Title

Tracking the Sun: Pricing and Design Trends for Distributed Photovoltaic Systems in the United States, 2022 Edition

Authors

Barbose, Galen
Darghouth, Naim
O'Shaughnessy, Eric
et al.

Publication Date

2022-09-12

Tracking the Sun

Pricing and Design Trends for Distributed Photovoltaic Systems in the United States

2022 Edition

Galen Barbose, Naïm Darghouth,
Eric O'Shaughnessy, and Sydney Forrester
Lawrence Berkeley National Laboratory

September 2022

trackingthesun.lbl.gov

BERKELEY LAB

This work was funded by the U.S. Department of Energy Solar Energy Technologies Office, under Contract No. DE-AC02-05CH11231.

Acknowledgements

This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Solar Energy Technologies Office Award Number 38444. For their support of this project, the authors thank Ammar Qusaibaty, Juan Botero, Michele Boyd, and Becca Jones-Albertus of the U.S. Department of Energy. The authors also thank the many individuals from utilities, state agencies, and other organizations who contributed data to this report and who, in many cases, responded to numerous inquiries and requests. Without the contributions of these individuals and organizations, this report would not be possible.

Overview

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

- Current edition focuses on projects installed through 2021
- Covers both stand-alone PV and paired PV+storage
- Describes trends related to:
  - **Project characteristics**, including system size and design, ownership, customer segmentation, and other attributes
  - **Median installed price trends**, both nationally and by state, including preliminary data for first half of 2022
  - **Variability in pricing** according to system size, state, installer, equipment type, and other factors, relying on both descriptive and econometric analysis

Accompanying Data Products
available at trackingthesun.lbl.gov

1. **Summary brief:** A short narrative summary of the full slide-deck report
2. **Data visualization tool:** Allows users to create custom figures and explore the full *Tracking the Sun* dataset
3. **Public data file:** The underlying project-level dataset, excluding confidential data
4. **Summary tables:** All figures and underlying summary tables are available in a MS Excel workbook

Report Structure

Data Sources, Methods, and Market Coverage

Data Sources

Tracking the Sun **relies on project-level data**

- Provided by state agencies, utilities, and other organizations, for PV systems participating in incentive programs, renewable energy credit registration systems, and interconnection processes
- Some of these data already exist in the public domain (e.g., California's Currently Interconnected Dataset), though LBNL may receive additional data under non-disclosure agreements
- Supplementary data from building permit records for Hawaii provided by Ohm Analytics (used in storage-related material)

66 entities spanning 30 states contributed data to this year's report (see Appendix)

- Some of these are legacy data sources that no longer contribute incremental data each year; incremental data for 2021 come from 41 organizations in 25 states

Key Definitions and Conventions

Customer Segments

- **Residential:** Single-family and, depending on the data provider, may also include multi-family
- **Small Non-Residential:** Non-residential systems ≤100 kW_{DC}
- **Large Non-Residential:** Non-residential systems >100 kW_{DC} (and ≤5,000 kW_{AC} if ground-mounted)

  ** Independent of whether connected to the customer- or utility-side of the meter*

Units

- Real 2021 dollars (unless otherwise noted)
- Direct-current Watts (W_{DC}), unless otherwise noted

Installed Price: Up-front price (2021\$/W_{DC}) paid by the PV system owner

- Prior to incentives (i.e., the gross price)
- Inclusive of any up-front loan-financing fees passed through the installer

Sample Frames and Data Cleaning

Full Sample

Used to describe system characteristics

The basis for the public dataset

1. Remove systems with missing size or install date
2. Standardize installer, module, inverter names
3. Integrate equipment spec sheet data
   - Module efficiency and technology type
   - Inverter power rating
   - Flag microinverters or DC optimizers
4. Convert dollar and kW values to appropriate units, and compute other derived fields

Installed-Price Sample

Used in analysis of installed prices

5. Remove systems if:
   - Missing installed price data
   - Third-party owned (TPO)*
   - Battery storage co-installed
   - Self-installed

Separate side analyses performed comparing (Third-party owned and Battery storage co-installed):

- *TPO vs. host-owned*
- *paired PV+storage vs. stand-alone PV*

** TPO includes both leases and power purchase agreements (PPAs). We exclude TPO systems from the installed-price analysis, as the prices reported for those systems may not be strictly comparable to those reported for host-owned systems.*

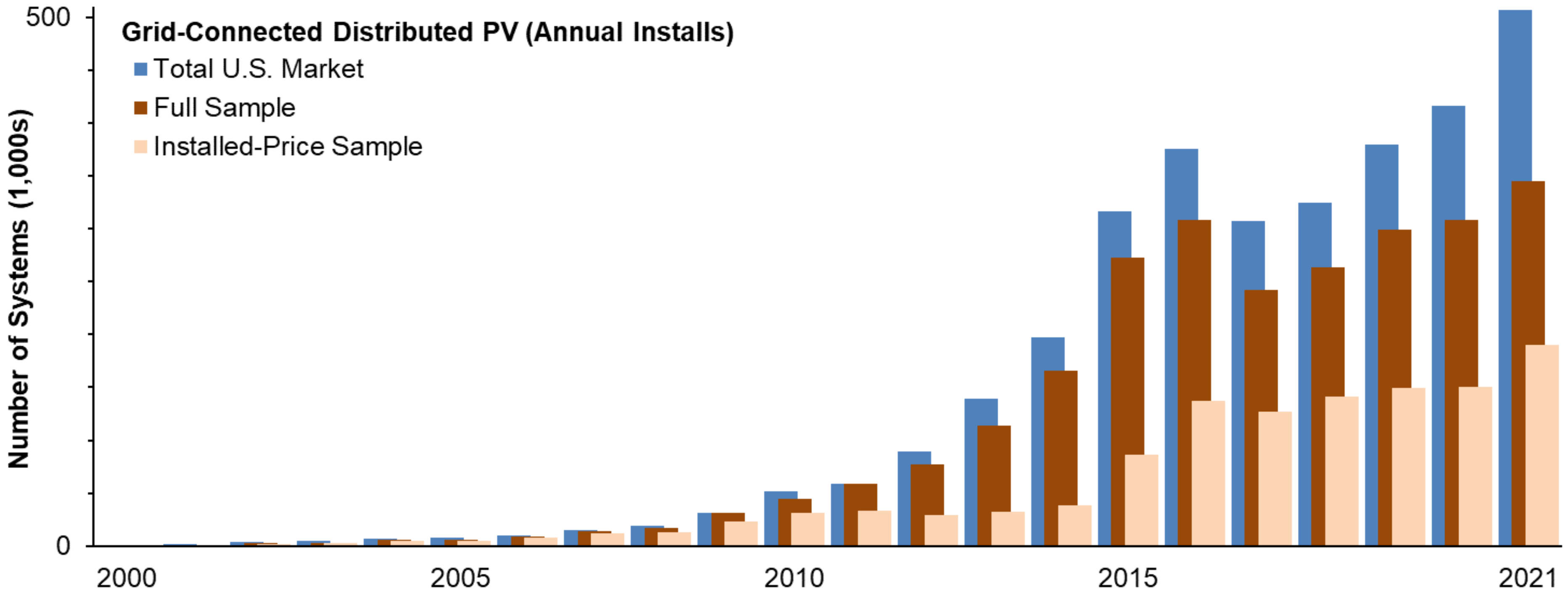
Sample Size Relative to Total U.S. Market

Full Sample

- **2.5 million** systems through 2021 (77% of U.S. market)
- 340,000 systems installed in 2021 (68% of U.S. market)

Installed-Price Sample

- **1.2 million** systems through 2021
- 190,000 systems installed in 2021



Gap between Full Sample and Total 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 Installed-Price Sample and Full Sample: Primarily TPO systems and systems missing installed price data; several states included in the full sample provided no installed price data

Notes: Total U.S. Market size is based on data from Interstate Renewable Energy Council for all years through 2010 and from Wood Mackenzie and the Solar Energy Industries Association (SEIA) for each year thereafter.

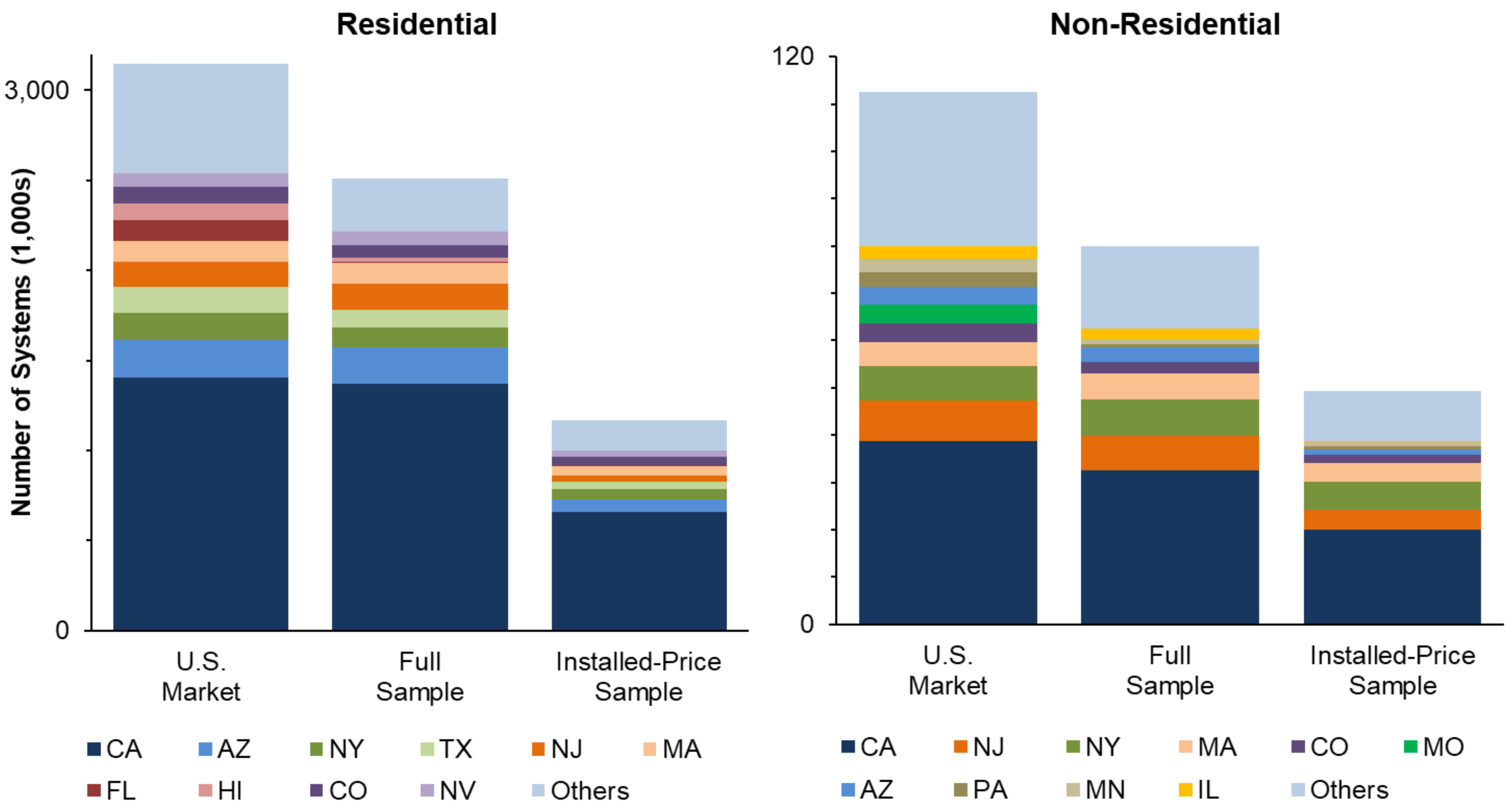
State-Level Sample Distribution and Market Coverage

Sample Distribution: CA dominates the sample, as in the larger U.S. market

Market coverage:

- Similar overall level of market coverage for both residential and non-residential
- In general, coverage among the larger state markets is fairly strong, the main exception being FL
- The bigger gap in the sample is for the collection of smaller state markets (aggregated in the figures as "Others")

Cumulative Installs through 2021 (thousands)



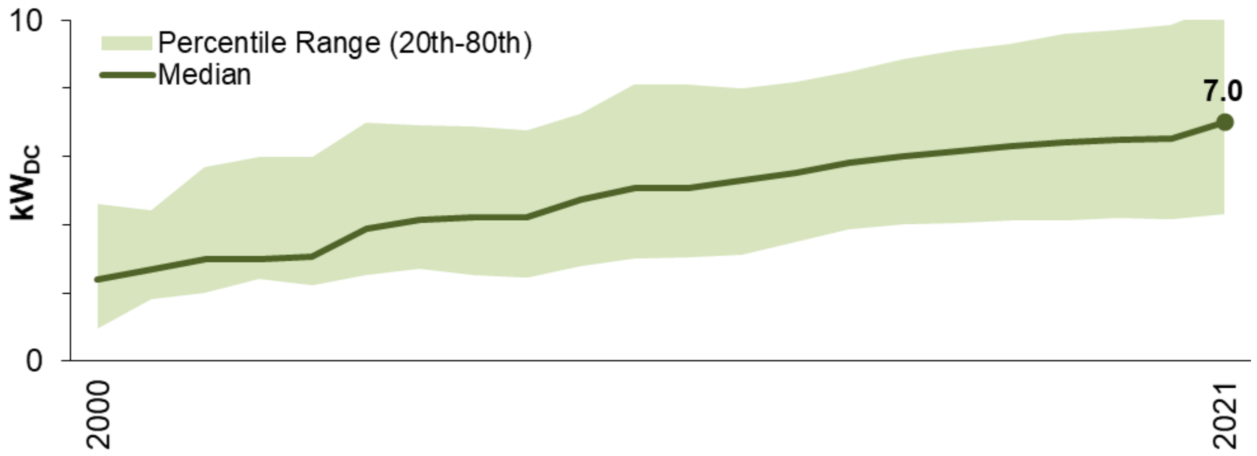
Notes: Data for the total U.S. market are from Wood Mackenzie and SEIA (2022). The figures show the top-10 states in each customer segment, based on cumulative U.S. installations through 2021, and all other states are combined in the "Other" category.

BERKELEY LAB

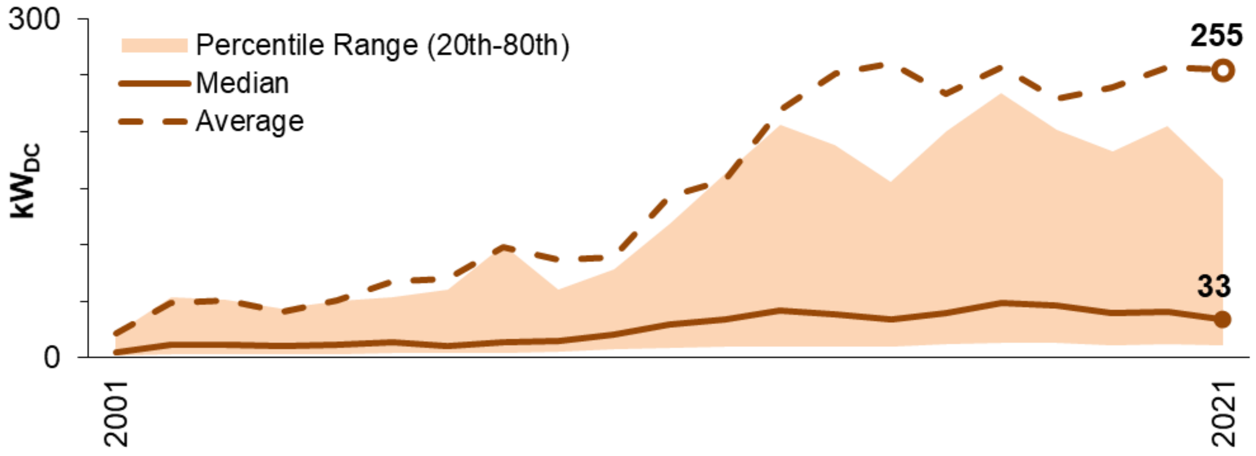
PV System Characteristics

System Size Trends

Residential System Size Time Trends



Non-Residential System Size Trends

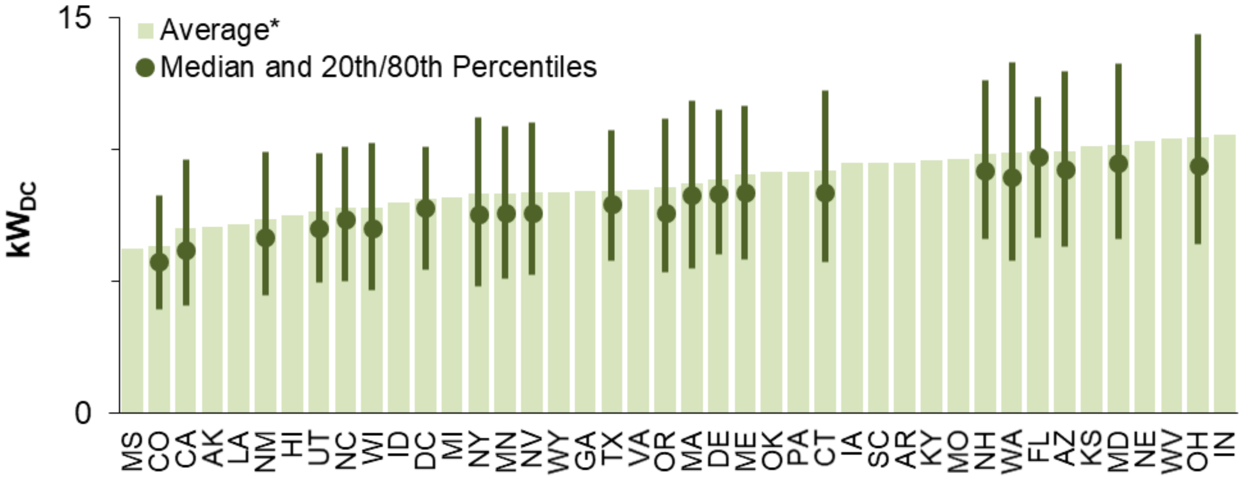


- Residential system sizes have been rising steadily over the past two decades, driven by declining costs and rising module efficiencies, among other factors
- Median residential system sizes reached 7.0 kW in 2021, with most systems ranging from 4-10 kW in size (the 20^{th} to 80^{th} percentile band)
- Non-residential sizes have also risen over time, especially at the upper end of the size range, though trends have flattened over the past decade
- While the median non-residential system size was just 33 kW in 2021, the distribution has a long upper tail, with 20% of systems in 2021 larger than 150 kW, and an average size of 255 kW
- Later trends distinguish small vs. large non-residential

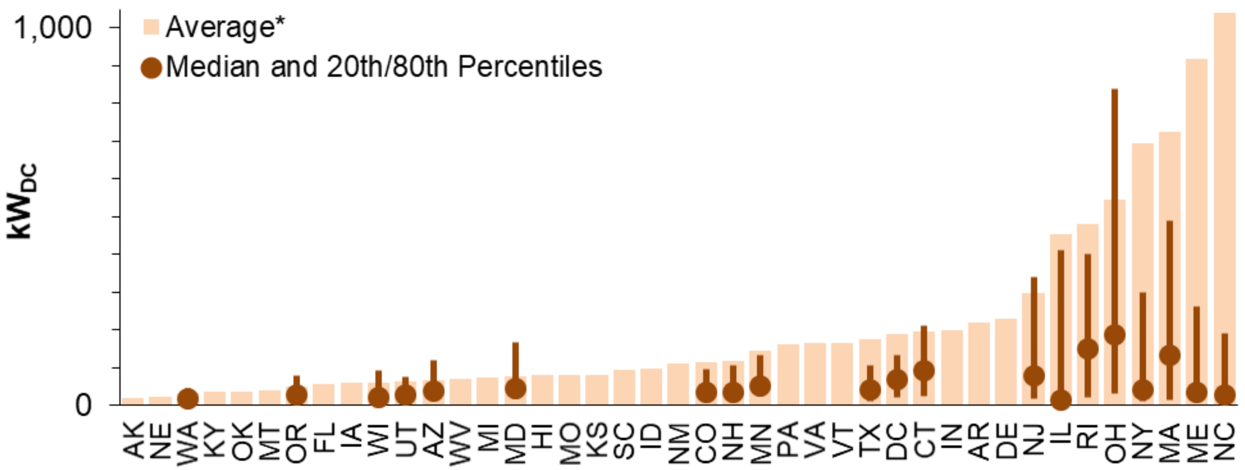
Notes: Summary statistics for any given year are shown only if at least 20 observations are available.

