Environmental Energy Technologies Division Lawrence Berkeley National Laboratory

Tracking the Sun VI

An Historical Summary of the Installed Price of Photovoltaics in the United States from 1998 to 2012

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— Report Summary —
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Project overview

Objective: Using project-level data, describe and analyze trends in the installed price of grid-connected PV systems in the United States

- Total installed price over time
  - Decomposed into module and non-module costs
  - Relationship to changes in PV incentive levels over time
- Comparisons to other major international PV markets
- Differences in installed price by system size and across states
- Differences in installed price by customer type, application, and technology
  - customer-owned vs. third party-owned systems
  - micro-inverter vs. central inverter
  - module efficiency level
  - Chinese vs. non-Chinese PV modules
  - residential vs. commercial vs. tax-exempt
  - residential new construction vs. residential retrofit
  - building-integrated vs. rack-mounted
  - rooftop vs. ground-mounted
  - tracking vs. fixed-tilt

- Each of the listed items is covered for **residential and commercial PV**
- A smaller set of trends is presented for **utility-scale PV**, given limitations of data and sample size

Outline of presentation

- **Data Summary**
- Installed Price Trends: Residential and Commercial PV
- Installed Price Trends: Utility-Scale PV
- Conclusions and Policy Implications

Terminology and data sources

Key Terminology

- ***Installed price:*** the purchase price paid to the installer/integrator, prior to receipt of incentives, tax credits, etc.
- ***Residential and Commercial PV:*** Roof-mounted systems and ground-mounted systems <2 MW
- ***Utility-Scale PV:*** Ground-mounted systems ≥2 MW

Sources for Installed Price Data

- ***Residential & Commercial PV:*** state and utility PV incentive programs (47 programs in total), supplemented with data from other public sources
- ***Utility-Scale PV:*** FERC Form 1 filings, the U.S. Treasury Department's Section 1603 Grant Program database, SEC filings, company presentations, and trade press articles

Methodological details

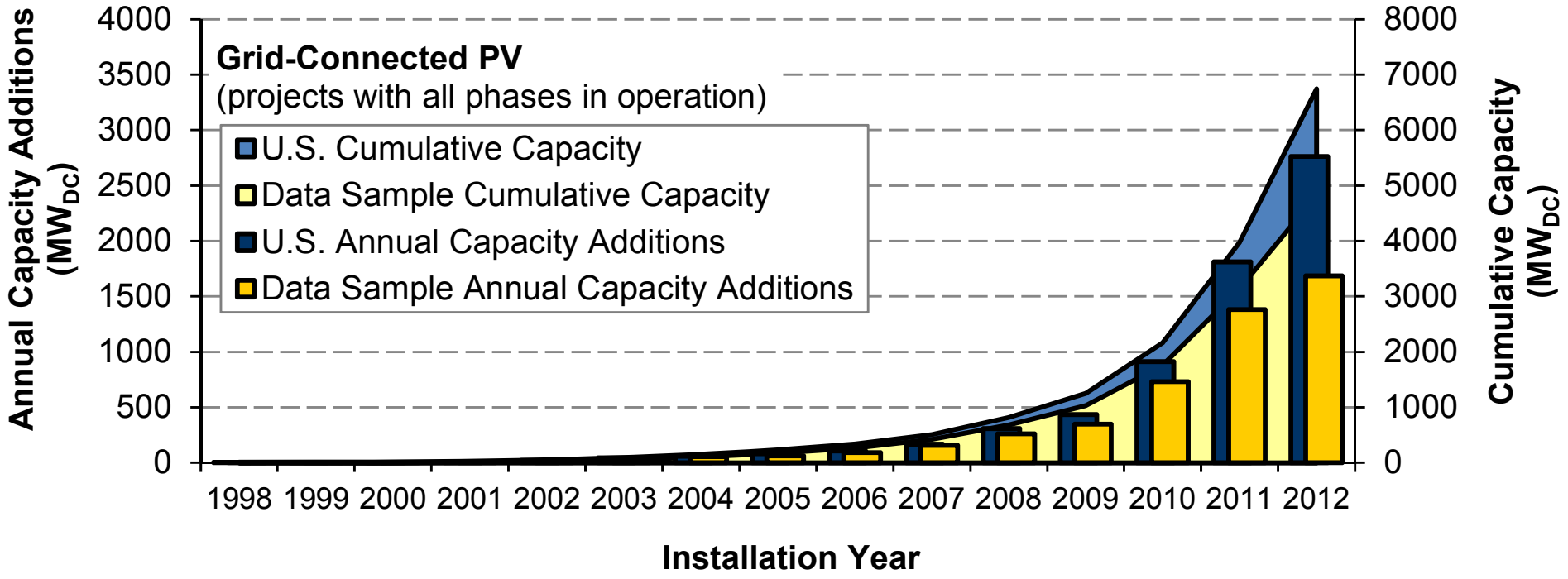
- Price and incentive data expressed in real 2012$
- System size and capacity data refer to rated module direct current (DC) power output at standard test conditions
- Data cleaned to remove systems with missing or clearly erroneous data for installed price, system size, or installation date
- All third party owned (TPO) residential & commercial systems for which reported installed prices were deemed likely to represent an *appraised value* were eliminated from the sample (see report appendix for details)
- Module and inverter manufacturer and model names standardized, and used to identify module efficiency and categorize projects as building integrated vs. rack-mounted, Chinese-brand vs. non-Chinese-brand module, and microinverter vs. central inverter
- Utility-scale PV sample consists of only fully operational projects for which all individual phases are in operation; separate project phases are not treated as individual projects

