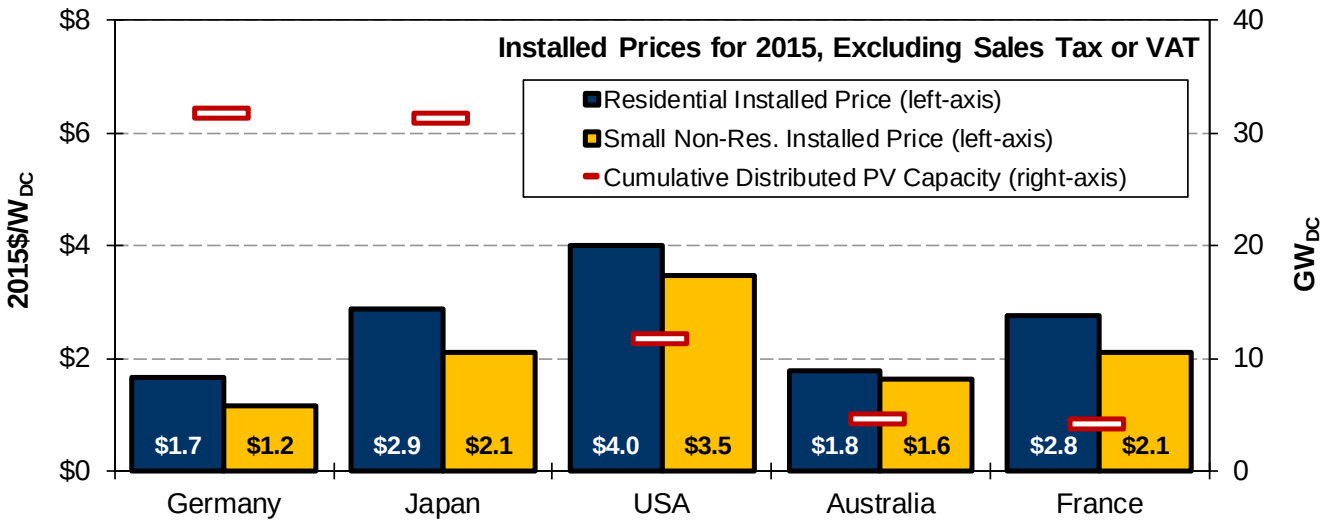
Medians differ from other benchmarks due to:

- Timing: Systems installed vs. quoted in 2015
- Location: Most systems in relatively high-cost states
- Price vs. cost: SolarCity and Vivint data represent costs
- Value-based pricing: Prices in some locations may reflect supra-normal margins
- System size/components: high-efficiency modules, microinverters, etc.
- Scope of costs included: loan origination fees, re-roofing costs, etc.
- Installer characteristics: size, experience, business model

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

The starkest differences are in comparison to Germany, where typical pricing for residential systems was around $1.7/W in 2015

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



Notes: Installed price data for Japan, France, and Australia are based on the IEA Photovoltaic Power Systems Programme's National Survey Reports (IEA-PVPS 2016) and for Germany are based on data compiled by the Center for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW 2016). Data for cumulative distributed PV capacity additions are based on IEA-PVPS (2016) and SPE (2016).

- Yet smaller countries 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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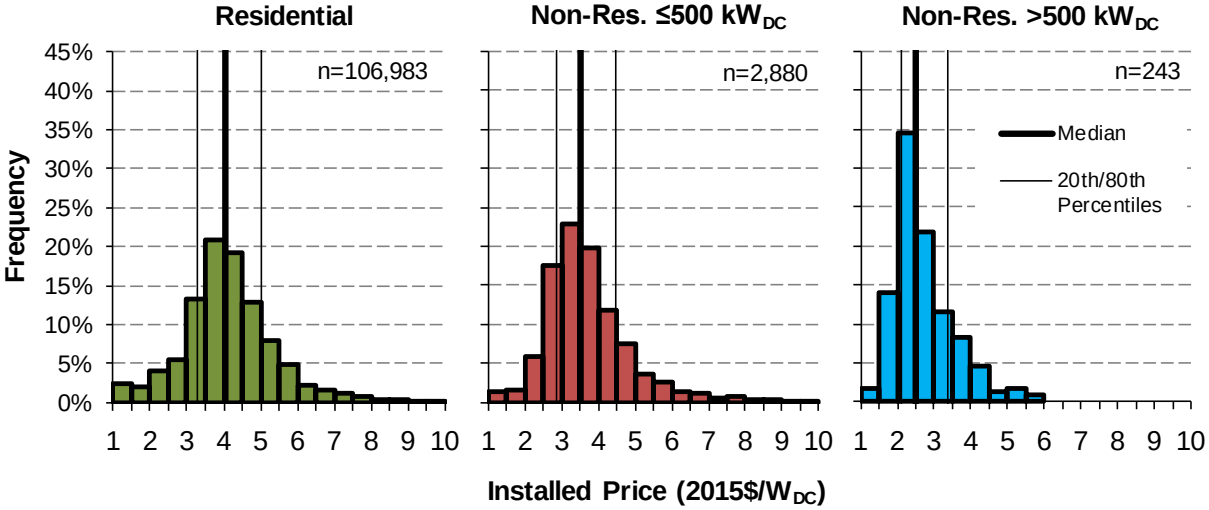
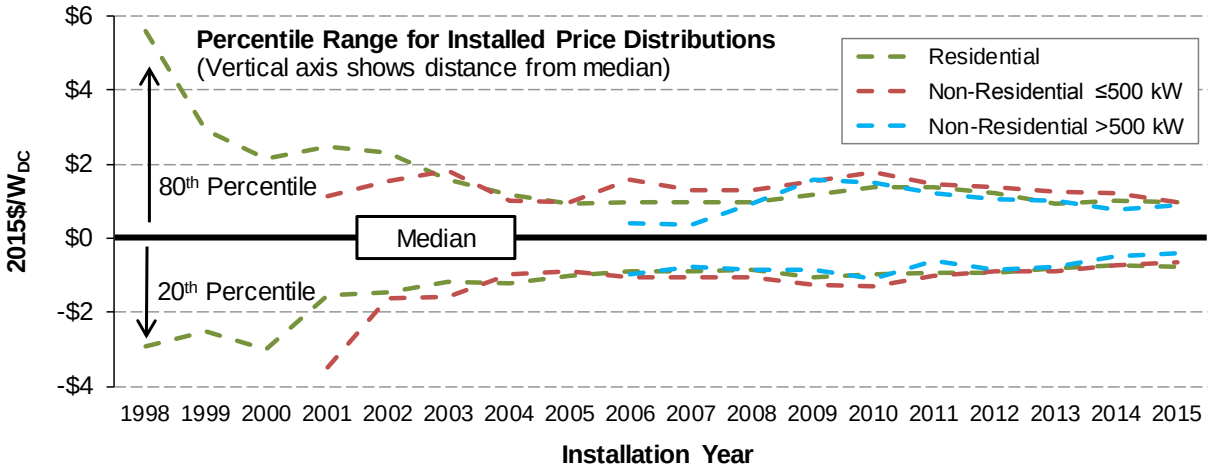
Installed Prices Vary Widely Across Projects