System Size Comparisons by State

Residential System Sizes by State (2021)



Non-Residential System Sizes by State (2021)

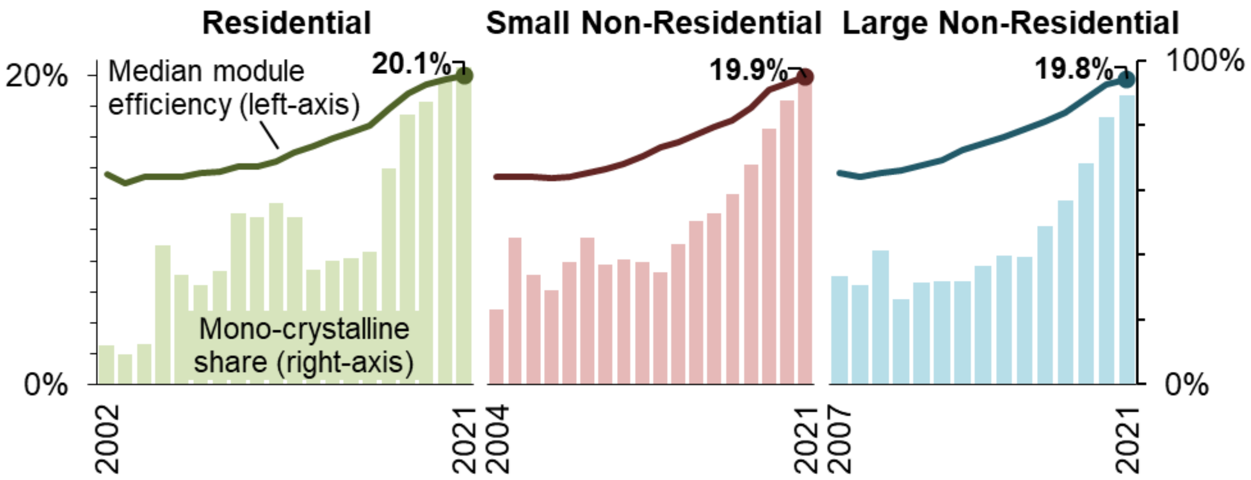


- Residential system sizes vary across states, reflecting regional factors such as typical consumption and insolation levels, among other factors
  - Median system sizes range from 6-10 kW, with a similar spread in average prices
  - System sizes also vary across projects within each state, reflecting customer-specific conditions
- State-level differences in non-residential system sizing are most notable at the upper tail of the distributions, which drives large differences in average sizes
  - States on the right-hand side all had a relatively significant share of large systems (keeping in mind how the non-residential sector is defined in this report)
  - In most states, the vast majority of non-residential systems installed in 2021 were <100 kW

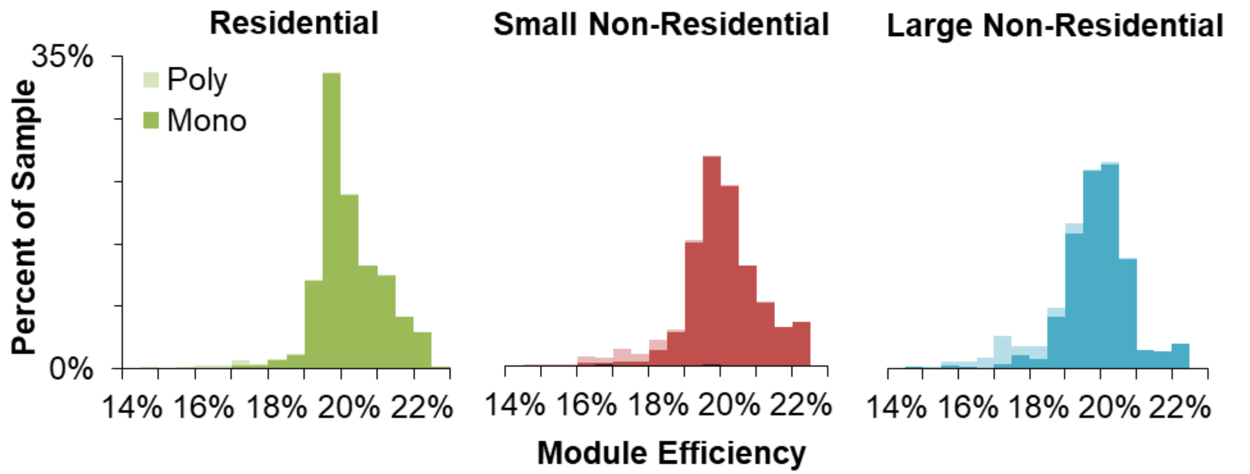
*Notes: *Averages are derived from project level data where available, and in the case of residential systems are calculated from systems <40 kW, in order to exclude erroneous data and remove large agricultural or multi-family housing projects classified as residential. For states not in the Tracking the Sun dataset, averages are derived from state-level statistics published in the annual "Solar Market Insight" report published by Wood Mackenzie and SEIA; medians and percentiles are unavailable for those states. Summary statistics for any given state and customer segment are shown only if at least 20 observations are available.*

Module Efficiency Trends

Module Efficiency Time Trends



Module Efficiency Distribution (2021)

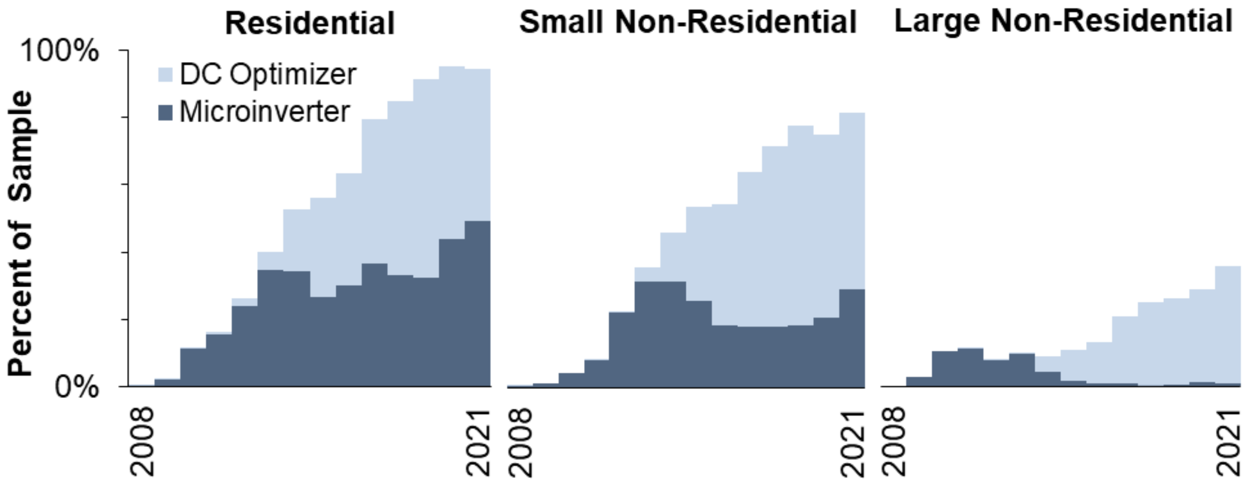


- Module efficiencies have risen steadily over time: for example, among residential systems, median module efficiencies rose from 13.6% in 2002 to 20.1% in 2021, with similar rises for non-residential systems as well
- Rise in recent years partly reflects rapid increase in market share of mono-crystalline modules (89-98% share in 2021, depending on the segment), as well as other factors—e.g., increasing use of passivated emitter rear-cell (PERC) technology
- Across systems installed in 2021, the vast majority had module efficiencies ranging from 19-21%; below that range are mostly poly-silicon modules, and above that range are premium-efficiency modules offered by a handful of manufacturers

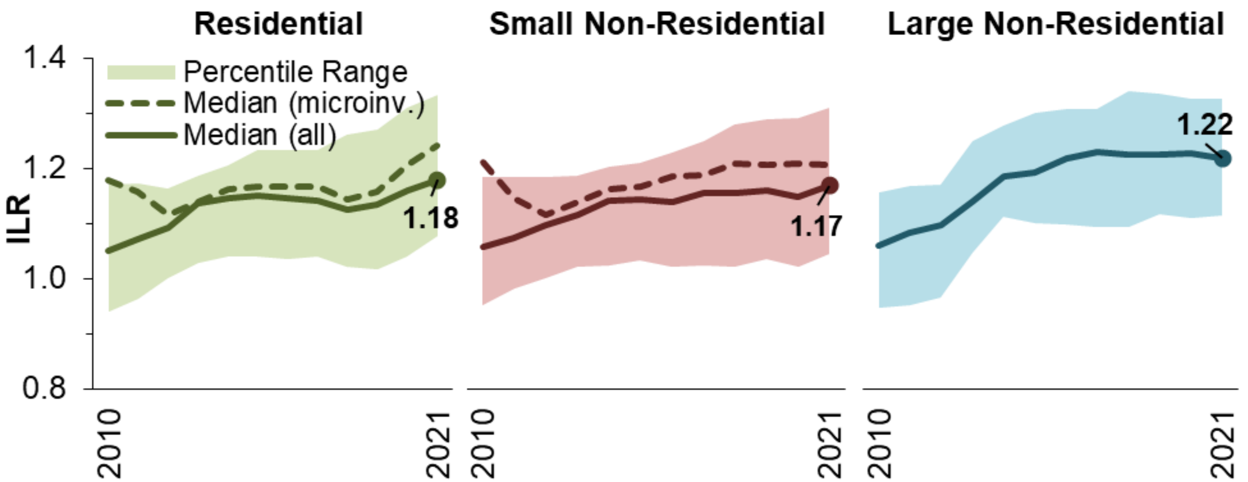
BERKELEY LAB

Inverter-Related Trends

Microinverter and DC Optimizer Trends



Inverter Loading Ratios (DC-to-AC Ratio)

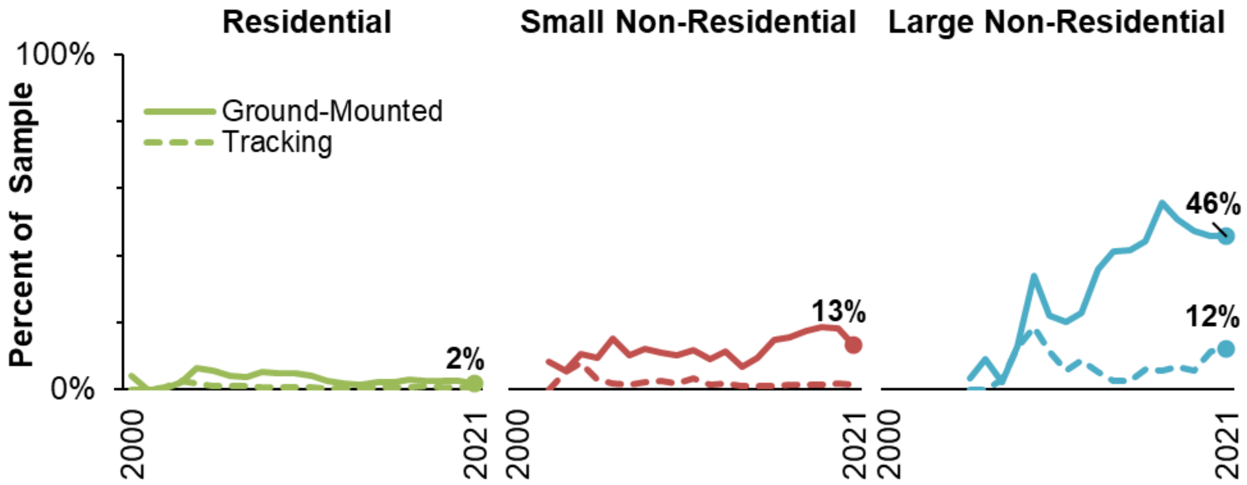


- Module-level power electronics (MLPEs), which include both microinverters and DC optimizers, have continued to gain share across the sample
- MLPEs are almost universal within the residential sector (94% of systems in 2021) and dominant for small non-residential (81%), but considerably less common for large non-residential (36%) albeit growing steadily
- DC optimizers dominate MLPE growth since 2013, but microinverter share has been on the rise in recent years
- Inverter-loading ratios (the ratio of module-to-inverter nameplate ratings) have generally grown over time with declining module costs; also tend to be higher for large non-residential systems and for systems with microinverters (depending on manufacturer)

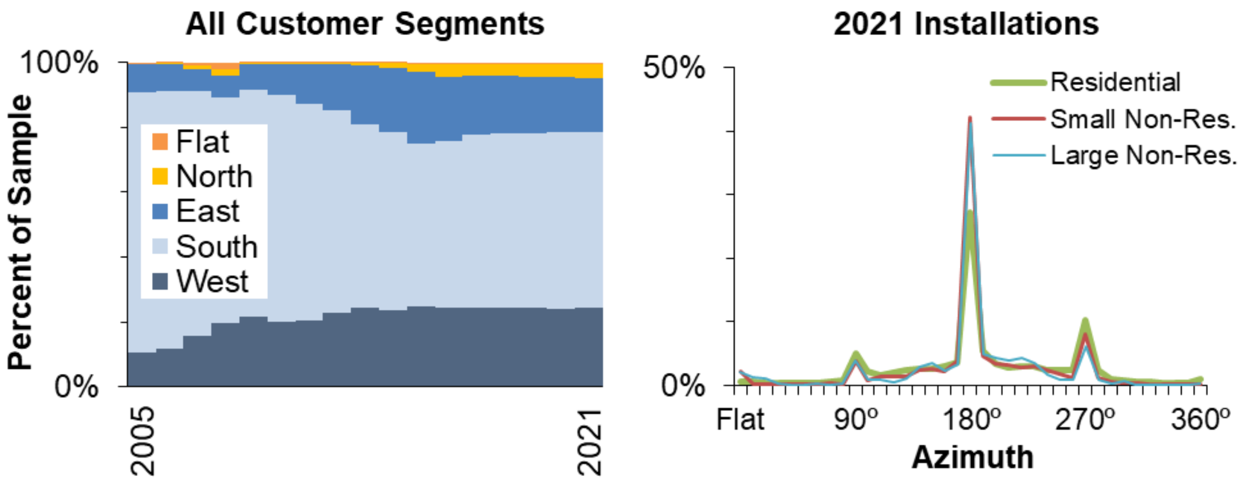
Notes: DC Optimizer share consists of only systems with SolarEdge inverters and may therefore slightly understate the actual share of power optimizers in the data sample.