Caveats to installed price data

- **The data are historical**, focusing primarily on projects installed through 2012, and therefore do not reflect the price of more-recently installed projects or prices currently being quoted for prospective projects
- **The data may differ from current installed price benchmarks** for a variety of reasons, including differences in timing, definitions, system size, location, project characteristics, and developer/owner profit margins
- **The data focus on the up-front purchase price** rather the levelized cost of electricity (LCOE) and therefore do not reflect improvements in performance over time or differences in performance among projects

The sample represents a large fraction of all U.S. PV capacity through 2012

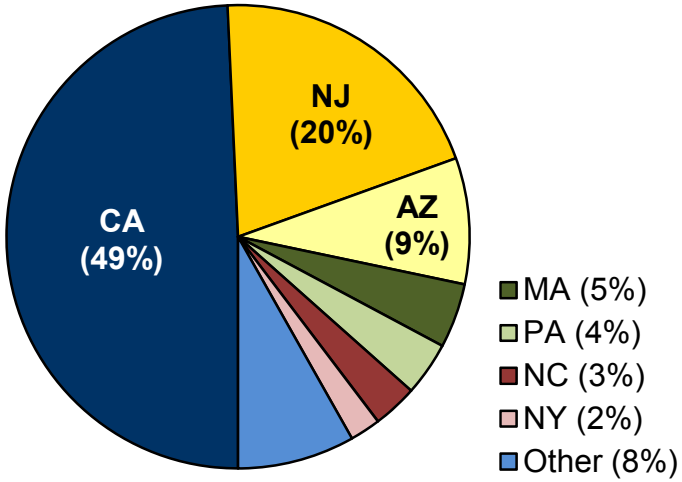
- The final dataset, after all data cleaning was completed, consists of >200,000 PV systems through 2012 totaling 4,800 MW
- Represents approximately 72% of cumulative grid-connected PV capacity installed in the U.S. through 2012, and 61% of 2012 capacity additions