Though have narrowed over time

Installed Price Distributions for Systems Installed in 2015



Installed Price Percentile Ranges over Time



Note: Percentile bands are shown only if 20 or more observations are available for a given year and customer segment.

Wide distributions in system pricing reflect variation in:

- Project characteristics
- Local market and regulatory environment
- Installer size, experience, business model
- Labor rates, taxes, permitting and interconnection processes

Narrowing is consistent with a maturing market characterized by increased competition and better-informed consumers

Recent Studies Shed Light on Installed Pricing Variation and Dynamics for Residential PV

LBNL and academic partners (Yale, U. of Wisconsin, U. of Texas) applied more-advanced statistical and econometric methods to the *Tracking the Sun* dataset, focusing on residential systems

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)

Nemet et al. (2016a) and **Nemet et al. (2016b)** collectively showed that high consumer incentives for solar tend to increase installed prices as a general matter, consistent with the earlier findings of Gillingham et al. (2014), yet the lowest-priced systems (within the lowest 10th percentile) are also associated with relatively high consumer incentives

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

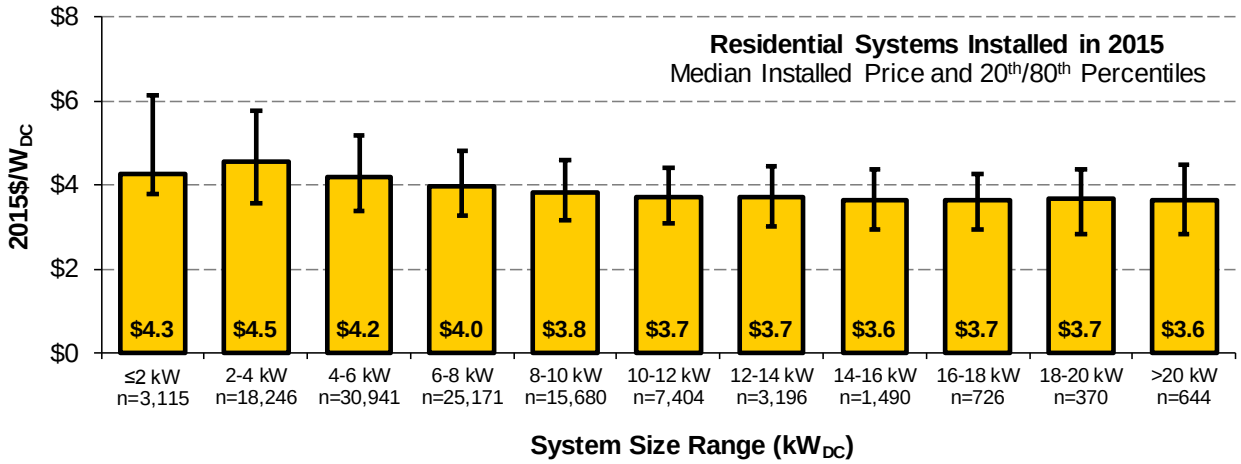
Burkhardt et al. (2014) found that local permitting procedures alone impact installed prices by $0.2/W, while the combination of permitting and other local regulatory procedures impacts prices by $0.6/W to $0.9/W

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

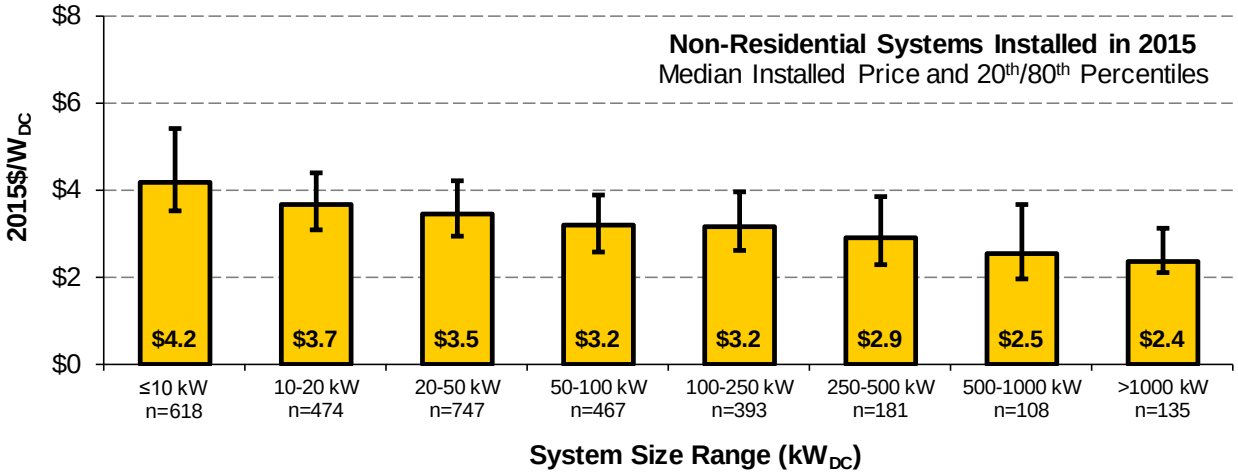
Studies available at http://emp.lbl.gov/projects/solar