Mounting Configuration and Panel Orientation

Ground-Mounting and Tracking Equipment (2020)



Panel Orientation



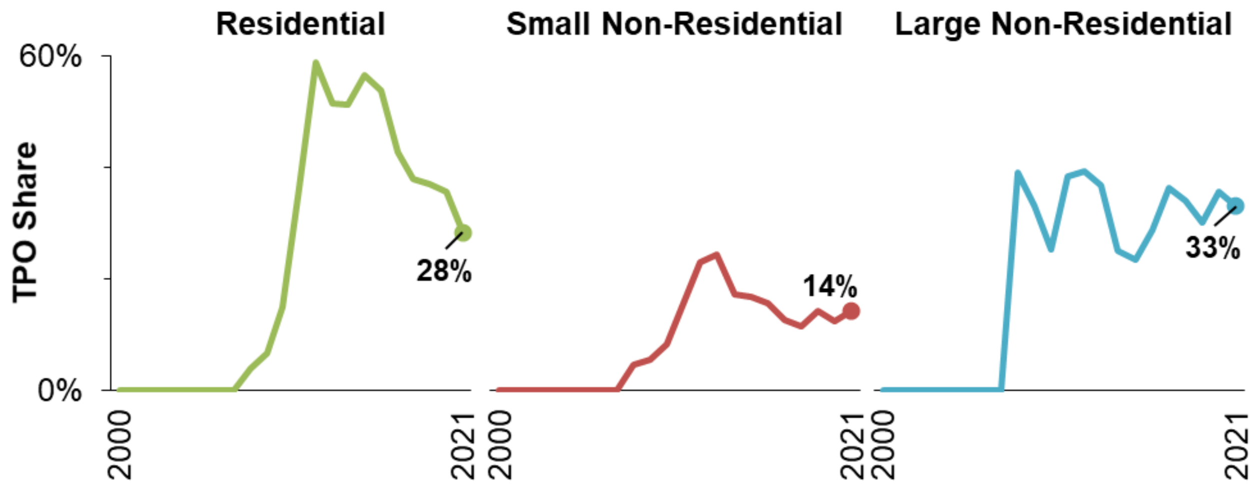
- Ground-mounting (as opposed to roof-mounting) is most prevalent among large non-residential systems, while use of tracking is limited
  - Almost half (46%) of large non-residential systems in 2021 are ground-mounted, while 12% have tracking
  - Ground-mounting much less common among residential and small non-residential systems, and negligible shares have tracking
- Panel orientations have become more diverse over time, though haven't changed much in recent years
  - 54% of systems installed in 2021 face south, 24% to the west, and most of the remainder to the east
  - Greater share of non-residential systems faces exactly due-south, likely due to greater prevalence of ground-mounting and flat rooftops than in residential sector

BERKELEY LAB

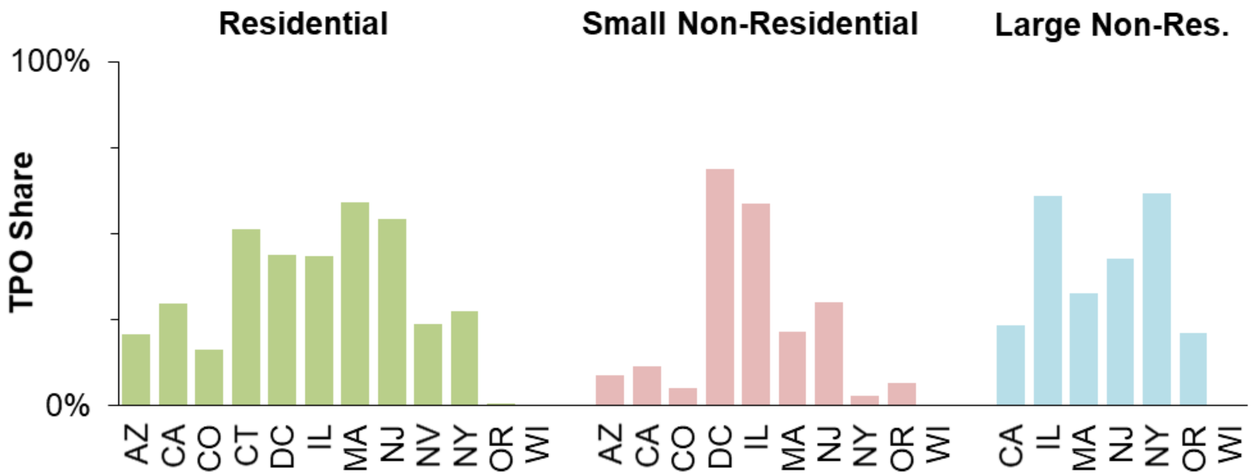
Notes: Summary statistics for any given year are shown only if at least 20 observations are available. Figures in the bottom panel exclude tracking systems, and in both figures, the orientation is based on the primary array (for systems with multiple arrays facing different directions). For the figure on the lower left, azimuths are grouped according to cardinal compass directions ±45º (e.g., systems within ±45º of due-south are considered south-facing). For the figure on the lower right, panel orientations are grouped in 10-degree bins.

Third-Party Ownership Trends

Third-Party Ownership Trends



Third-Party Ownership by State (2021)

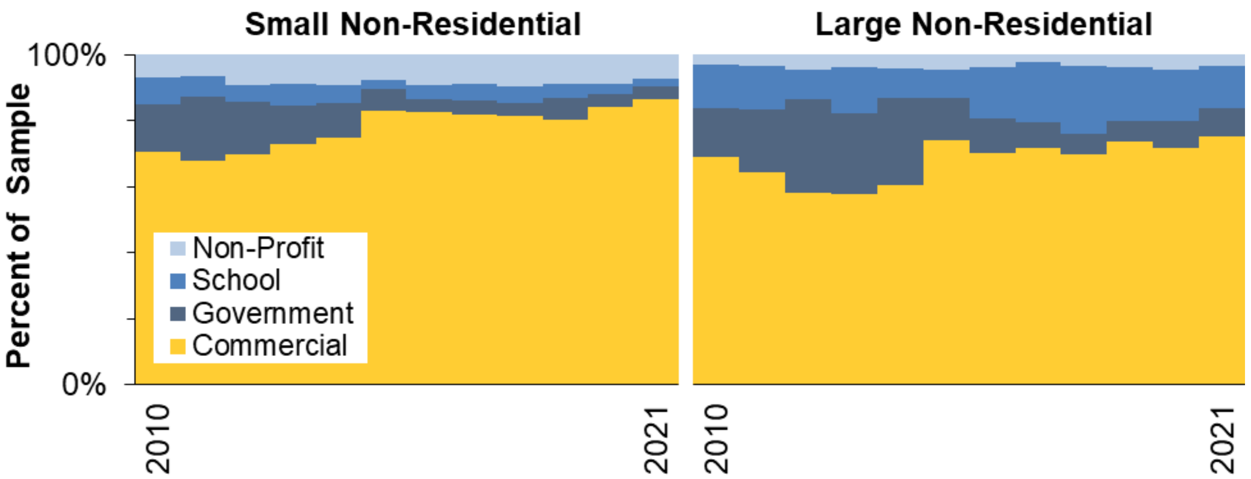


- Third-party ownership (TPO) in the residential sample has declined over time from its historical high of 59% in 2012 to 28% in 2021
  - Reflects emergence of residential loan products
- For the non-residential sample, TPO shares have remained comparatively steady and have historically been lower for small vs. large non-residential systems
- TPO shares at the state level vary substantially
  - Generally are higher among states with sizeable rebate programs (CT, IL) or high solar renewable energy certificate prices (DC, MA, NJ)
  - Some states limit TPO or restrict eligibility for incentive programs to only host-owned systems

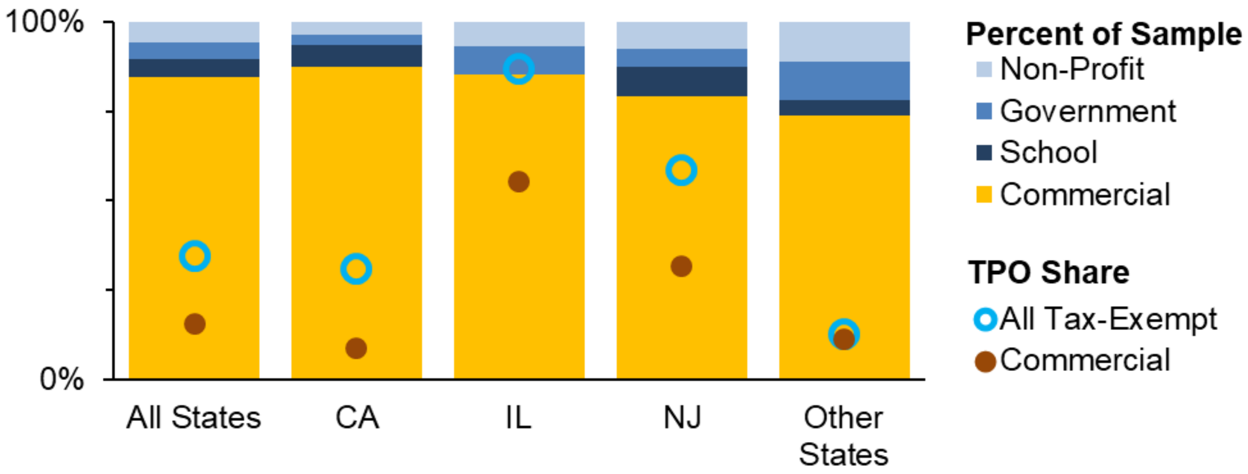
Notes: In the bottom figure, data are shown for individual states only if TPO status is available for at least 20 systems and for at least 50% of records for the given state, year, and customer segment. Furthermore, we exclude a number of states from the figure where the underlying data source may not be representative of the state as a whole, in terms of TPO shares (e.g., TX and FL, where our data come from only municipal utilities, or MD, where our data come from a statewide incentive program available only for host-owned systems).

Non-Residential Customer Segmentation

Non-Res. Customer Segmentation Trends over Time



Non-Res. Customer Segmentation by State (2021)



- For-profit commercial customers make up >75% of non-residential site hosts, with the remainder consisting of some combination of tax-exempt site hosts (schools, government, non-profits)
- Non-profits have been most prevalent among small non-residential systems, while schools and government facilities are more common within the large non-residential segment
- The overall mix of non-residential customer segments generally similar across states
- TPO generally more prevalent among tax-exempt site hosts than for commercial hosts (35% vs. 16% in 2021), as TPO allows tax-exempt customers to monetize tax benefits

BERKELEY LAB

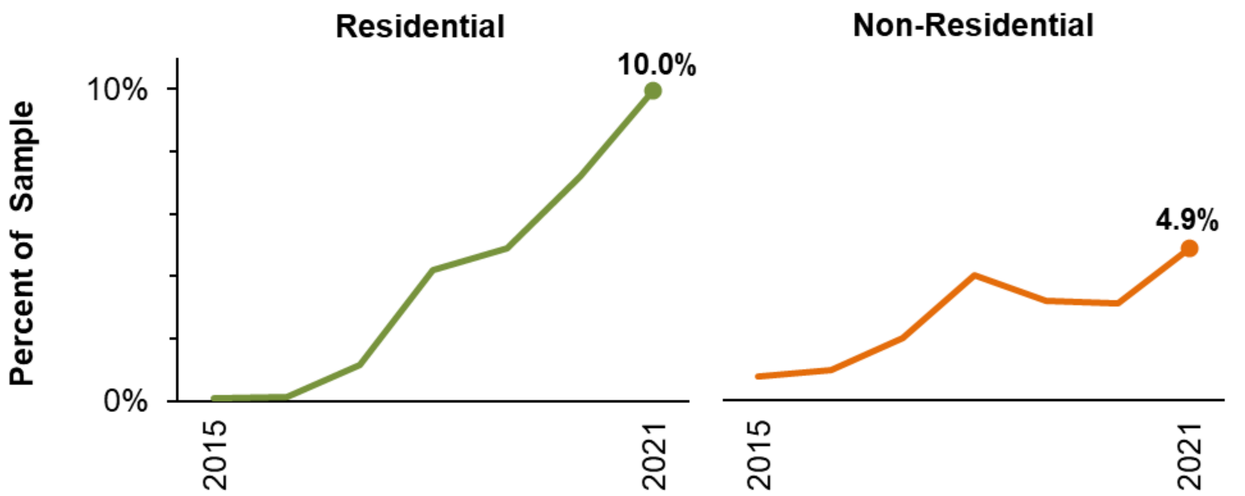
Notes: The figures are based on a subset of the non-residential records for which data on the specific subsegment are available. In the bottom figure, the four states shown are those with the most available data and are among the largest non-residential markets in 2020.

Paired PV+Storage System Characteristics

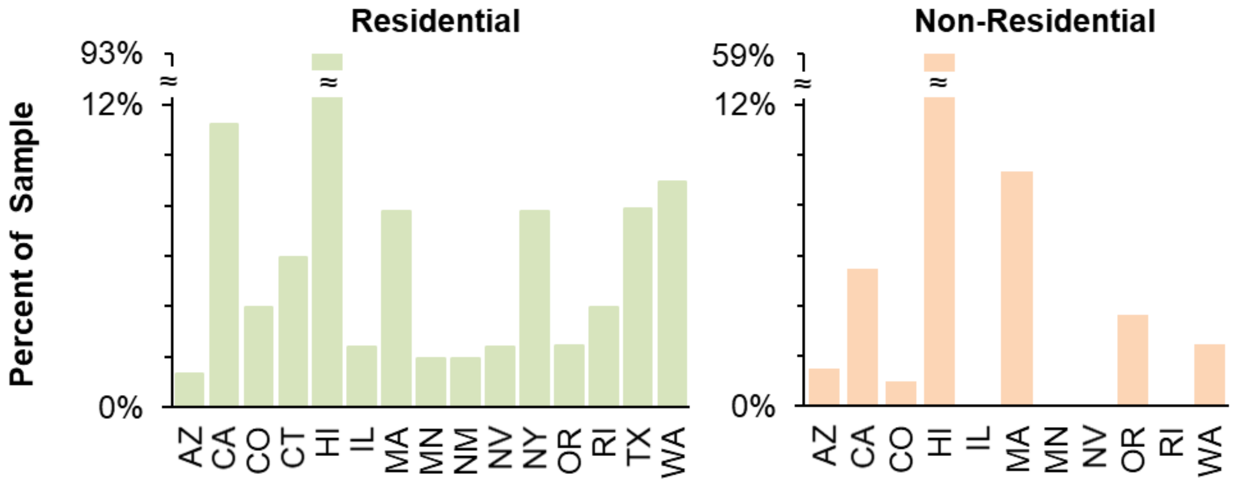
Storage Attachment Rates

Percent of PV systems installed each year with storage

Storage Attachment Rates over Time



Storage Attachment Rates by State (2021)

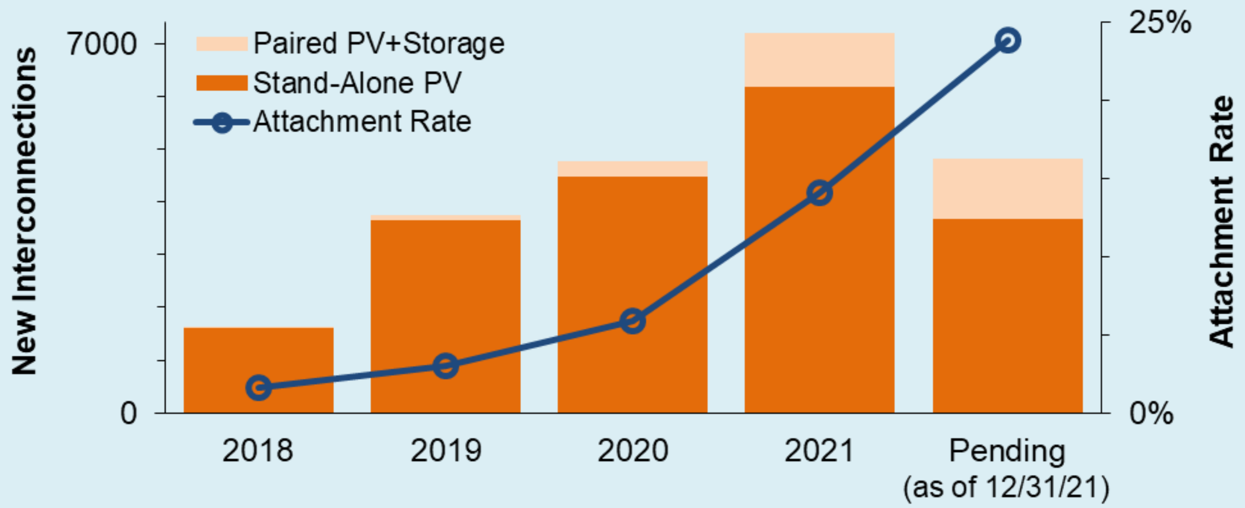


- Residential attachment rates have steadily risen over time, reaching 10% of the sample in 2021
- Non-residential attachment rates have fluctuated over time, but rose to an historical high of ~5% in 2021
- HI has, by far, the highest attachment rates of any state (93% residential, 59% non-res.), driven partly by net metering reforms that incentivize self-consumption
- CA, which hosts the vast majority of paired systems, has attachment rates of 11% (res.) and 5% (non-res.), driven by storage rebates and resilience concerns
- Other pockets of activity exist in the residential market (e.g., MA, NY, TX, WA)
- MA also stands out in the non-residential sector (9%), driven by SMART incentives

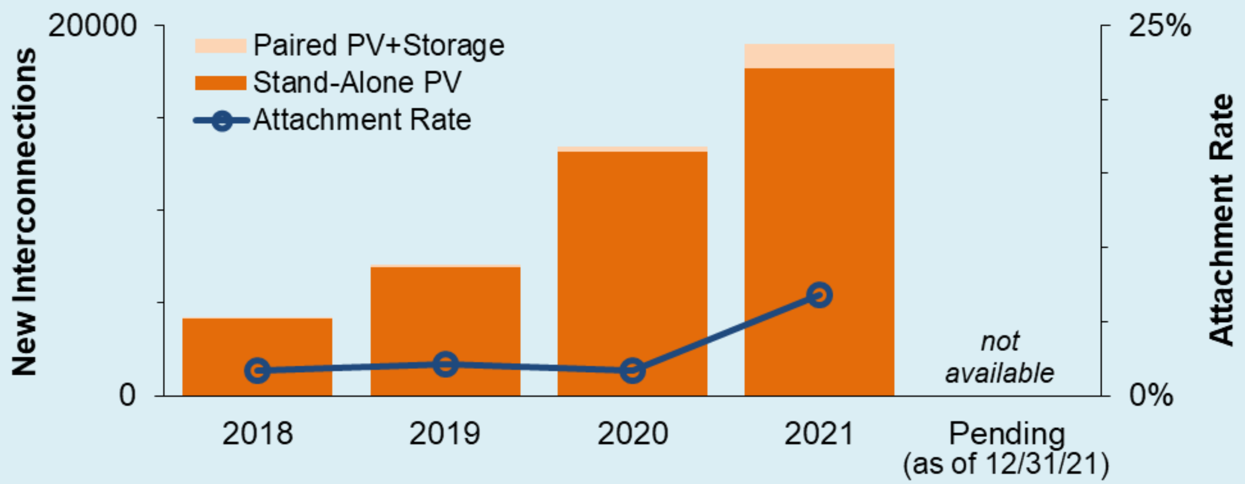
Notes: All storage-related figures aggregate non-residential systems into a single customer segment, as the sample sizes for large non-residential systems are generally quite small. The bottom figure shows only those states for which storage status is available for at least 20 systems and at least 50% of all statewide systems in the sample for the particular customer segment and year shown. Note the breaks in the y-axes for Residential and Small Non-Residential systems, to accommodate the data for HI.