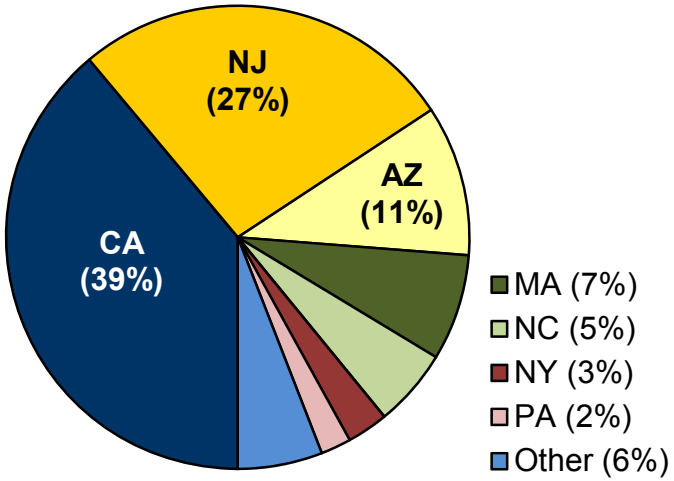
Data source for U.S. total grid-connected PV capacity additions: Sherwood (2013). LBNL modified those values by deducting the capacity associated with the operational phases of several large utility-scale PV projects that were still under construction as of year-end 2012.

Residential & commercial PV data sample:
Distribution across states and by system size

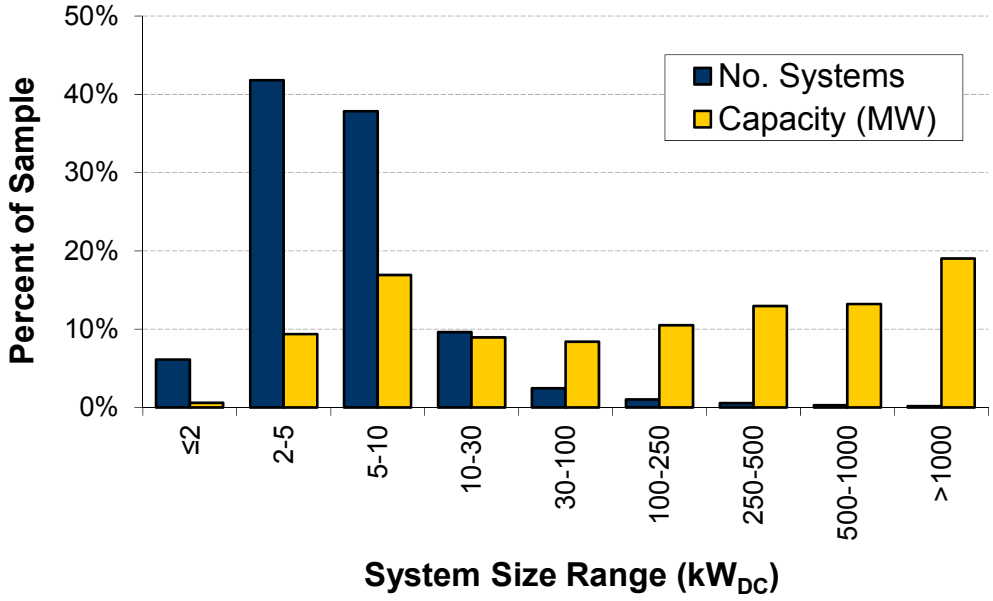
Distribution of Capacity Across States (1998-2012)



Distribution of Capacity Across States (2012 only)