Economies of Scale Occur Among Both Residential and Non-Residential Systems

Residential Systems



Non-Residential Systems



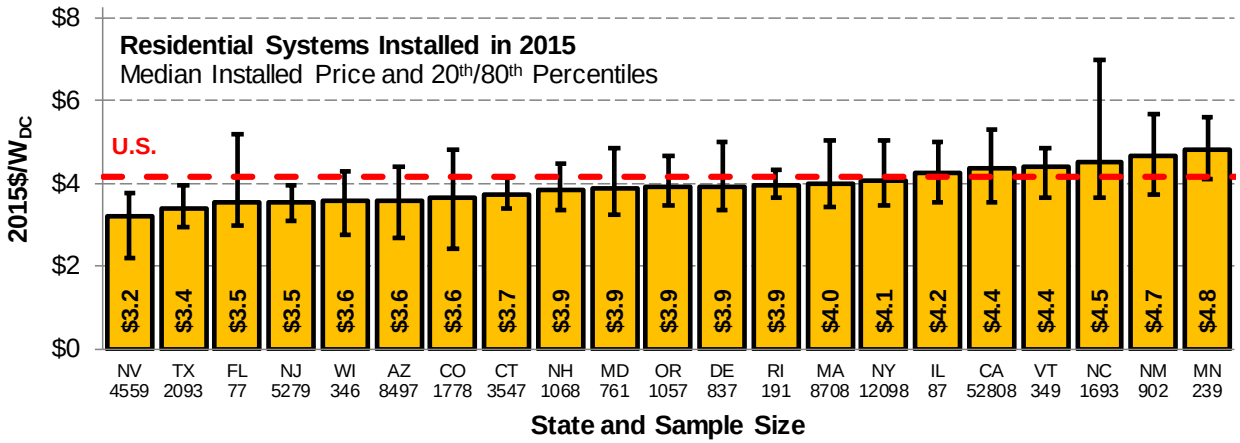
- For residential systems installed in 2015, median prices were roughly 16% lower for 8-10 kW systems than for 2-4 kW systems
- Among non-res. systems installed in 2015, median installed prices were 43% lower for the largest (>1,000 kW) than for the smallest (≤10 kW) non-res. systems
- Even greater economies of scale arise when progressing to utility-scale systems, which are outside the scope of this report

Installed Prices Differ Among States

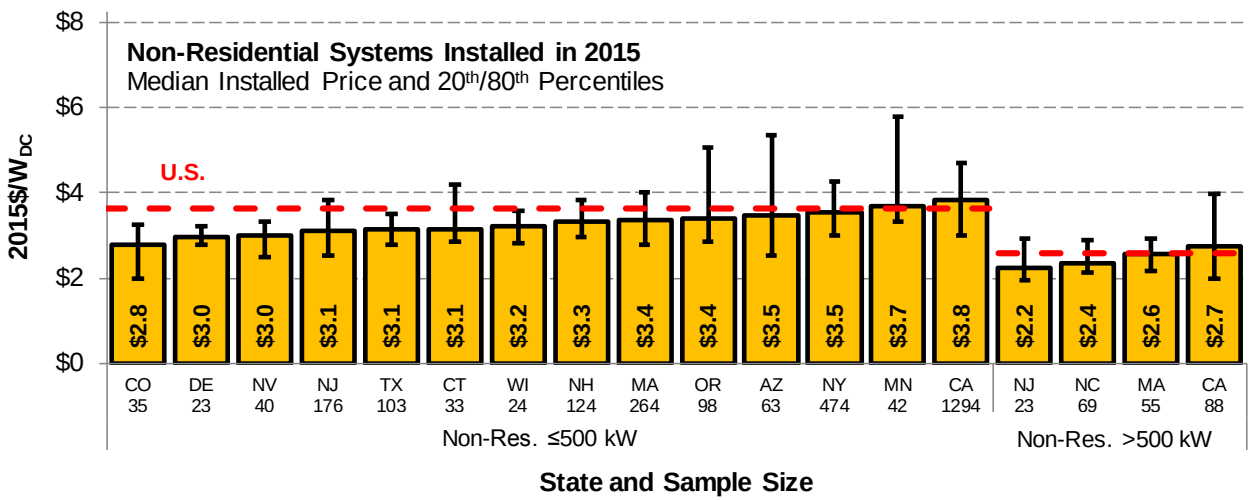
Relatively high prices in some large state markets