PV+Storage Growth in Texas after 2021 Winter Storm

CenterPoint *(serving Houston metro area)*



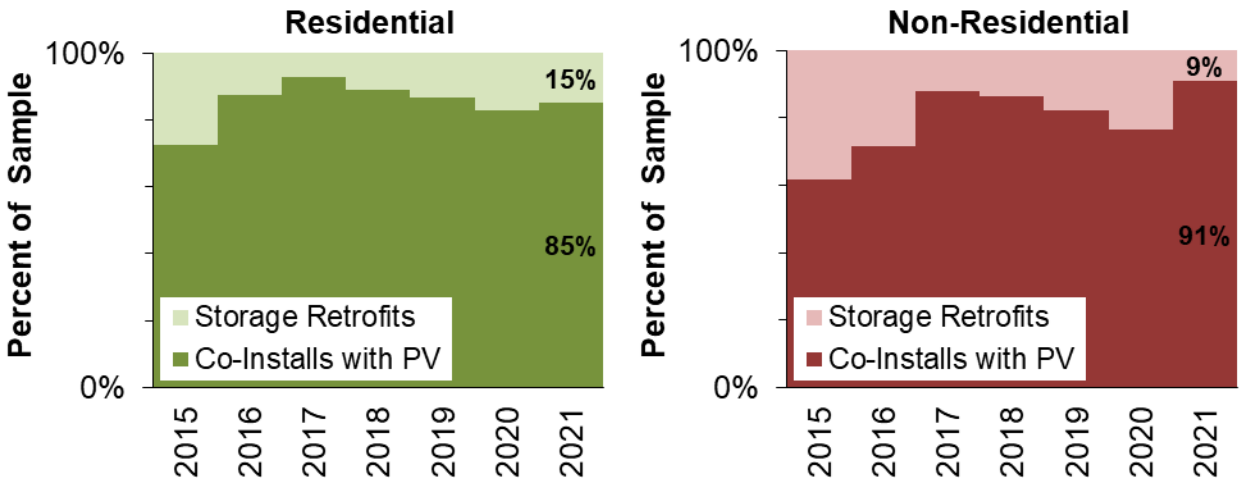
Oncor *(serving Dallas/Fort Worth metro area)*



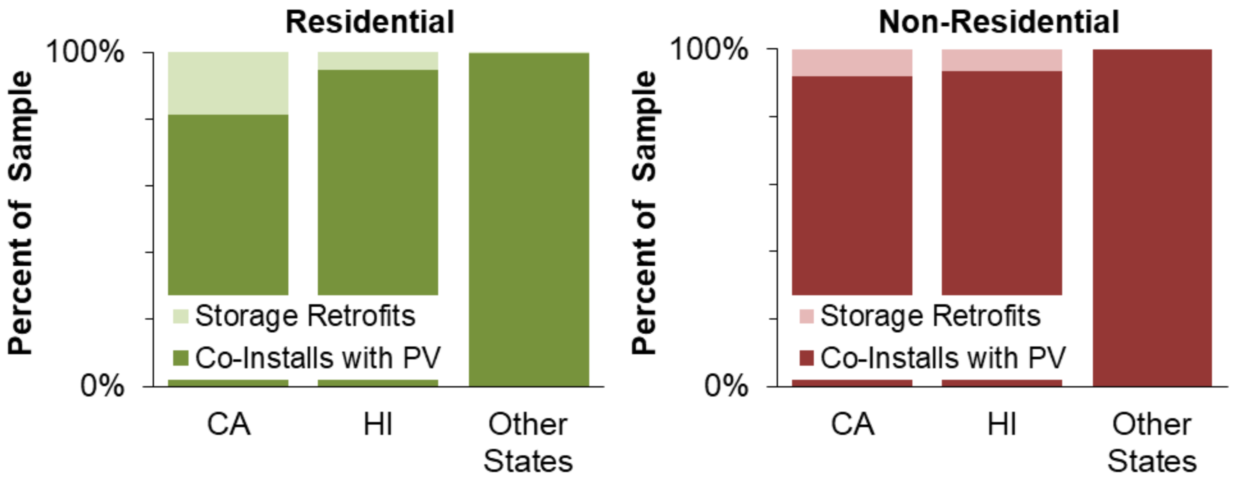
- An uptick in PV+storage adoption occurred after Winter Storm Uri, which hit Texas in February 2021
- From 2020-2021, new PV+storage interconnections increased by more than 3x in CenterPoint’s service territory (from roughly 300 to 1,000) and by roughly 6x in Oncor’s service territory (from 200 to 1,300)
- The uptick in attachment rates was most pronounced for CenterPoint, rising to 14% in 2021, and to 24% among applications pending at the end of the year
- Retail service providers in Texas also typically credit PV grid exports at less than the full retail rate, incentivizing PV customers to co-install storage in order to maximize self-consumption

Storage Retrofits to Existing PV Systems

Retrofits vs. Co-Installs by Year



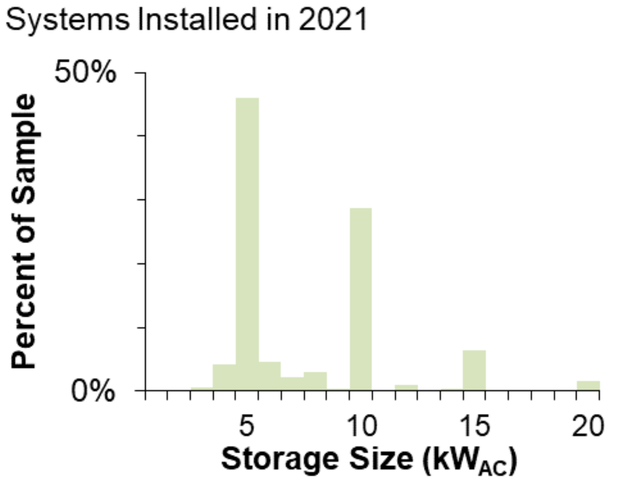
Retrofits vs. Co-Installs by State (2021 Installs)



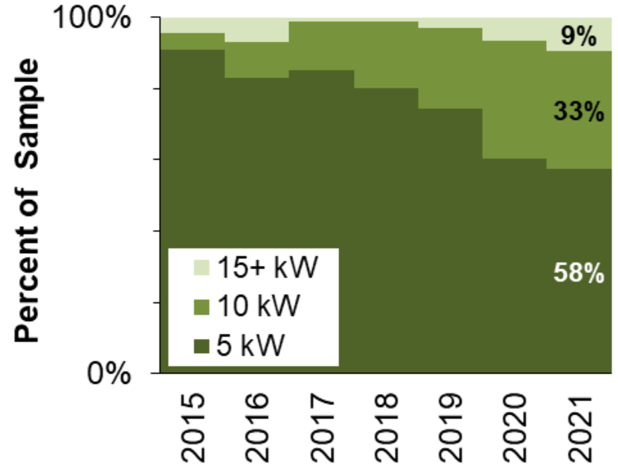
- Some storage systems paired with PV are installed as retrofits onto existing PV systems, rather than co-installed at the same time
- In both the residential and non-residential sectors, roughly 10-20% of all paired storage systems installed each year are retrofits (in 2021, 15% of residential systems and 9% of non-residential systems)
- Within the residential market, retrofits are considerably more common in California than in other states, likely driven the combination of wildfire-related resilience concerns and new time-of-use (TOU) rates with high peak-to-off-peak price differentials

Residential Paired System Sizing

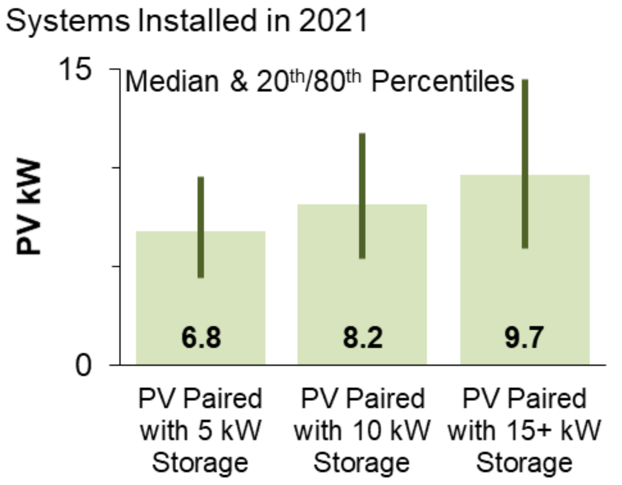
Storage Size Distribution



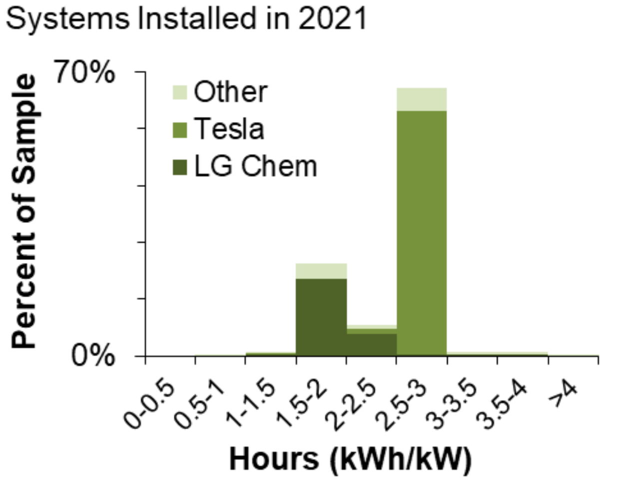
Storage Size Trend



PV Sizing with Storage



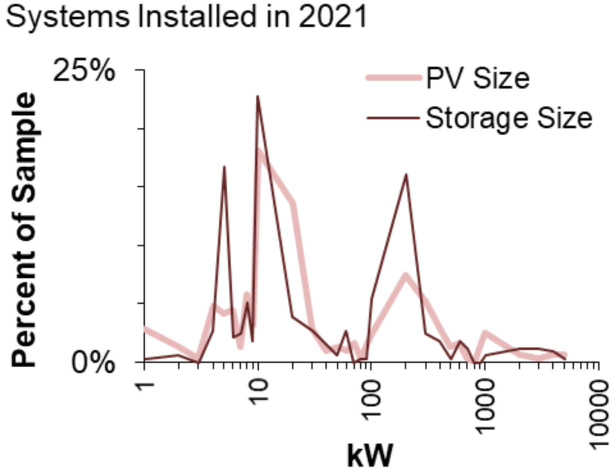
Storage Duration



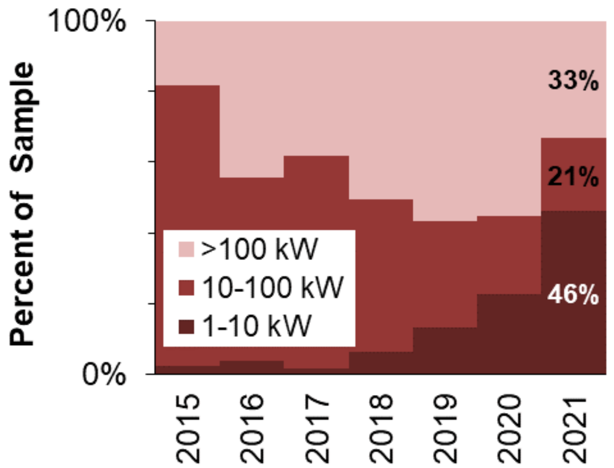
- Most residential storage systems paired with PV come in increments of 5 kW-storage
- The market has been trending toward systems with larger batteries, presumably driven in part by backup power demand → 42% of paired systems installed in 2021 had 10 kW or more of storage
- Paired systems with larger amounts of storage also tend to have more PV capacity
- Virtually all systems installed in 2021 had storage durations ranging from 1.5-3 hours (rated kWh/kW); reflects the two products that dominated market share (the LG Chem RESU10H @ 1.9 hrs and the Tesla PowerWall @ 2.7 hrs)

Non-Residential Paired System Sizing

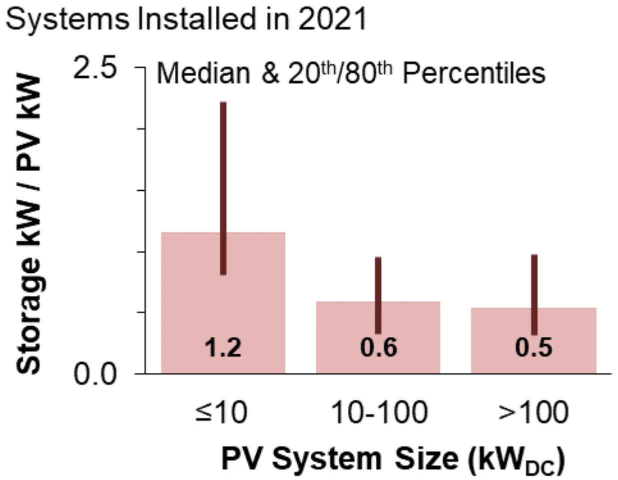
Size Distributions



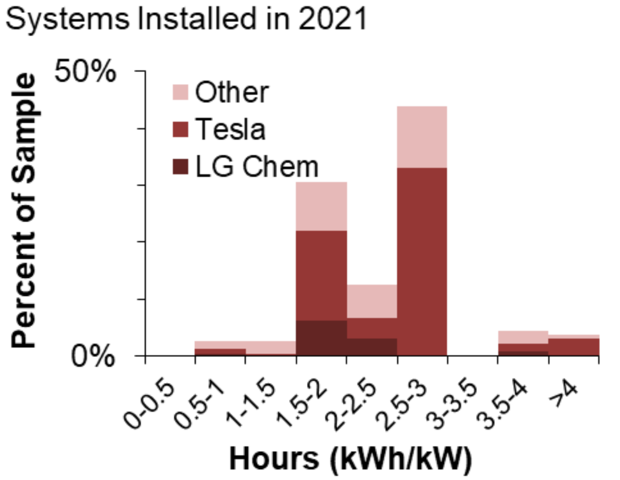
Storage Size Trends



kW Ratio: Storage to PV



Storage Duration



- Most paired non-residential systems installed in 2021 were relatively small, with PV and storage components both <20 kW; about 1/3rd were >100 kW
- Marks a shift: Paired applications in the non-residential market have been moving into progressively smaller applications in recent years; no longer the exclusive domain of large users with high demand charges
- The smallest class of non-residential systems typically have PV and batteries of roughly equal size (median kW ratio of 1.2), but with a long upper tail; larger systems typically have batteries sized at about half their respective PV size (median kW ratio of 0.5-0.6)
- As with residential, most non-residential systems have storage durations ranging from 1.5-3 hours, even with a somewhat more diverse product mix

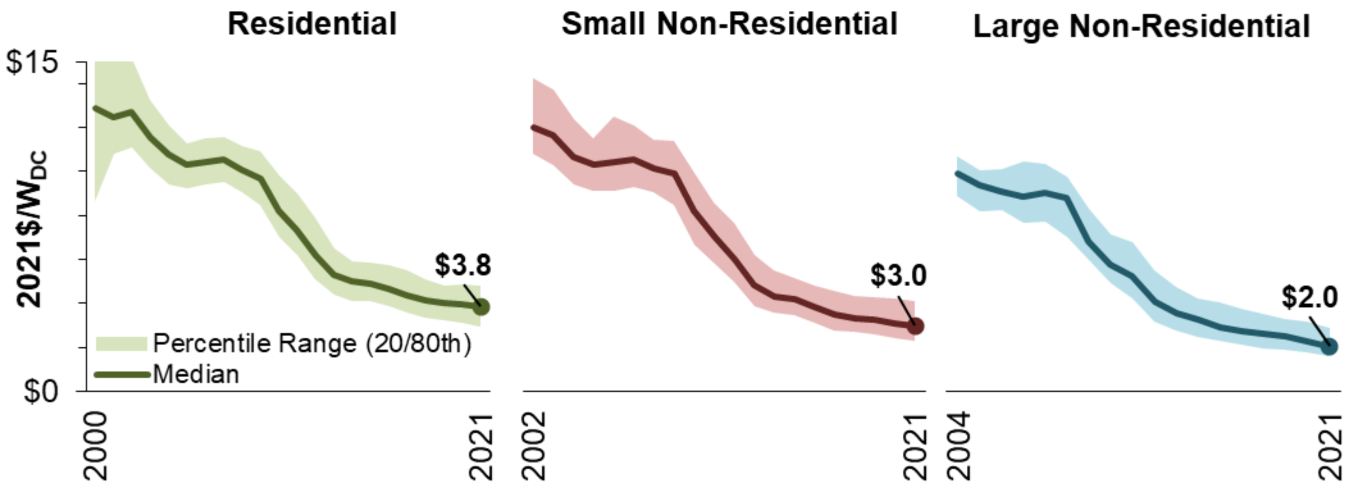
Median Installed Price Trends

A Few Notes on Installed-Price Data

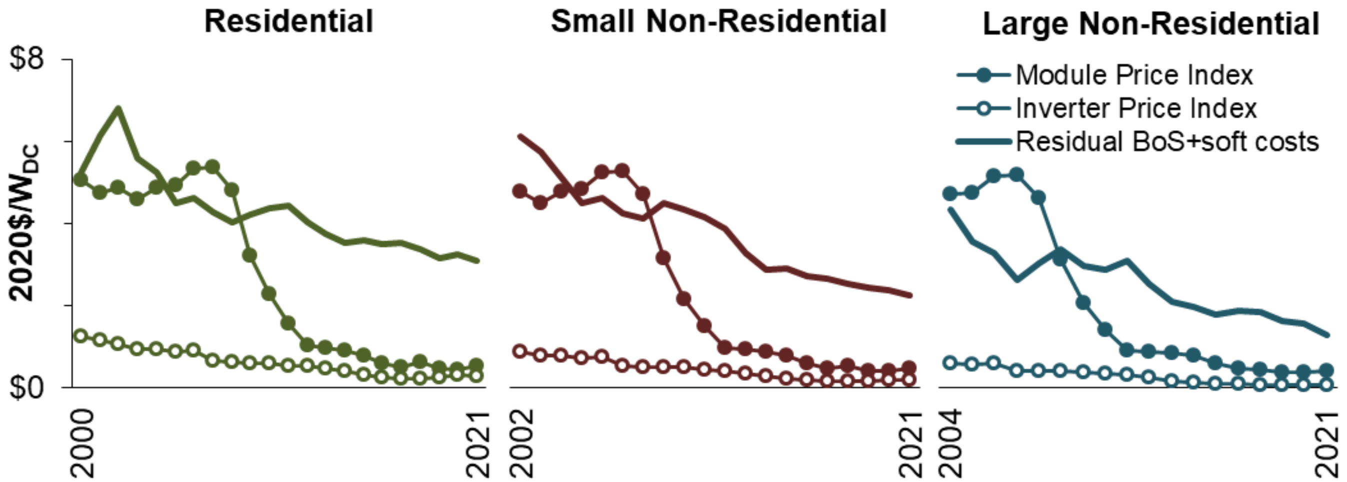
- Unless otherwise noted, results are based on host-owned, stand-alone PV systems (excludes TPO, systems paired with storage)
- Prices may include dealer fees for loan-financed systems
- Data are historical, based primarily on systems installed through the end of 2021, and may not be representative of systems installed more recently or current quotes for prospective projects
- Data are self-reported by PV installers or customers