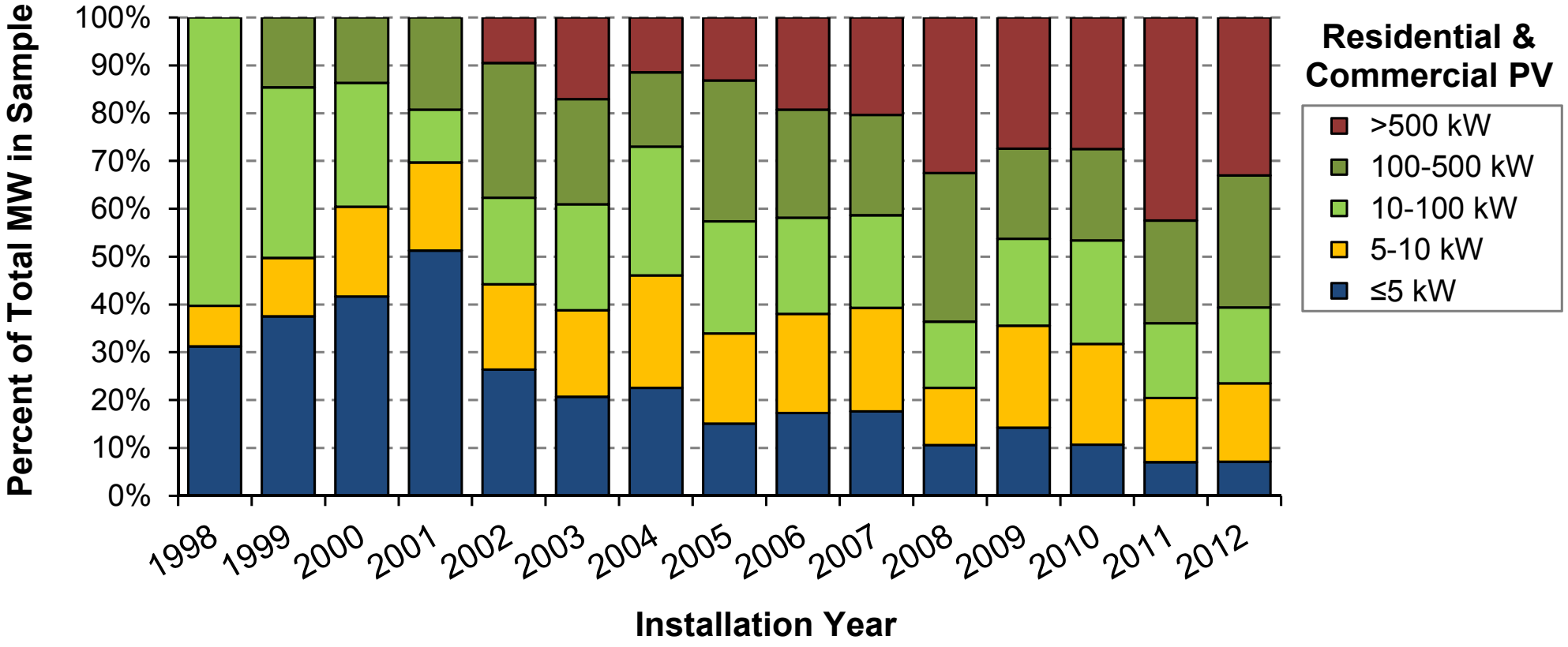
Sample Distribution by System Size (1998-2012)



- CA represents almost half of cumulative installed capacity in the data sample; 2012 capacity additions are somewhat more evenly distributed across states
- The vast majority of systems are relatively small (≤10 kW), but the sample capacity is evenly distributed across system sizes

Residential & commercial PV data sample:
System size trend over time

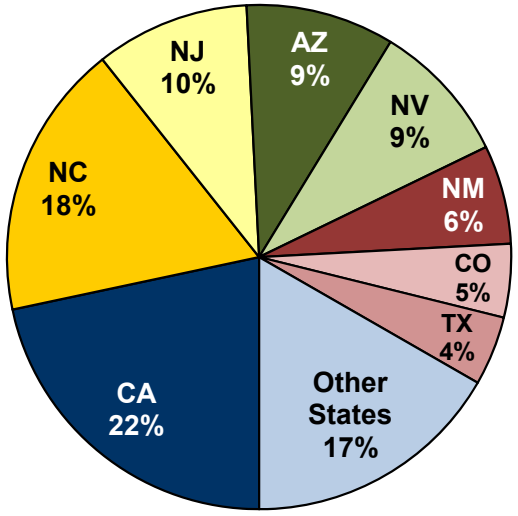
Over time, an increasing portion of residential and commercial PV capacity has consisted of relatively large systems