- 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



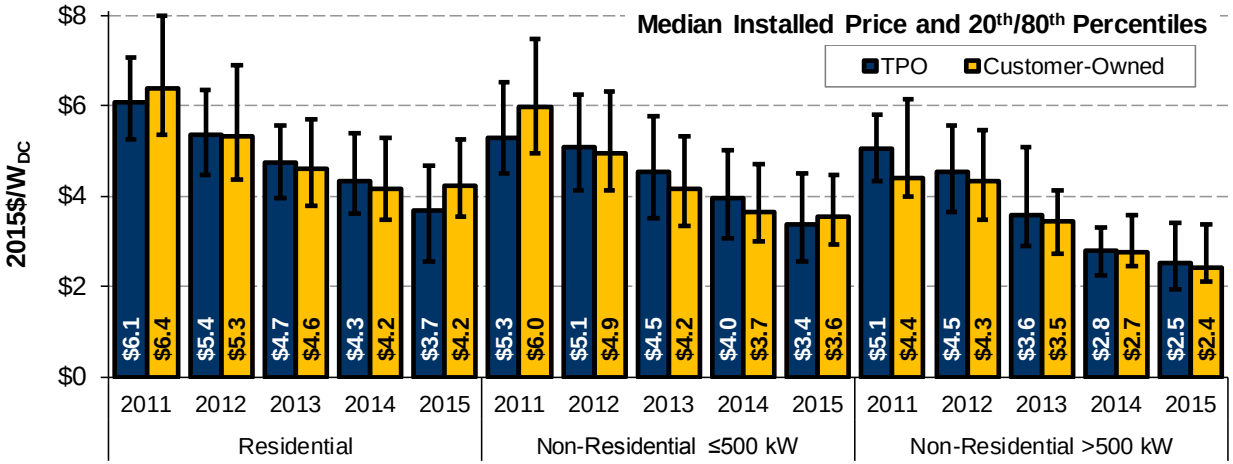
Non-Residential Systems

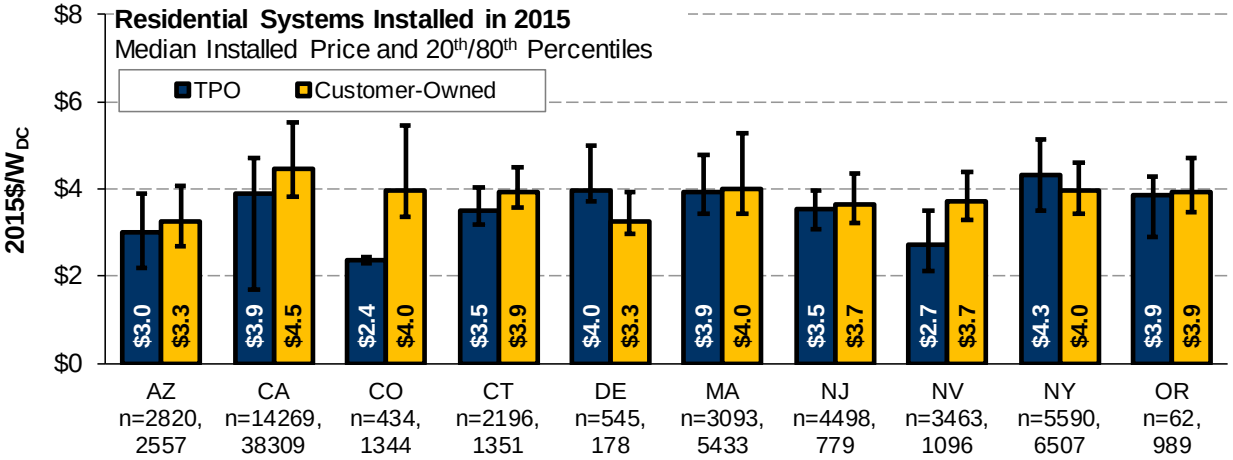


Note: Results shown only if 20 or more observations are available for the state

Installed Prices Reported for TPO Systems Are Generally Similar to Customer-Owned Systems

- At the *national* level, installed price differential between integrated TPO and customer-owned systems has inverted over time, but has generally been small (top figure)
- Implies that growth of TPO has not had a material impact on national median installed price trends
- In some states, installed prices differ more substantially between TPO and customer-owned residential systems, potentially contributing to cross-state price differences (bottom figure)

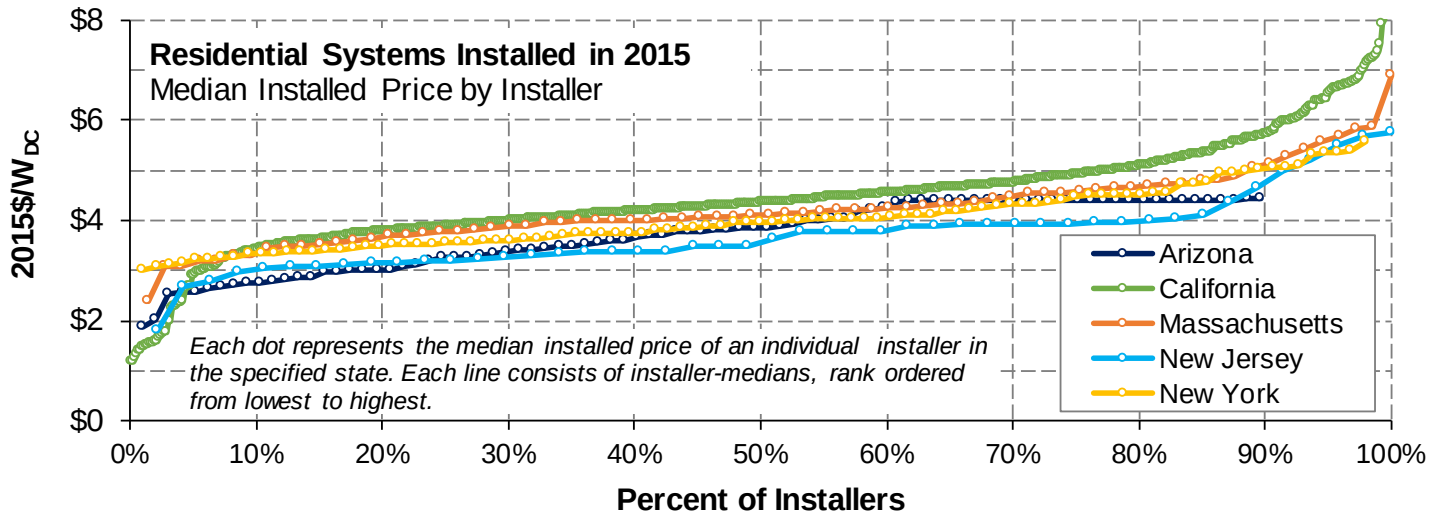




Notes: The values shown here for TPO systems are based on systems financed by non-integrated TPO providers, for which installed price data represent the sale price between the installation contractor and customer finance provider.