National Median Prices and Component Costs over Time

National Installed Prices over Time



Underlying Trends in Component Costs



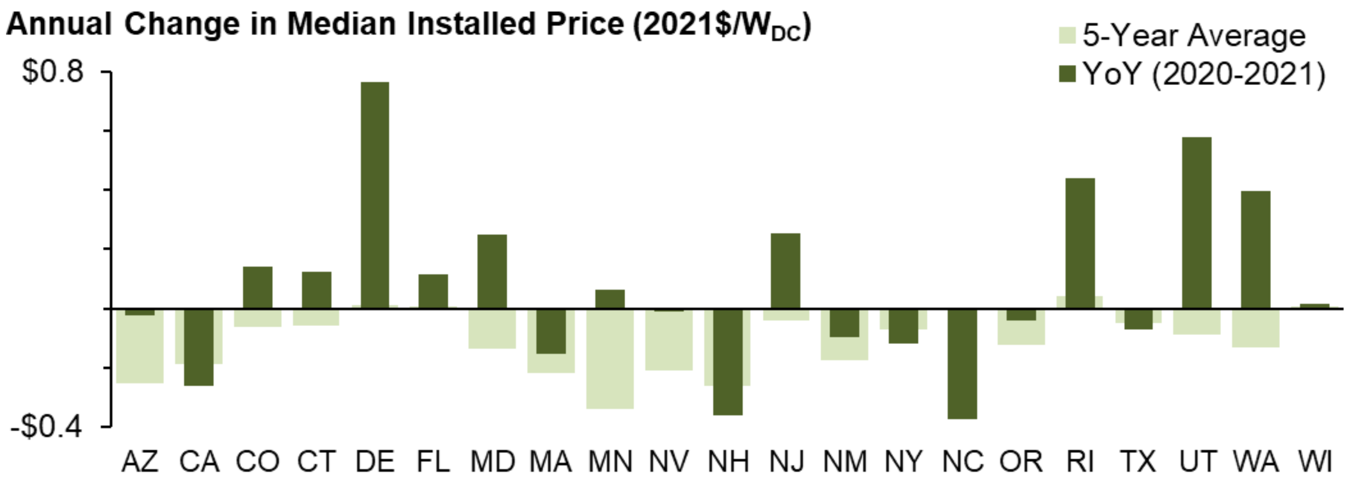
- Over the long-term, median installed prices have fallen by roughly $0.4/W per year, on average, but price declines have tapered off since 2013, after which price declines averaged $0.1-0.2/W across segments
- That tapering off is mostly a function of the underlying module-cost trajectory, but also reflects growing customer acquisition costs, loan fees, and other costs embedded in the “Residual BoS+soft costs” (bottom fig)
- Over the long-term, these residual BoS+soft costs have fallen by roughly $0.1-0.2/W per year, on average
- Over the last year of the analysis period (2020-2021), median U.S. prices fell by $0.1-0.2/W after adjusting for inflation across the three customer segments, maintaining the same trajectory since 2013
- The YoY price decline occurred despite a slight uptick in module prices in 2021 and supply chain constraints

BERKELEY LAB

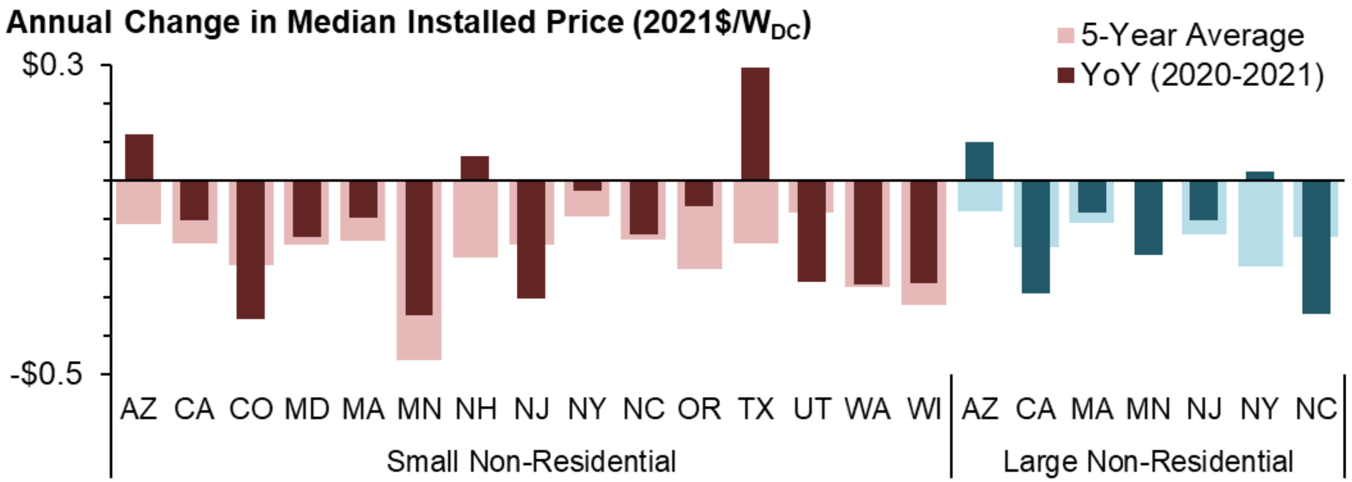
Notes: Summary statistics for any given year are shown only if at least 20 observations are available. The Module and Inverter Price Indices are based on data from SPV Market Research and Wood Mackenzie, with adjustments by Berkeley Lab in order to extend those indices back in time and to differentiate among customer segments. The Residual term is calculated as the median installed price for each customer segment minus the corresponding Module and Inverter Price Indices in the preceding year (to reflect some supply-chain lag).

State-Level Trends in Median Installed Prices

Residential Annual Change in Median Prices



Non-Residential Annual Change in Median Prices

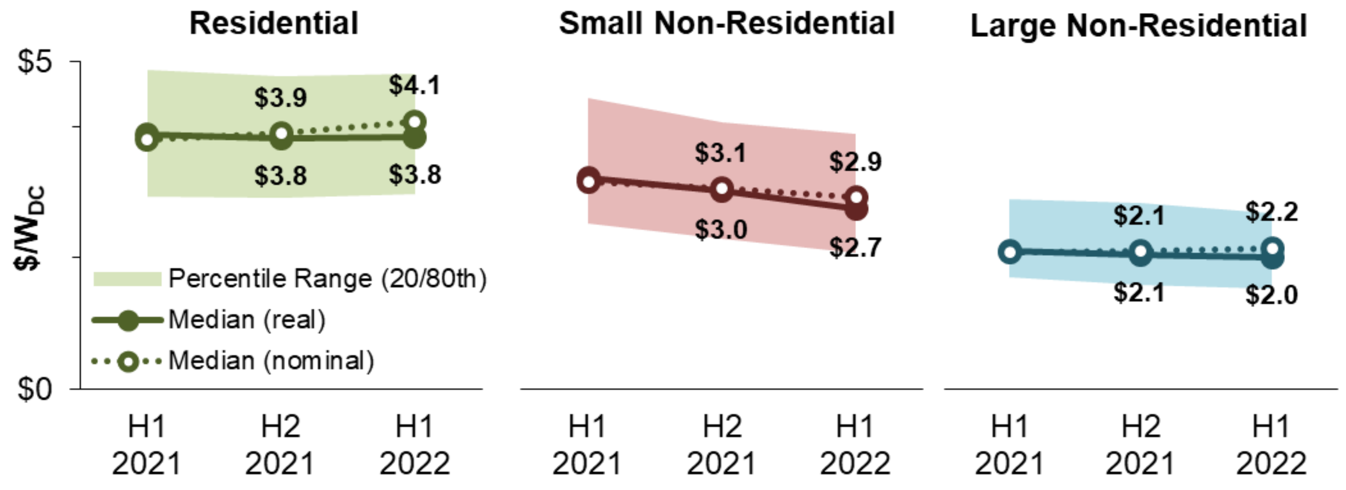


- National trends in median prices are driven heavily by CA, owing to its large share of the sample/market
- Year-over-year (YoY) pricing trends at the state-level can deviate from national trends, but can be fairly volatile (especially for states and sectors with small sample*)
- In the residential sector, median prices increased YoY in more than half of all states, in some cases significantly
- Trends over a 5-year timeframe are more uniform, with most states showing average annual declines of up to $0.2/W per year
- In the non-residential sector, almost all states saw some YoY decline in median prices; longer lead times can delay the effects of supply-chain constraints
- Over the past 5 years, median non-residential prices have fallen by $0.1-0.3/W per year in most states

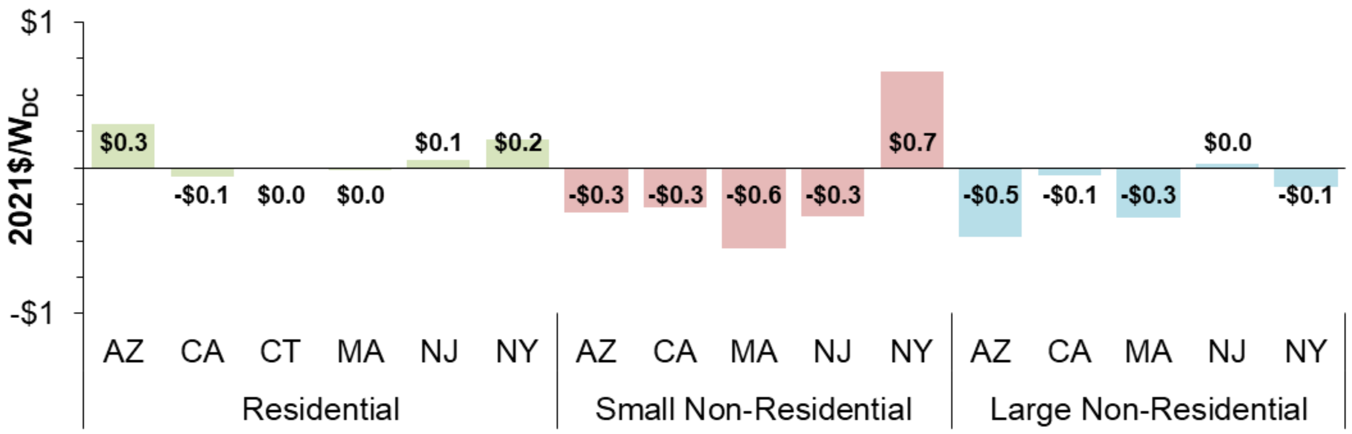
*Notes: Summary statistics for any given state are shown only if at least 20 observations are available in both the start-year and end-year of the comparison period. *Even with that limitation, the YoY changes in median prices for some states and sectors may simply reflect random variability in the underlying sample, rather than any fundamental shift.*

Installed Price Trends for the First Half (H1) of 2022

National Installed Prices (Real and Nominal)



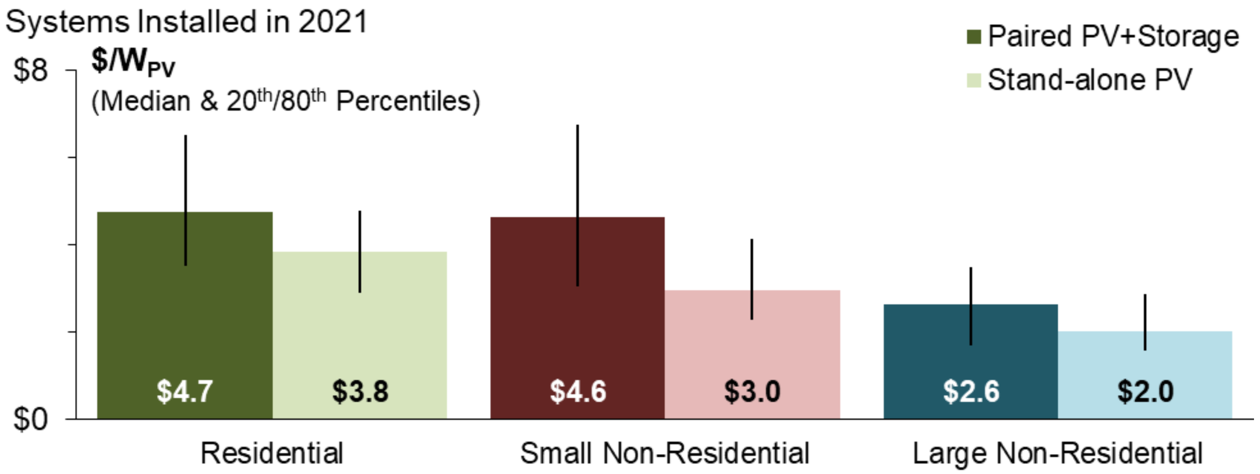
Change in Median Installed Prices: H2-2021 to H1-2022



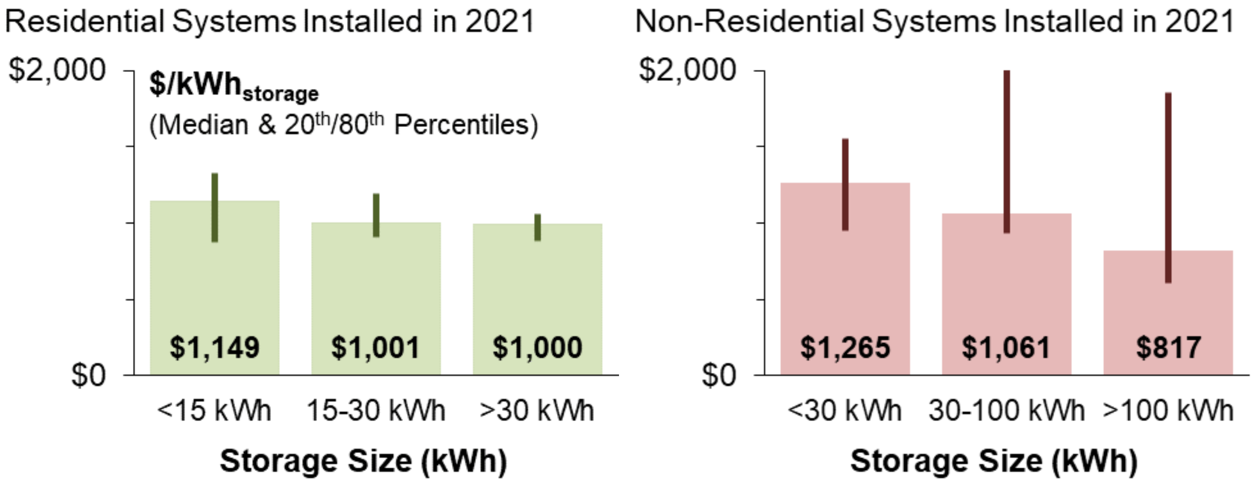
- Figure on the top includes both real and nominal prices
- Nominal prices rose slightly (by $0.1-0.2/W) for residential and large non-residential systems in H1 2022, but fell by $0.2/W for small non-residential systems
- In real (inflation-adjusted) dollars, national median prices remained essentially flat for residential systems while falling for both non-residential classes
- Supply chain constraints, widely acknowledged within the industry as putting upward pressure on prices, are partly absorbed within the inflation adjustment
- Among the subset of states in the bottom figure, trends in the residential sector are mixed, with half showing an increase in real prices in H1 2022
- State-level trends in the non-residential sector are more consistent directionally, with almost all showing continued real-price declines in H1 2022

Installed-Price Premium for Paired PV+Storage Systems

Installed Price Comparison: Standalone vs. Paired PV

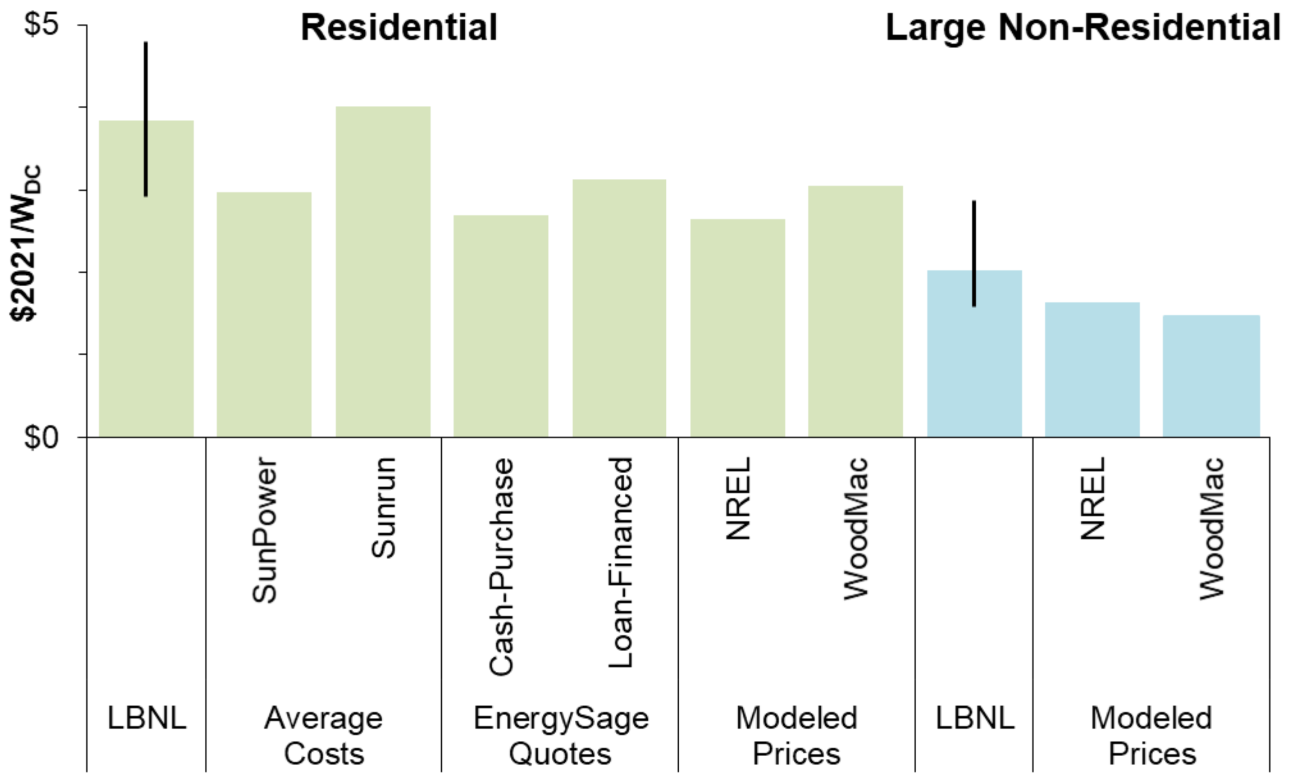


Reported Storage Costs from California's SGIP



- Though otherwise excluded from the trends described in this section, installed prices for paired PV+storage systems are consistently higher than for stand-alone PV
- Direct comparisons can be misleading, given confounding factors; the multi-variate regression analysis (described later) estimates a $1.9/W_{PV}$ storage premium for residential PV (for a 5 kW battery with 10-15 kWh of storage capacity)
- Given typical residential PV and storage sizes, this equates to an underlying incremental cost of roughly $1200/kWh_{storage}$
- In comparison, median costs for similarly sized residential storage systems funded through California's Self Generation Incentive Program (SGIP) were $1,149/kWh in 2021
- The SGIP data also point toward modest economies of scale with storage system sizing, especially for large non-residential systems (though the error bands are quite wide)