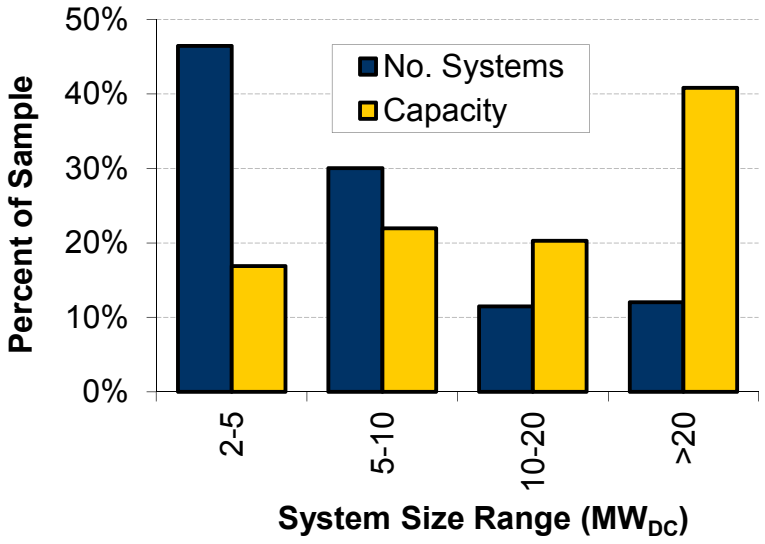
Utility-scale PV data sample:
Distribution across states and by system size

- The 190 utility-scale PV systems in the data sample are located in a total of 19 states, with more than 80% of that capacity distributed across 8 of those states (CA, NC, NJ, AZ, NV, NM, CO, and TX)
- Systems range in size from 2 MW (by definition) to 60 MW; most systems (77%) are ≤10 MW, but most of the sample capacity (61%) consists of systems >10 MW

Distribution of Capacity Across States



Sample Distribution by System Size



Outline of presentation

- Data Summary
- **Installed Price Trends: Residential and Commercial PV**
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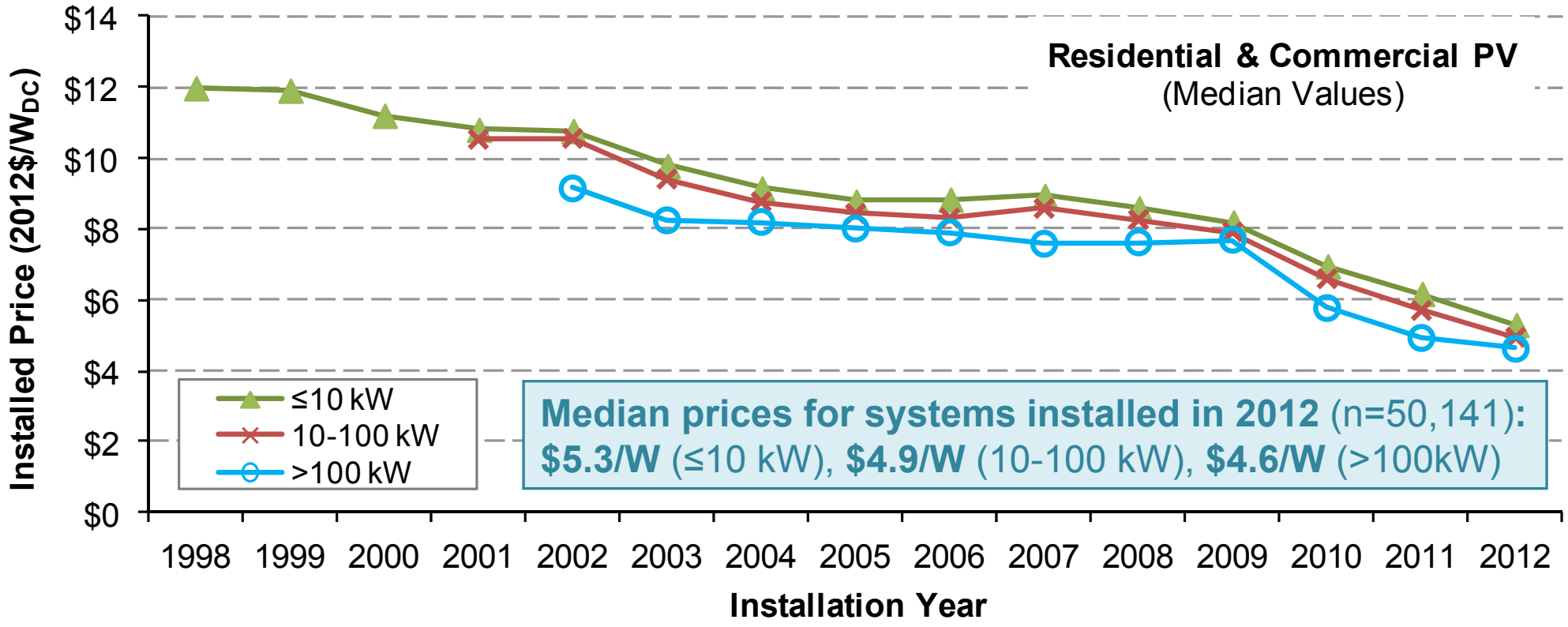
Installed prices continued their precipitous decline in 2012