Prices Vary Considerably Across Residential Installers Operating within the Same State

Within each of the four states shown, ***installer-level median prices*** differ by $0.2/W to $1.2/W between the 20% and 80%iles (and by more across the full set of installers)



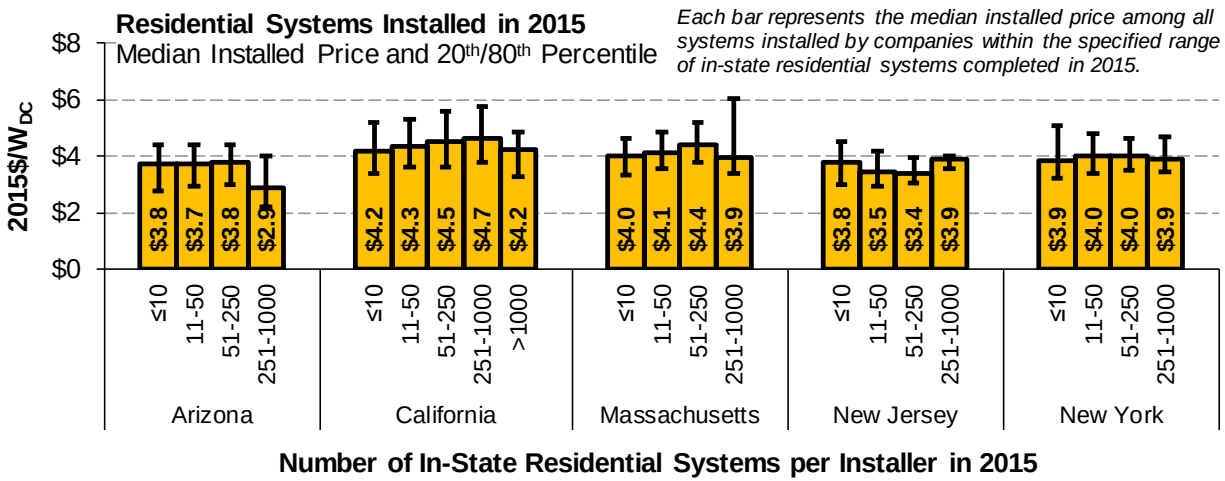
Notes: Each line includes only installers that completed at least 10 residential systems in the given state in 2015.

- "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 Arizona have median prices below $3.0/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.)

Larger Residential Installers *Seemingly* Do Not Have Lower Prices

The figure segments projects according the number of in-state systems the associated installers completed in 2015

- **Arizona:** Notably lower prices for highest-volume installers
- **Other states:** Small differences, with no discernible or logical relationship between price and installer volume



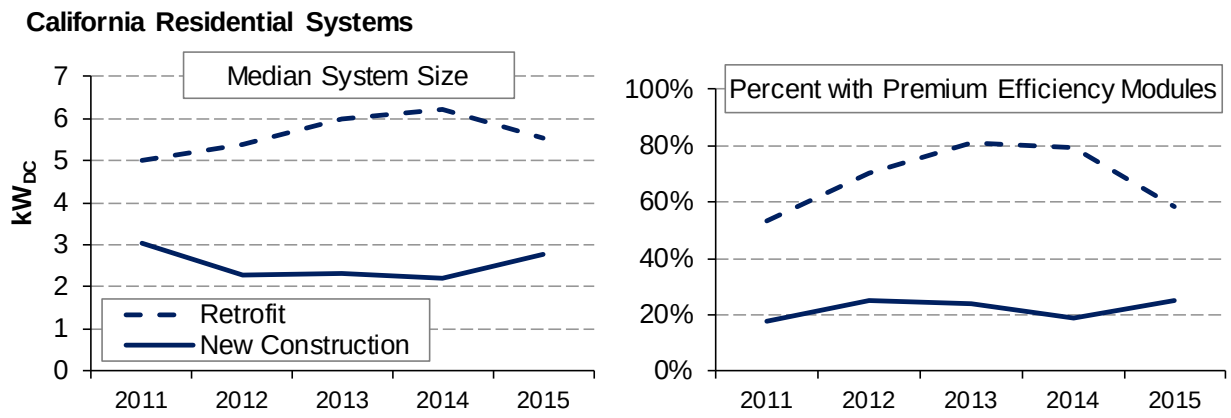
Notes: Each bin includes at least 3 installers and, with the exception of the ≤10 systems bin, at least 10% of all residential systems in the sample installed in-state in 2015. Installer volumes are calculated from the full data sample, and therefore include integrated TPO systems and other excluded systems that are not used for the purpose of calculating installed price statistics.