Comparison of PV Cost and Pricing Benchmarks

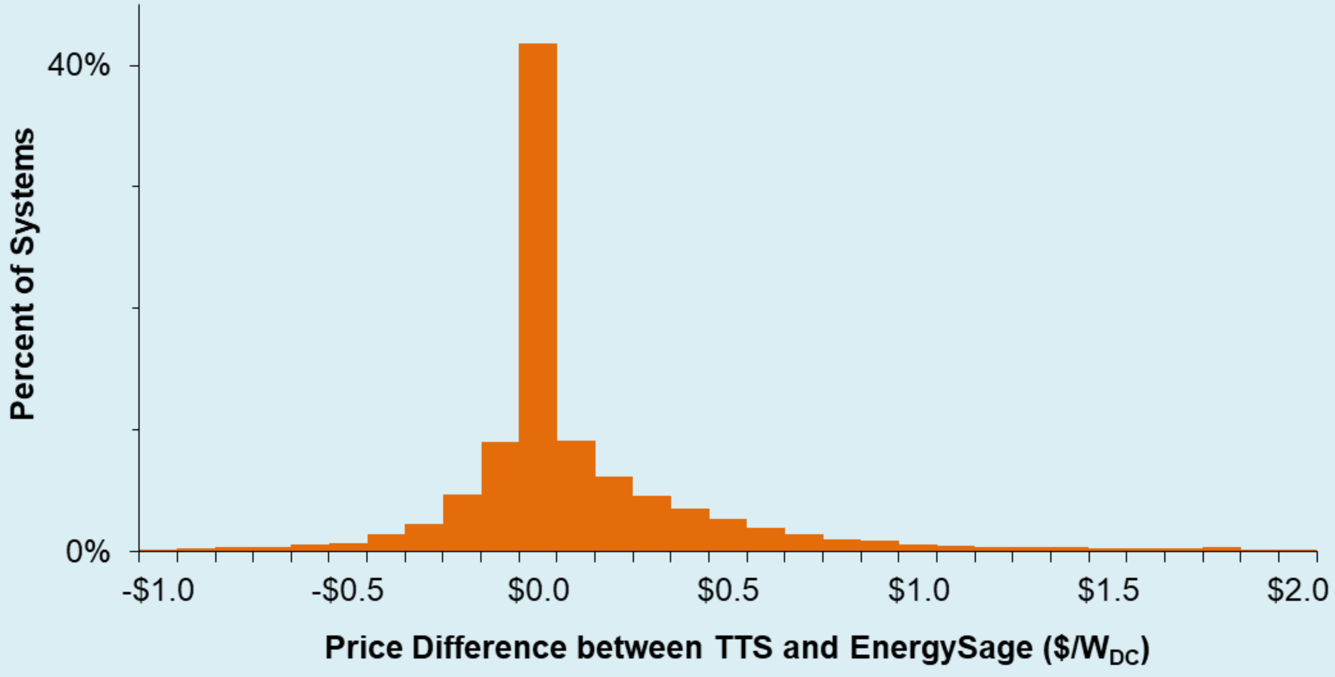


Notes: ***LBNL*** *data are the median and 20th and 80th percentile values among projects installed in 2021.* ***SunPower and Sunrun*** *data are based on the companies' quarterly shareholder reports in 2021 (courtesy of D. Feldman, NREL) and are equal to the sum of reported average installation, sales, and general & administrative costs, averaged across the four quarters.* ***EnergySage*** *data are the median price quotes issued in 2021, for cash-purchase standalone PV systems, as calculated by Berkeley Lab from data provided by EnergySage.* ***NREL*** *data represent modeled turnkey costs in Q1 2021 for a 7.2 kW residential system and a 500 kW ground-mounted commercial system (Ramasamy et al. 2021).* ***WoodMac*** *data are from the Solar Market Insight 2021 Year-in-Review, and are based on modeled turnkey prices, averaged across quarters.*

- A variety of other PV cost and pricing benchmarks exist, based on differing methods and data sources, and serving different purposes
- On the residential side, national median installed prices from Tracking the Sun (TTS) are similar to average costs reported by SunRun, but other benchmarks align more closely with the 20th percentile values
- On the non-residential side, fewer benchmarks are available and are limited to large systems, both of which align more closely with 20th percentile levels from TTS
- In general, divergence across benchmarks can reflect differences in factors such as price vs. cost, mark-ups, system design, installer characteristics, scope of costs included, and other factors
- Dealer fees for loan-financed systems likely add 10-25% to the reported price for some subset of TTS systems

Comparison to Matched EnergySage Quotes

Comparison of Prices using either ES Cash or Loan Price, whichever is closer to TTS
Stand-alone residential PV systems (all years)

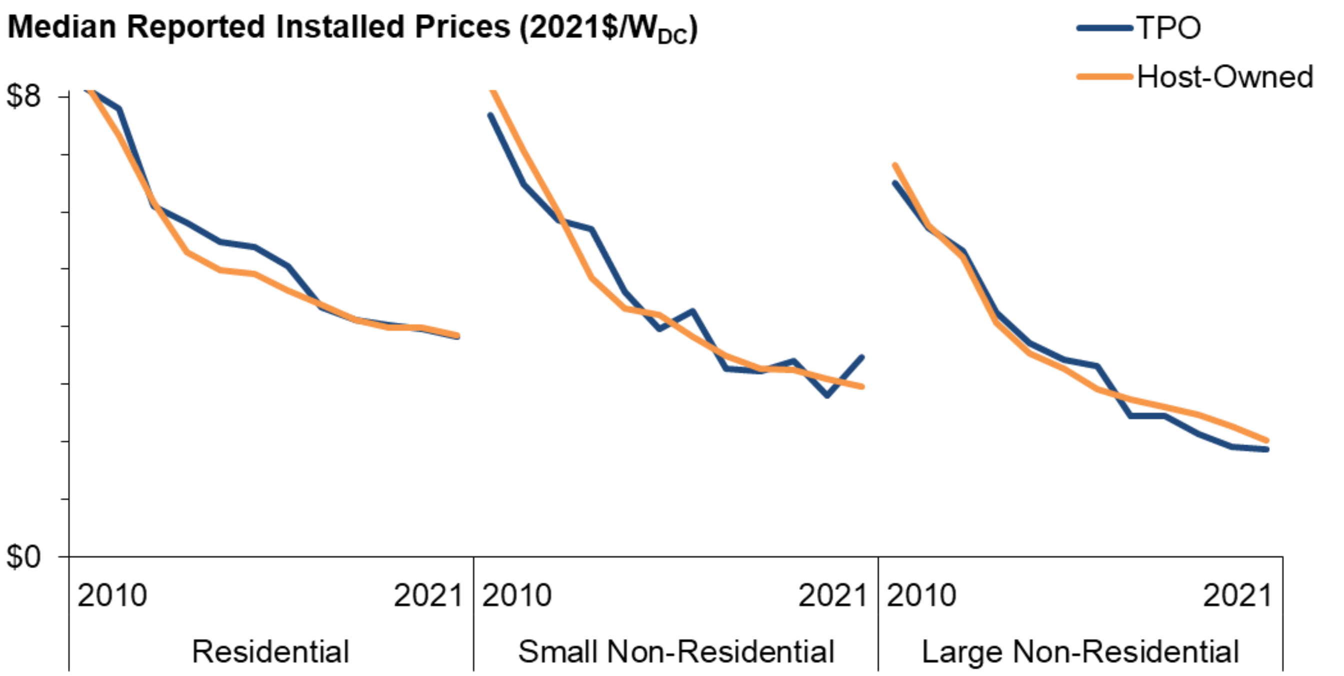


- As the previous slide shows, price quotes issued over EnergySage are generally lower than the national median installed price from Tracking the Sun
- For a subset of EnergySage price quotes culminating in an installed system, we can identify the corresponding record from the Tracking the Sun dataset, and compare prices between the two data sources
- The distribution indicates generally close agreement (a median of $0.0/W), confirming that the differences shown previously are not driven by underlying data reporting discrepancies—but, more likely, are due to the effects of quote platforms on price competition
- Where differences do exist among this matched set, they are generally small (two-thirds are within -0.2 to +0.2/W), and can go in either direction, though they do skew to the right

Installed Prices Reported for TPO Systems

- Depending on the particular project or firm, installed prices reported for TPO systems may represent:
  - An appraised value or fair-market value construct (as often used as the basis for federal tax credits)
  - An actual transaction price between the third-party financier and an independent installer, which may or may not reflect all soft costs
- As a precautionary step, pricing data reported for TPO systems are excluded from the installed-price analysis, on the grounds that they cannot be meaningfully compared to prices reported for host-owned systems
- Nevertheless, the data show that prices for TPO systems generally correspond quite closely to those for host-owned systems

Installed Prices for TPO vs. Host-Owned Systems

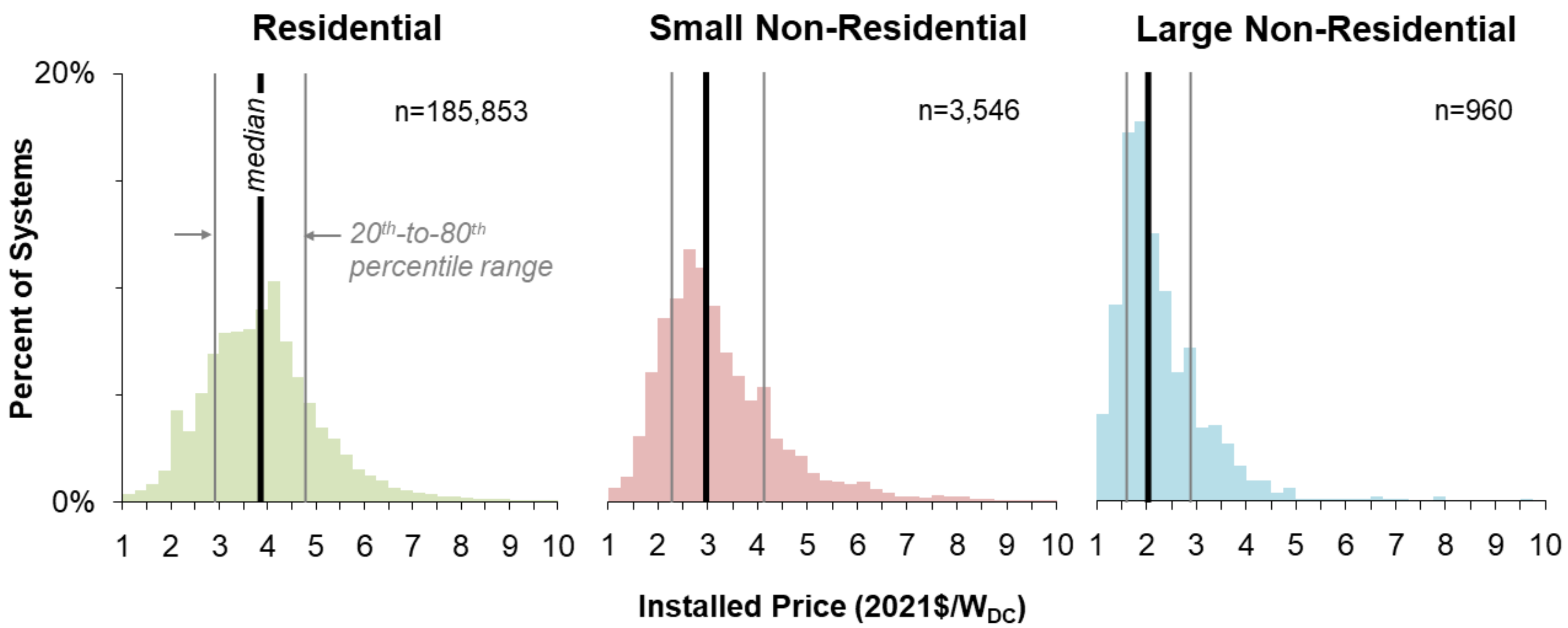


Note: TPO systems not otherwise included in installed-price analysis; figure above for reference only

Variability in Installed Prices

Installed-Price Variation Across Systems

Installed-Price Distribution for Stand-Alone PV Systems Installed in 2021



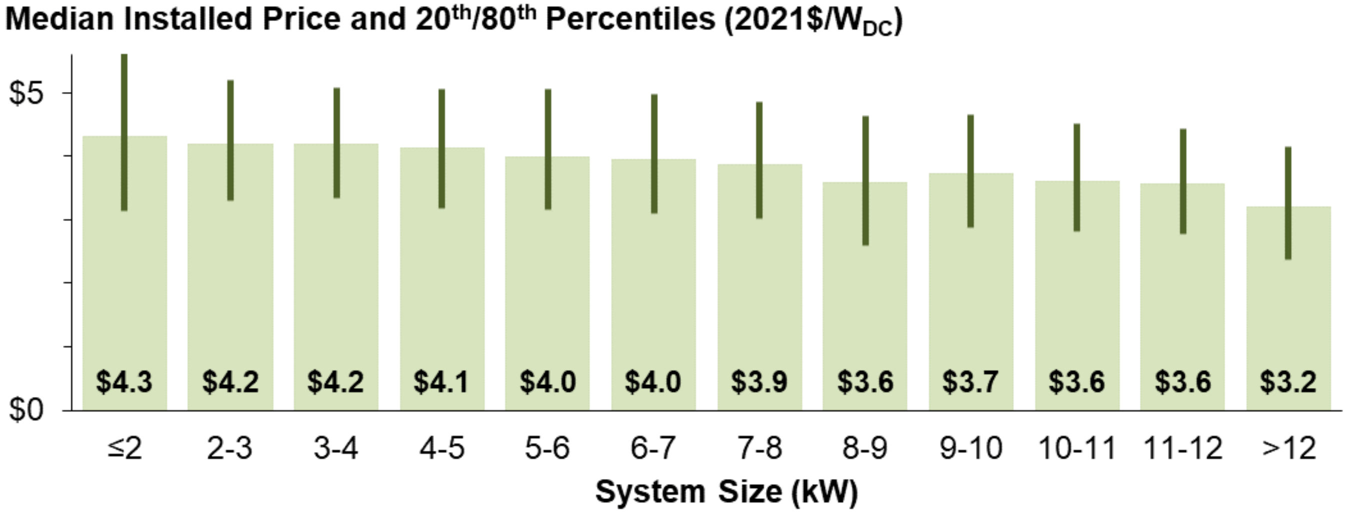
20th to 80th Percentile Bands for Systems Installed in 2021

- \$2.9/W - \$4.8/W (residential)
- \$2.3/W - \$4.1/W (small non-residential)
- \$1.6/W - \$2.9/W (large non-residential)

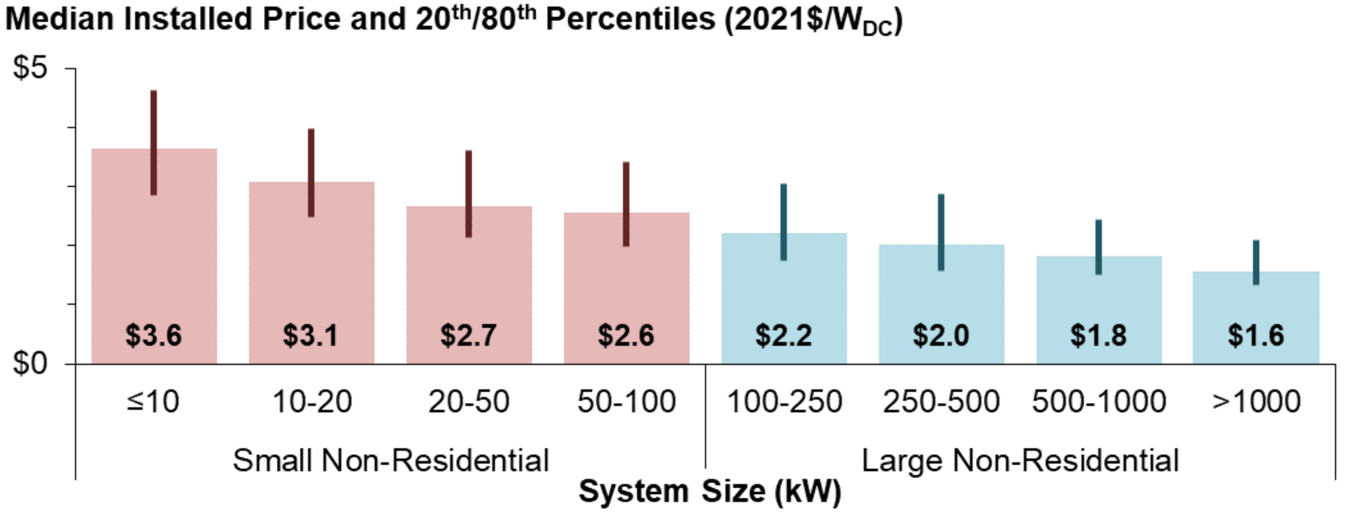
- Wide pricing variability persists within each customer segment
- Reflects underlying differences in:
  - Project characteristics
  - Installer attributes
  - Local market, policy, and regulatory environment
- We explore a subset of pricing drivers in the following slides, through a combination of ***descriptive analysis*** and a multi-variate ***regression model***
  - A variety of other studies have also investigated pricing drivers, often leveraging TTS data