Median installed prices fell by $0.3-0.9/W (6-14%) from 2011-2012, across the three size ranges shown, and have fallen by an average of $0.5/W (6-7%) annually over the full historical period

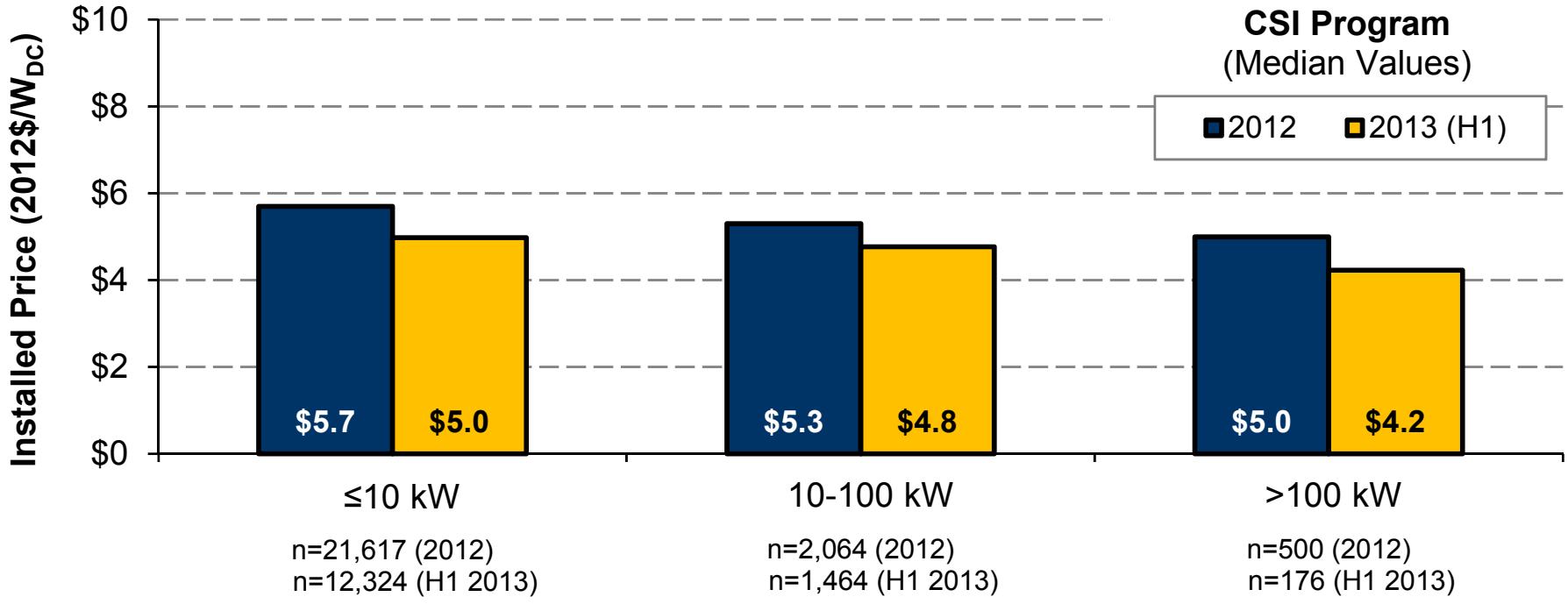


Note: Median installed prices are shown only if 15 or more observations are available for the individual size range