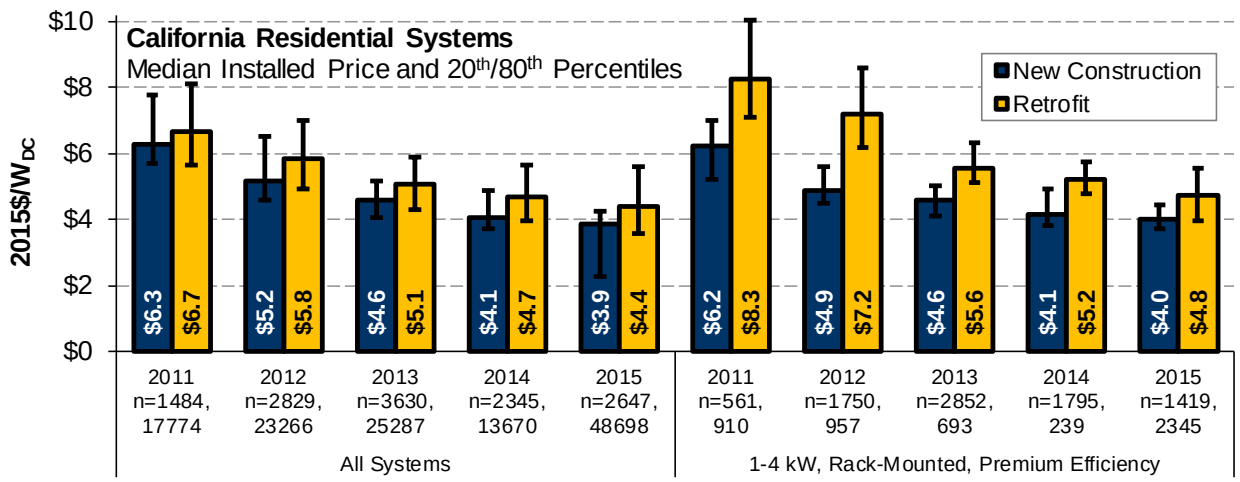
What to conclude?

- Installer size effects arise at geographical scales other than the state-level?
- Installer size effects are simply obscured by other unrelated factors?
- Installer size effects are offset by countervailing factors (e.g., higher customer acquisition costs for high-volume installers)?

Residential New Construction Offers Significant Installed Price Advantages Compared to Retrofit

- 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 were $0.5/W less than retrofits in 2015 (bottom chart)
- Price advantage is even greater ($0.8/W) 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)

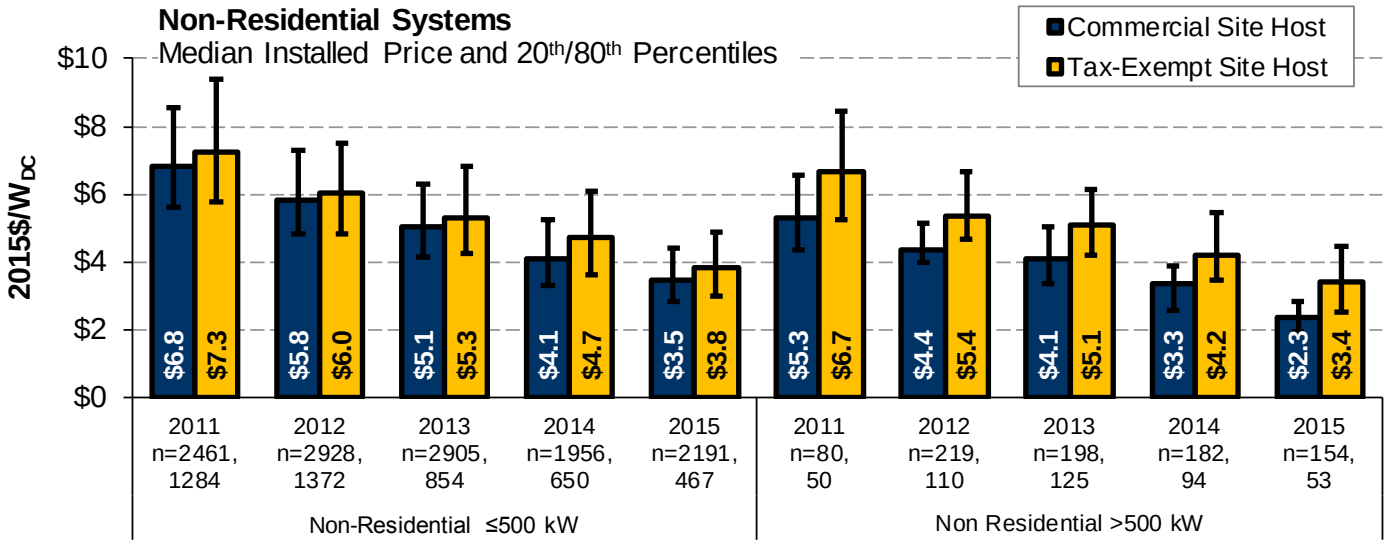




Installed Prices Are Higher for Systems at Tax-Exempt Customer Sites than at For-Profit Commercial Sites

Tax-exempt customers

- Schools, government facilities, non-profits, religious organizations
- Represent 18% of non-res. systems ≤500 kW and 26% of non-res. systems >500 kW in sample



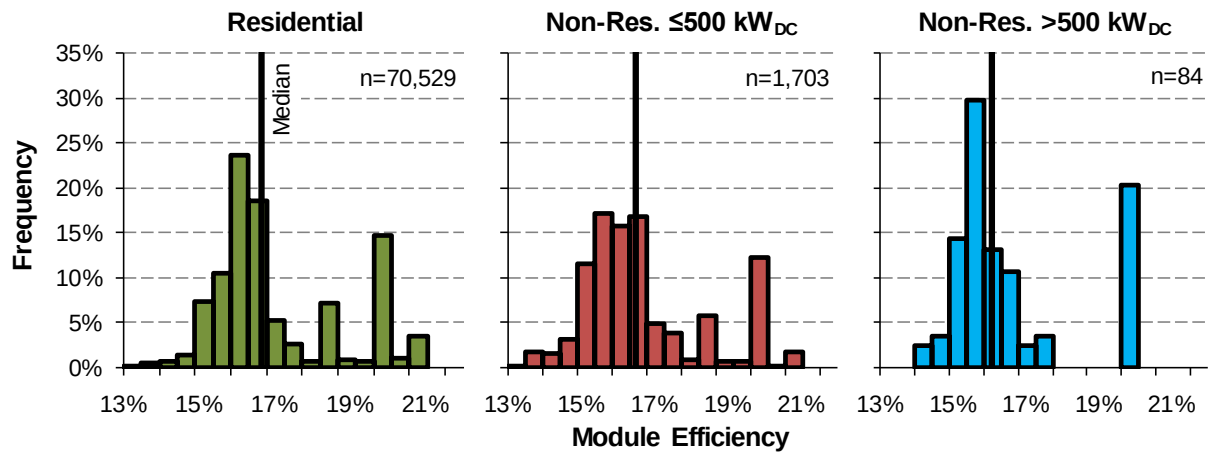
Compared to systems installed at for-profit commercial sites