Economies of Scale with PV System Size

Residential Systems Installed in 2021



Non-Residential Systems Installed in 2021

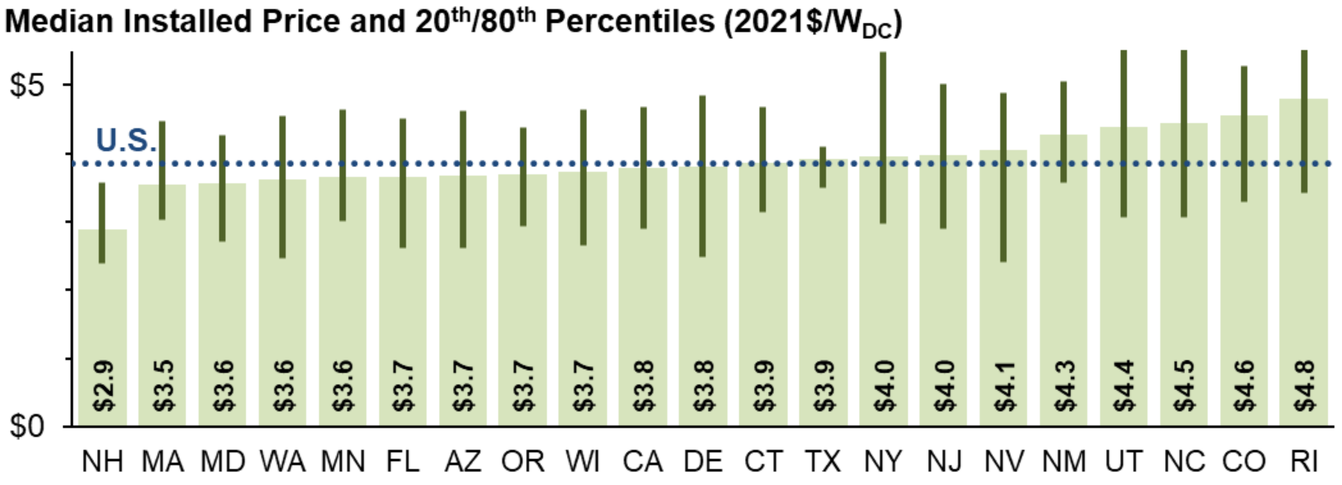


- Economies of scale arise because of the many fixed costs (e.g., permitting, customer acquisition, financing, etc.)
- Among residential systems installed in 2021, median prices were $1.1/W lower for the largest residential systems compared to the smallest
- This price differential coincides exactly with what the later regression model implies for the same size range
- Among non-residential systems, which span an even wider size range, median prices were $2.0/W lower for systems >1,000 kW, compared to the smallest non-residential systems ≤10 kW

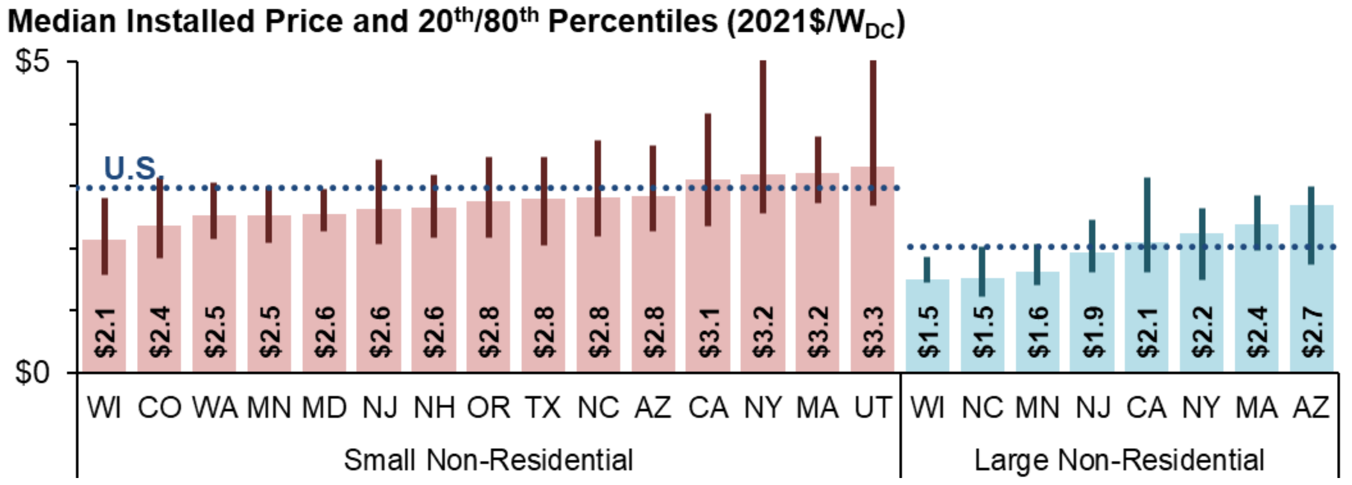
BERKELEY LAB

State-Level Differences in Installed Prices

Residential Systems Installed in 2021



Non-Residential Systems Installed in 2021

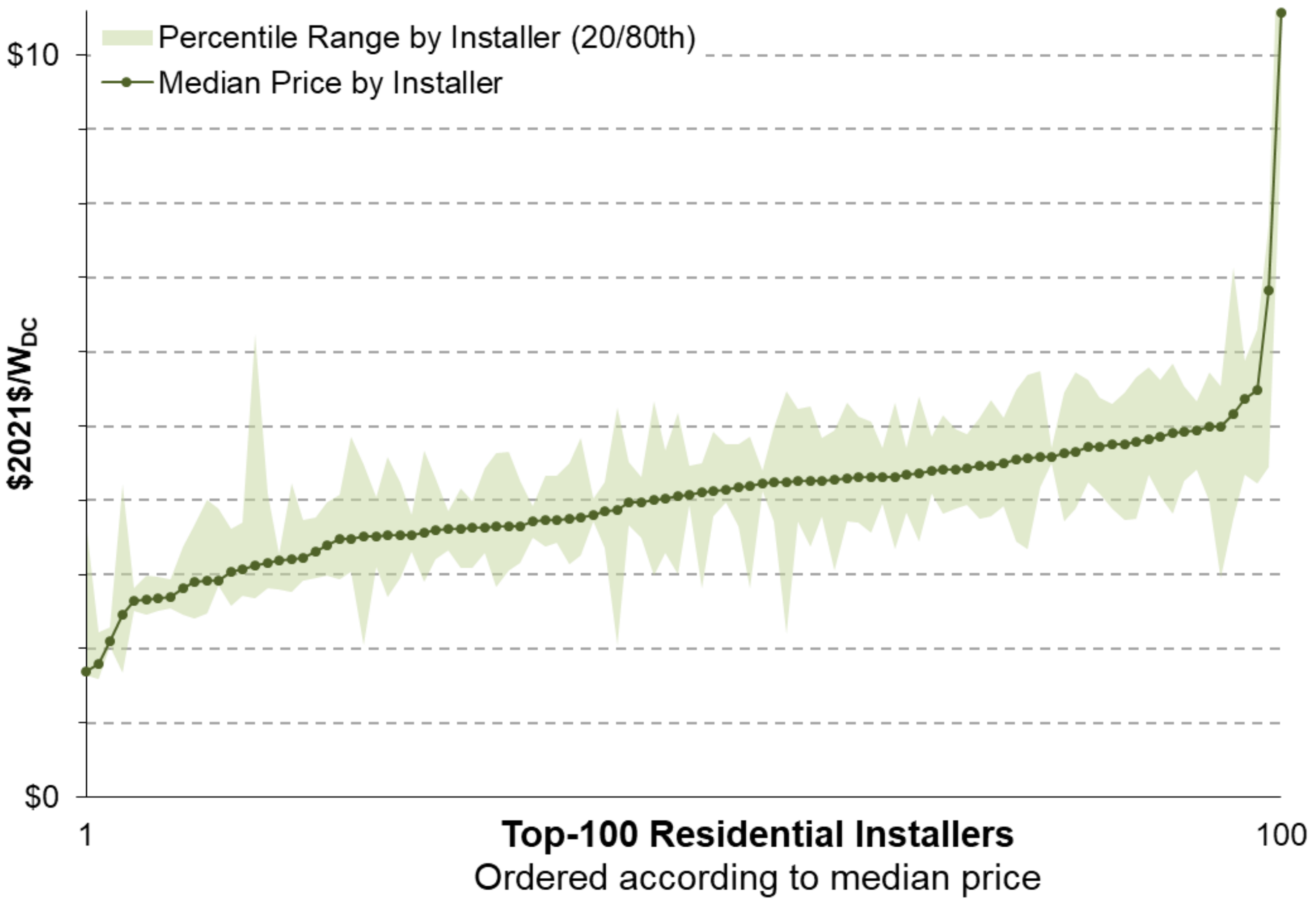


- Median prices vary substantially across states within each of the customer segments
- Differences are especially pronounced in the residential sector, where median prices varied by almost $2/W across the 21 states shown (driven by particularly low prices in NH)
- Cross-state pricing differences can reflect idiosyncratic features of particular states (e.g., a single large installer with anomalous prices) as well as more-fundamental differences in market and policy conditions
- The later regression analysis controls for some of those differences (e.g., market size, installer concentration, population density, income levels), though still shows substantial cross-state differences

Notes: Summary statistics for any given state are shown only if at least 20 observations are available.

Installer-Level Pricing Differences

Top-100 Host-Owned Residential Installers in 2021

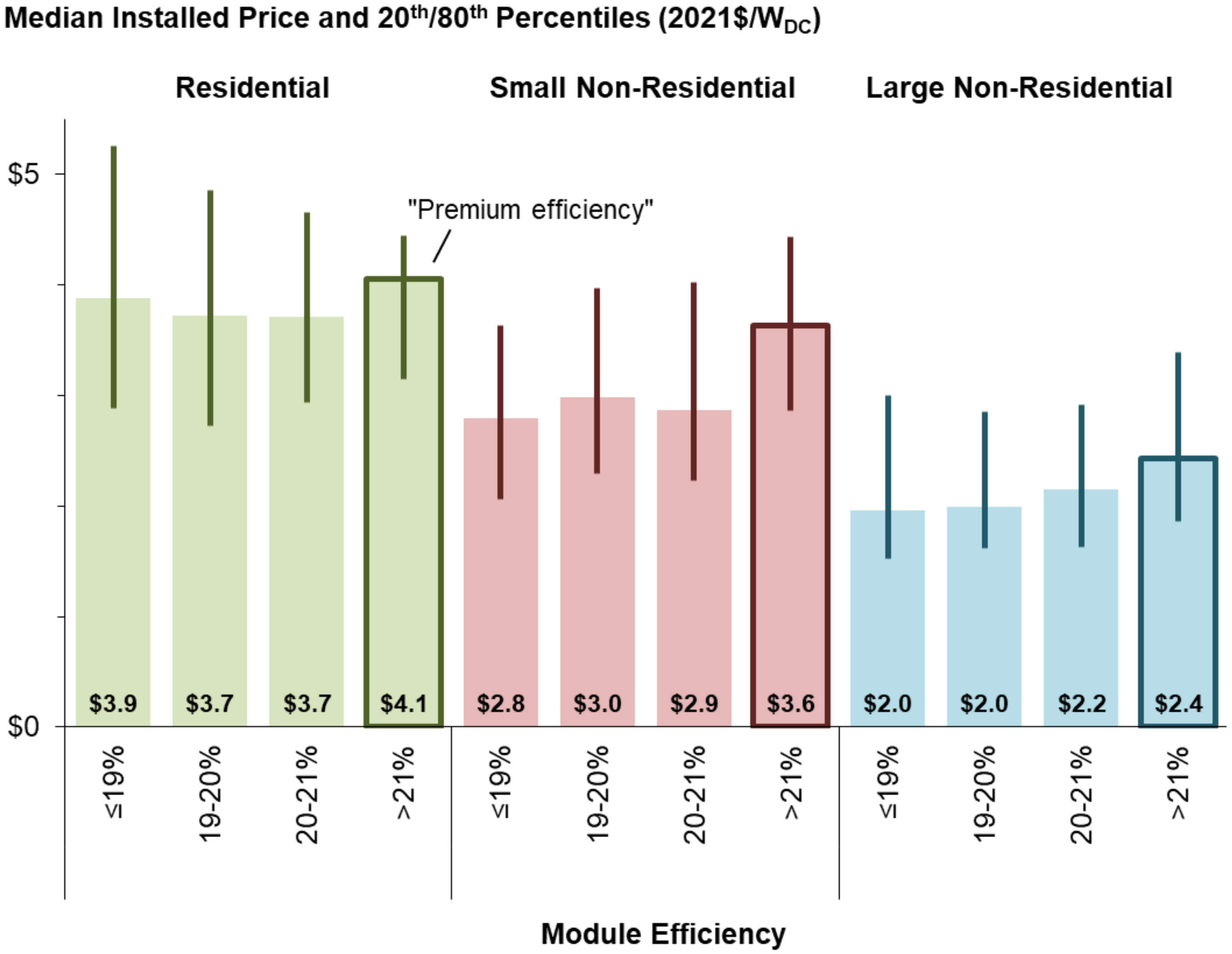


Notes: Each dot represents the median installed price of an individual installer, ranked from lowest to highest, while the shaded band shows the 20th to 80th percentile range for that installer.

- Ignoring the tails, median prices across the top-100 residential installers in 2021 ranged from $2.5/W to $5.0/W, with more than half registering median prices above $4.0/W
- Firm-level experience is one potential reason for pricing differences across installers; the later regression analysis implies roughly a $0.14/W range in prices between firms at the 20th and 80th percentile levels of experience
- Other firm-level characteristics may also contribute to the variation shown here (e.g., equipment preferences and relationships, business models, loan partners), as well differences in how each installer reports prices
- In addition, some apparent firm-level pricing differences may also just reflect features of the local markets in which different firms operate

Installed-Price Differences by Module Efficiency

Installed Prices by Module Efficiency for 2021 Systems

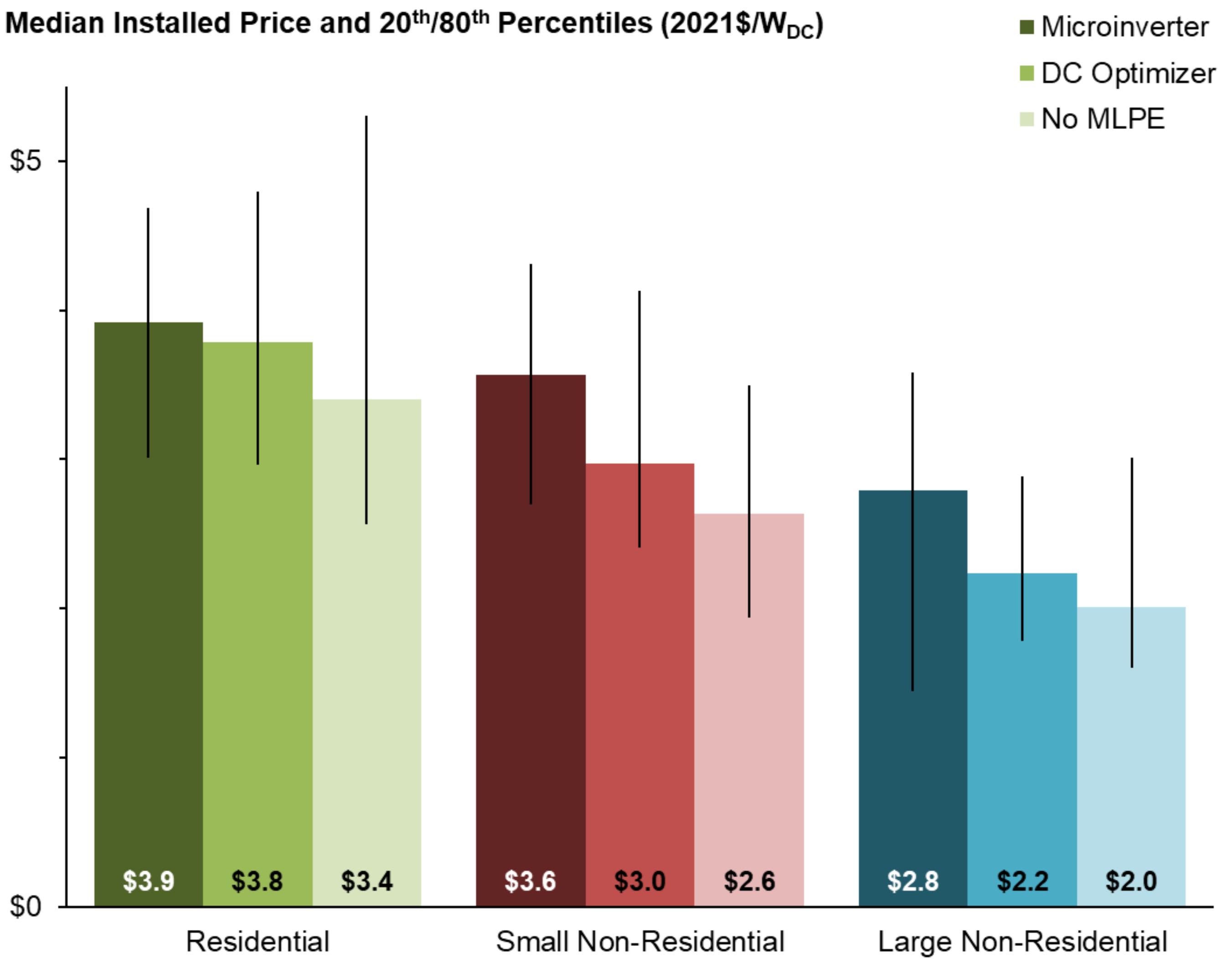


- Higher efficiency modules can sell at a premium, but may allow for savings on BoS costs, potentially offsetting the higher module price
- The trends are somewhat irregular, but in general, systems with the “premium efficiency” (>21%) modules tend to have higher prices
- These descriptive trends are consistent with the regression model, which shows that residential systems with module efficiencies >21% cost roughly $0.1/W more, on average, after controlling for other factors