- Median prices at tax-exempt sites in 2015 were $0.3/W higher for systems ≤500 kW and $1.1/W higher for systems >500 kW
- May reflect more onerous permitting and procurement; smaller sizes; potentially less negotiating power; concentration in California; and higher incidence of prevailing wage/union labor requirements, domestically manufactured components, and shade or parking structures

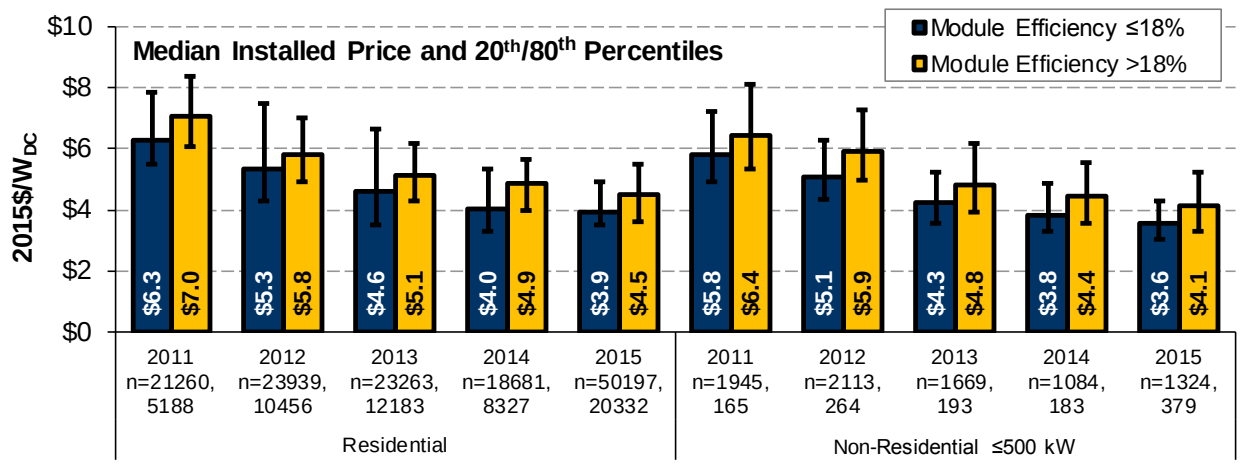
Installed Prices Are Substantially Higher for Systems with High-Efficiency Modules

- Roughly 30% of 2015 systems in the sample have module efficiencies >18% (top chart)
- Systems with >18% efficiency modules had a median installed price $0.5-0.6/W higher than systems with mid/low-efficiency modules in 2015
- Cost premium for high-efficiency modules appears to outweigh associated reduction in BOS costs (though tradeoffs between module technologies entail a broader set of considerations)