BERKELEY LAB

Installed-Price Differences by Inverter Technology

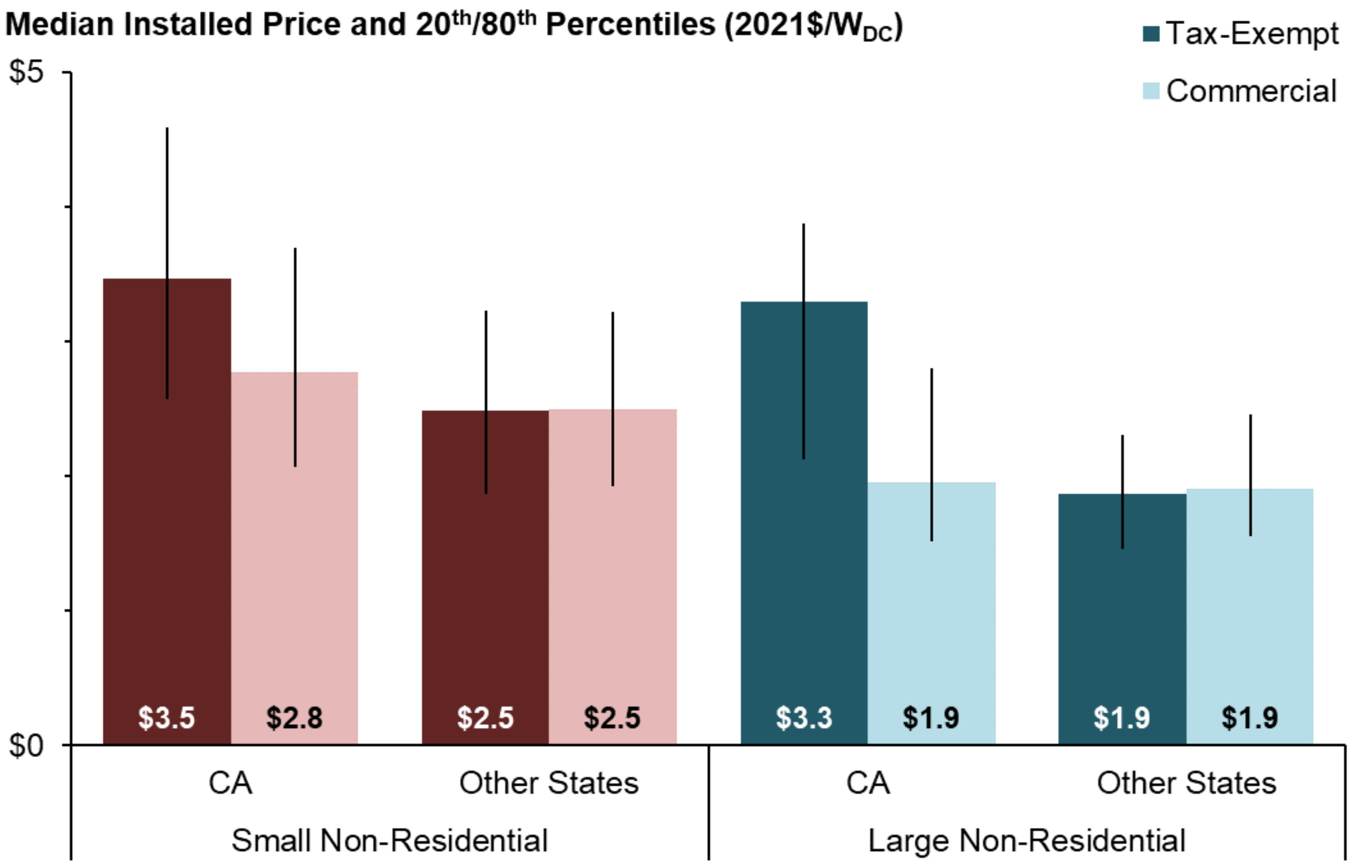
Installed Prices for 2021 Systems with and without MLPEs



- Installed-price differences by inverter technology type show a consistent pattern across all three customer segments, with the highest price for systems with microinverters, lower for those with DC optimizers, and lowest for those without any MLPEs
- For example, among residential systems, median prices are $0.5/W higher for systems with microinverters and $0.4/W higher for systems with DC optimizers, compared to those with neither
- Regression analysis (presented in the next section) shows similar values, though the implied premium is slightly higher for residential systems with DC optimizers than for those with microinverters ($0.4/W)

Installed-Price Differences by Non-Residential Customer Type

Tax-Exempt vs. Commercial Non-Res. Systems in 2021



Notes: Summary statistics are based on a somewhat narrow subset of data providers who provide customer segmentation details for non-residential systems.

- In California, installed prices are higher for tax-exempt site hosts (schools, government, non-profits), compared to prices for commercial site hosts
- Differences are especially pronounced among large non-residential systems
- But no apparent difference exists across these customer types in other states (though for many states, detailed data on business type are unavailable)
- In general, higher prices for systems at tax-exempt customer sites could reflect a number of possible characteristics of tax-exempt customers, for example:
  - requirements for domestically manufactured components or prevailing wage/union labor
  - prevalence of shade or parking structures
  - lower borrowing costs

BERKELEY LAB

Multi-Variate Regression Analysis of Residential Installed Prices

Econometric Model Overview and Results

- Multi-variate linear-regression model used to explain variation in ***residential*** installed prices in 2021

$$p = \alpha + system\beta_1 + market\beta_2 + installer\beta_3 + S + Q + \varepsilon_i$$

- Dependent variable (*p*) is installed price (in $/W); independent variables include system, market, and installer-level factors, as well as state (*S*) and quarterly (*Q*) fixed-effects; many of the system-related variables are binary
- Complements the descriptive analysis by showing the effects of individual pricing drivers while controlling for other confounding factors
- The coefficients in the table represent the average change in PV installed price ($/W) given a unit change in each of the variables listed (or, for binary variables, if that variable is true)
- Many of these individual results are referenced earlier in the descriptive analysis; others are discussed on the next slide

	Variable	Coefficient
System	System size (kW)	-0.19*
	System size squared	0.01*
	Premium module (binary)	0.11*
	Microinverter (binary)	0.47
	DC optimizer (binary)	0.52*
	New construction (binary)	-0.38*
	Ground-mounting (binary)	0.38*
	Battery storage (binary)	1.89*
Market	HHI (market concentration)	-0.02
	HHI squared	-0.43
	Market size (x1,000)	-0.03*
	Population density (x1,000)	0.05*
	Median zip-code income (x10,000)	0.00*
Installer	experience (x1,000)	-0.01*
	N	158,651
	R^2	0.16

* p<0.05

Notes: *For further details on the model specification and variable definitions, please Barbose et al. (2019).*

BERKELEY LAB

Additional Insights from Residential Regression Results

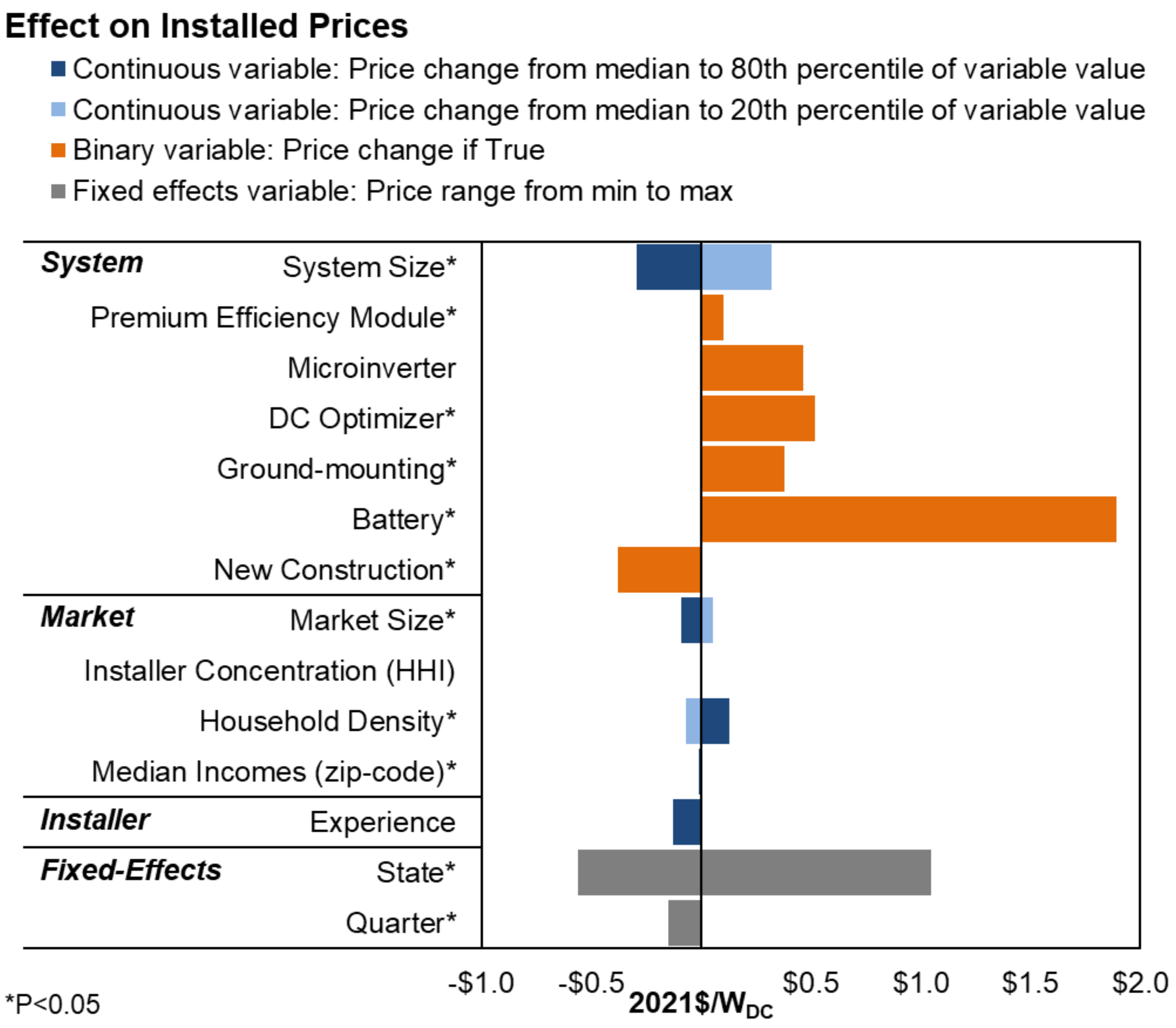
- **New Construction:** The model suggests that prices are $0.4/W lower for systems installed during new home construction, consistent with previous research.[a]
- **Ground-Mounting:** Though relatively uncommon in the residential sector, the model indicates that ground-mounting adds about $0.4/W to the installed price.
- **Market structure:** The coefficients are not statistically significant, but are negative, suggesting that prices are generally lower in more-concentrated markets. Other studies have shown that this may be true up to a point, but that prices are generally higher in very concentrated markets.[b]
- **Market size:** The negative coefficient on market size suggests that prices are generally lower in markets with more cumulative PV installations.
- **Population Density:** The positive coefficient on population density suggests that prices are generally higher in more densely-populated areas (e.g., in cities rather than rural areas).
- **Median Zip-Code Income:** The coefficient on median income is zero, suggesting that prices are independent of income levels. Note that previous studies have found different results.[c]

Additional Resources
For further reading on analyses of PV prices related to these findings, see: a) “Solar Economies of Scope through the Intersection of Four Industries.” 2018. NREL. b) “Non-monotonic effects of market concentration on prices for residential solar photovoltaics in the United States.” 2020. Energy Economics; c) “Deconstructing Solar Photovoltaic Pricing.” 2016. The Energy Journal.

Sensitivity of Installed Prices to Modeled Drivers

This figure provides a sense of scale for the relative contribution of each pricing driver to overall pricing variability

- Of the system-level pricing drivers, battery storage has by far the biggest effect ($1.9/W), though microinverters, DC-optimizers, ground-mounting, and new construction all have relatively large effects ($0.4-0.5/W) as well
- Effects associated with the various market- and installer-related drivers are all relatively small (less than $0.2/W), but in general are directionally intuitive
- Of particular note is the wide range across the state fixed-effects variables ($1.6/W), suggesting the presence of strong state-level pricing drivers beyond those explicitly captured in the model (e.g., cost-of-living, retail rates, incentives, solar insolation, permitting processes)

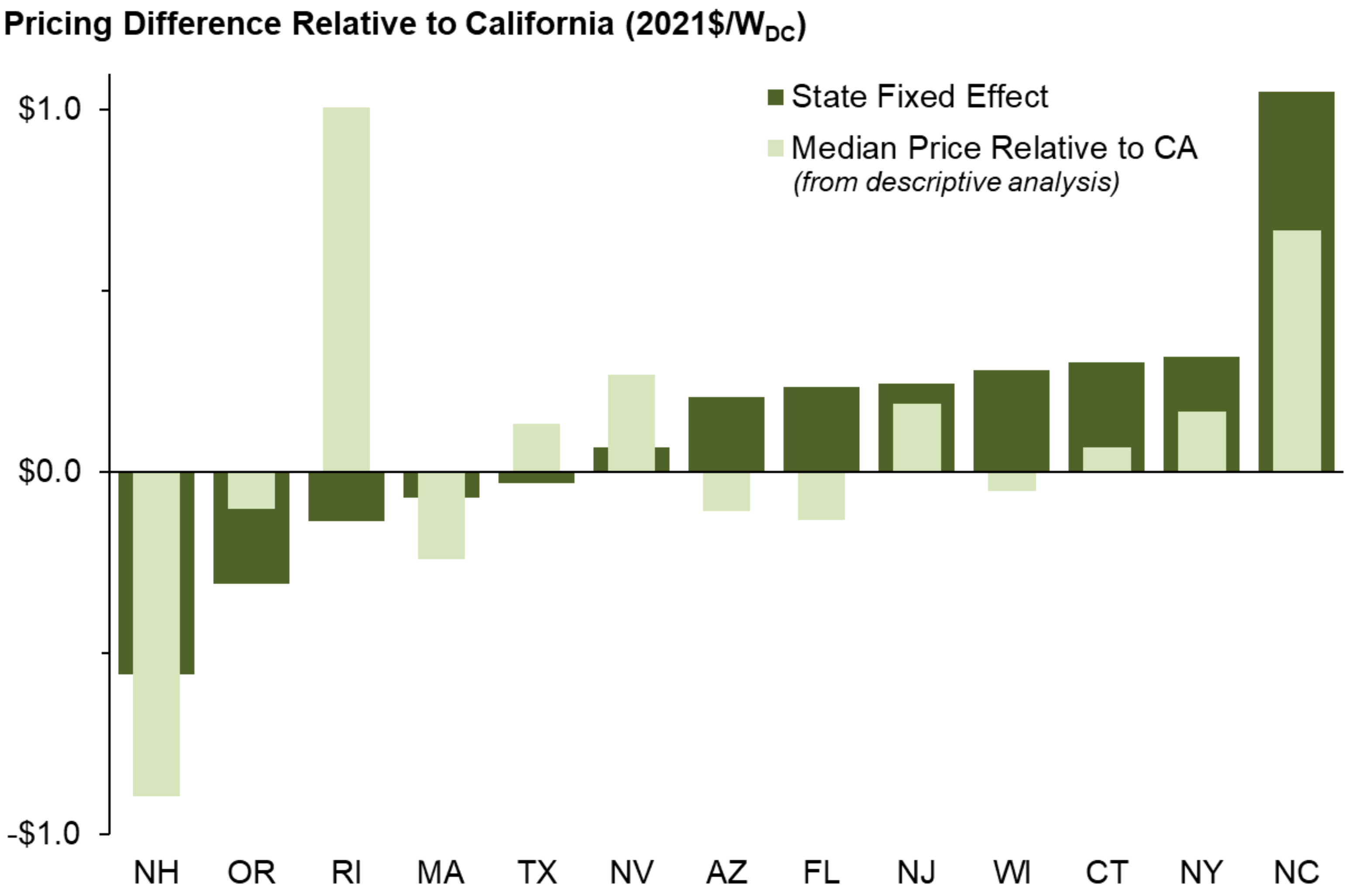


Notes: For continuous variables, the figure shows the effect on system prices associated with moving from the median to the 20th percentile and from the median to the 80th percentile values of each variable. For binary variables, the figure shows the effect if that binary variable is true, and for fixed effects variables, the figure shows the range between the minimum and maximum effect of the variables in each set.

State Fixed-Effects

Residual Pricing Differences After Controlling for Other Factors

State Fixed Effects Compared to Difference in Median Prices



- State fixed effects represent the difference in average residential price, relative to California, after controlling for other variables
- Fixed effects may be larger or smaller than the simple difference in state median prices, and may even point in different directions
- RI is a dramatic case, where the fixed effects are far smaller than the difference in medians, indicating that much of the apparent price difference is related to modeled variables
- Across most of the states shown, fixed effects vary within a band of roughly ±$0.3/W, which reflects additional unexplained differences across states (e.g., due to unobserved variables and/or idiosyncrasies of the data)

BERKELEY LAB

For more information

Download the report, data, and other related materials:
http://trackingthesun.lbl.gov

Join our mailing list to receive notice of future publications:
http://emp.lbl.gov/reports/re

Follow us on Twitter @BerkeleyLabEMP

Contact the corresponding authors:

Galen Barbose (GLBarbose@lbl.gov, 510-495-2593)
Naïm Darghouth (NDarghouth@lbl.gov, 510-486-4570)

BERKELEY LAB

This work was funded by the U.S. Department of Energy Solar Energy Technologies Office, under Contract No. DE-AC02-05CH11231.

Appendix

List of Entities Contributing Data

AR State Energy Office
AZ Ajo Improvement Company
AZ Arizona Public Service*
AZ Duncan Valley Electric Cooperative
AZ Mohave Electric Cooperative
AZ Morenci Water and Electric
AZ Navopache Electric Cooperative
AZ Salt River Project*
AZ Sulfur Springs Valley Electric Cooperative
AZ Trico Electric Cooperative
AZ Tucson Electric Power*
AZ UniSource Energy Services*
CA Center for Sustainable Energy (Bear Valley Electric)
CA Center for Sustainable Energy (PacifiCorp)
CA City of Palo Alto Utilities
CA Energy Commission*
CA Imperial Irrigation District
CA Los Angeles Department of Water & Power
CA Public Utilities Commission*
CA Sacramento Municipal Utility District*
CO Xcel Energy/Public Service Company of Colorado*
CT Green Bank*
CT Public Utilities Regulatory Authority*
DC Public Service Commission*
DE Dept. of Natural Resources and Env. Control*

FL Energy & Climate Commission
FL Gainesville Regional Utilities*
FL Orlando Utilities Commission*
HI County of Honolulu (via Ohm Analytics)*
IL Dept. of Commerce & Economic Opportunity
IL Power Agency*
MA DOER*
MA Clean Energy Center*
MD Energy Administration*
ME Efficiency Maine
MN Department of Commerce
MN Xcel Energy/Northern States Power*
NC Sustainable Energy Association*
NH Public Utilities Commission*
NJ Board of Public Utilities*
NM Energy, Minerals & Natural Resources Dept.*
NM Public Service Company of New Mexico*
NM Xcel Energy*
NV NV Energy*
NY State Energy Research and Development Authority*
OH Public Utilities Commission*
OR Energy Trust of Oregon*
OR Department of Energy*
OR PacifiCorp
PA Dept. of Community and Economic Development

PA Department of Environmental Protection
PA Sustainable Development Fund
RI National Grid*
RI Commerce Corporation*
TX Austin Energy*
TX CenterPoint*
TX CPS Energy*
TX Frontier Associates*
TX Oncor*
UT Office of Energy Development*
VA Dept. of Mines, Minerals and Energy
VT Energy Action Network
VT Energy Investment Corporation
WA Puget Sound Energy*
WA Washington State University
WI Focus on Energy*

**denotes active data providers*

BERKELEY LAB