Module Efficiency Distributions for Systems Installed in 2015

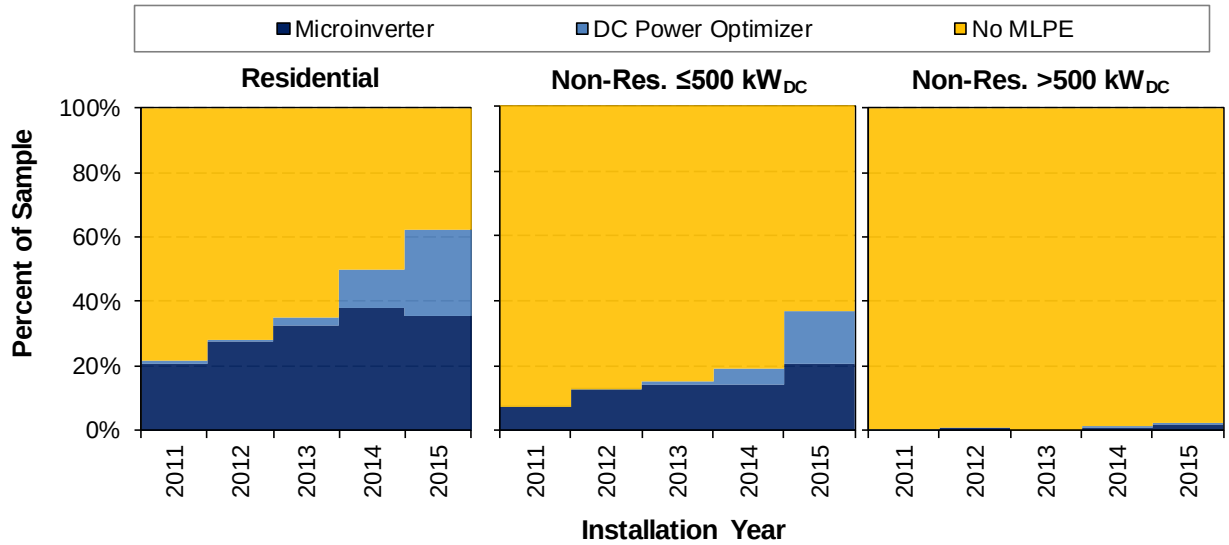


Installed Price Differences Based on Module Efficiency

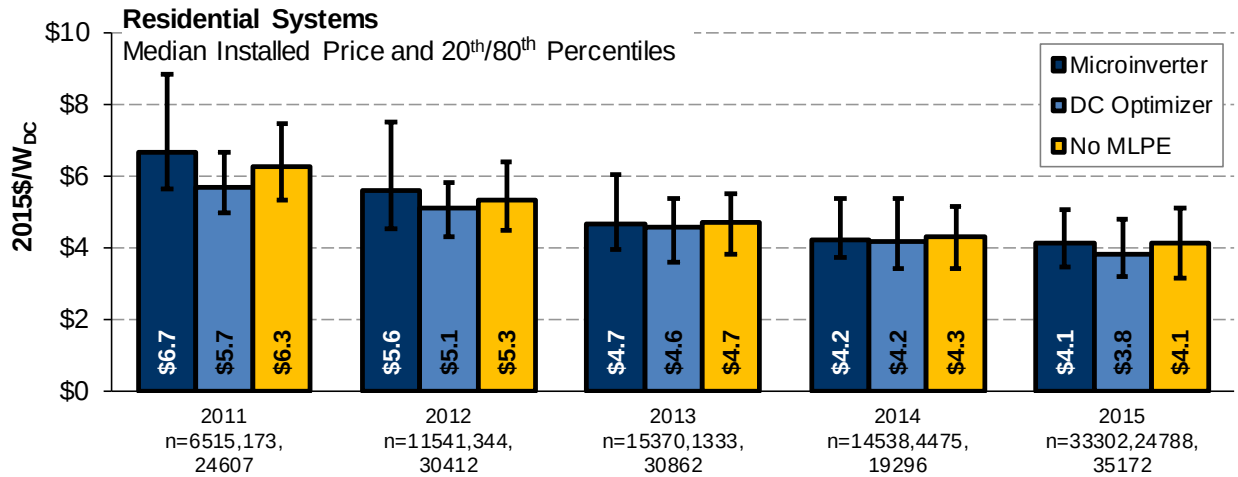


Microinverters Have an Apparently Small Effect on Installed Prices

- 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 devises may offer some offsetting reductions in other BOS and soft costs

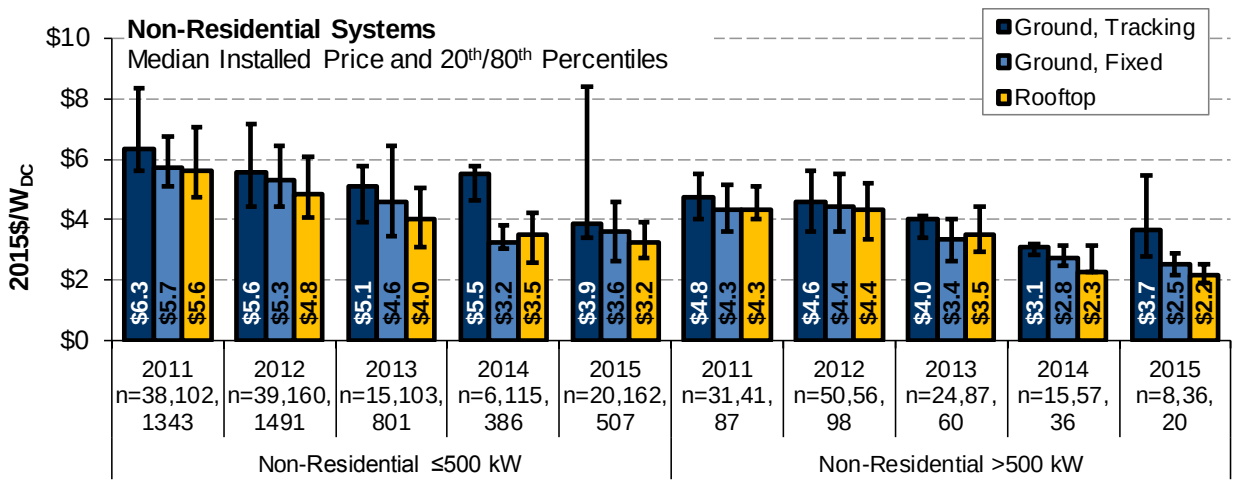


Notes: The DC power optimizer share includes only systems using SolarEdge inverters, and therefore understates the actual share of DC power optimizers in the data sample.



Installed Prices for Non-Residential Systems Vary with Use of Tracking Equipment

- A relatively high percentage of large (>500 kW) non-residential systems in the data sample are ground-mounted (68% in 2015), often with tracking (13% in 2015)
- A smaller portion, but still significant number, of non-res. systems <500 kW are also ground-mounted



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.

- As expected, systems with tracking have higher installed prices than those without, though small sample sizes create somewhat erratic results
- Over the five-year period shown, the differential in median installed prices between systems with and without tracking averaged roughly $0.6/W (18%) for large non-residential systems and $0.8/W (21%) for smaller non-residential systems

Outline

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

Conclusions

- PV installed prices declined substantially from 1998 through 2015 (and into 2016), but the pace and source of those reductions have varied over time
- Dramatic declines in module prices from 2008 to 2012 were the driving force behind reductions in installed system prices over that period, but module prices have since flattened (or risen slightly)
- The continued decline in installed prices is attributable to steady reductions in non-module costs and suggests that recent efforts by industry and policymakers to target soft costs have begun to bear fruit
- Lower installed prices in other major national PV markets and within 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 some combination of incentive policy designs that provide a stable and straightforward value proposition, targeted policies aimed at specific soft costs, and basic and applied research and development

For more information

Download the report along with the companion briefing and data file:

trackingthesun.lbl.gov

Contact the authors:

Galen Barbose, GLBarbose@lbl.gov, 510-495-2593

Naïm Darghouth, NDarghouth@lbl.gov, 510-486-4570

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