Preliminary data for California show that installed prices have continued to fall into 2013

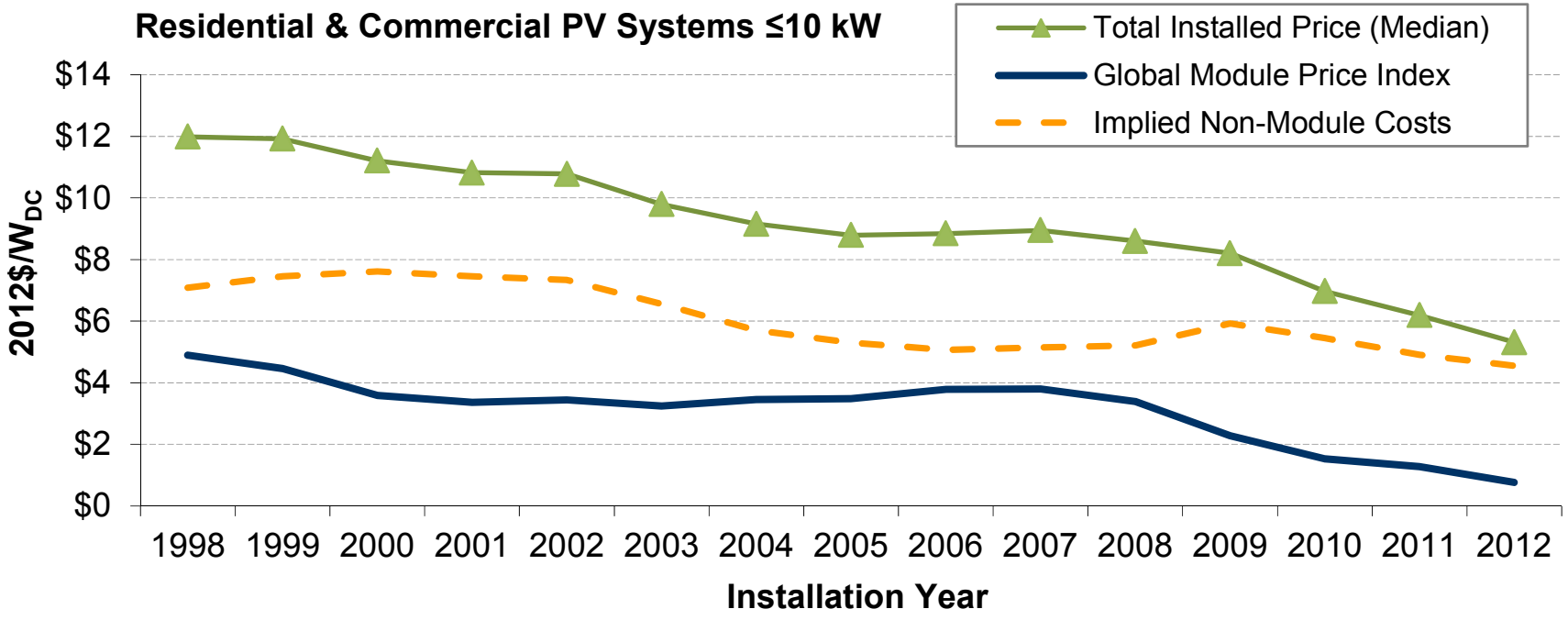
Median installed prices in the California Solar Initiative (CSI) program fell by roughly $0.5-0.8/W (10-15%) during the first half of 2013, relative to 2012, across the three size ranges shown

Median Installed Prices For Residential & Commercial Systems in the California Solar Initiative (CSI) Program: **2012 vs. the First-Half of 2013**



Recent installed price declines primarily reflect falling module prices

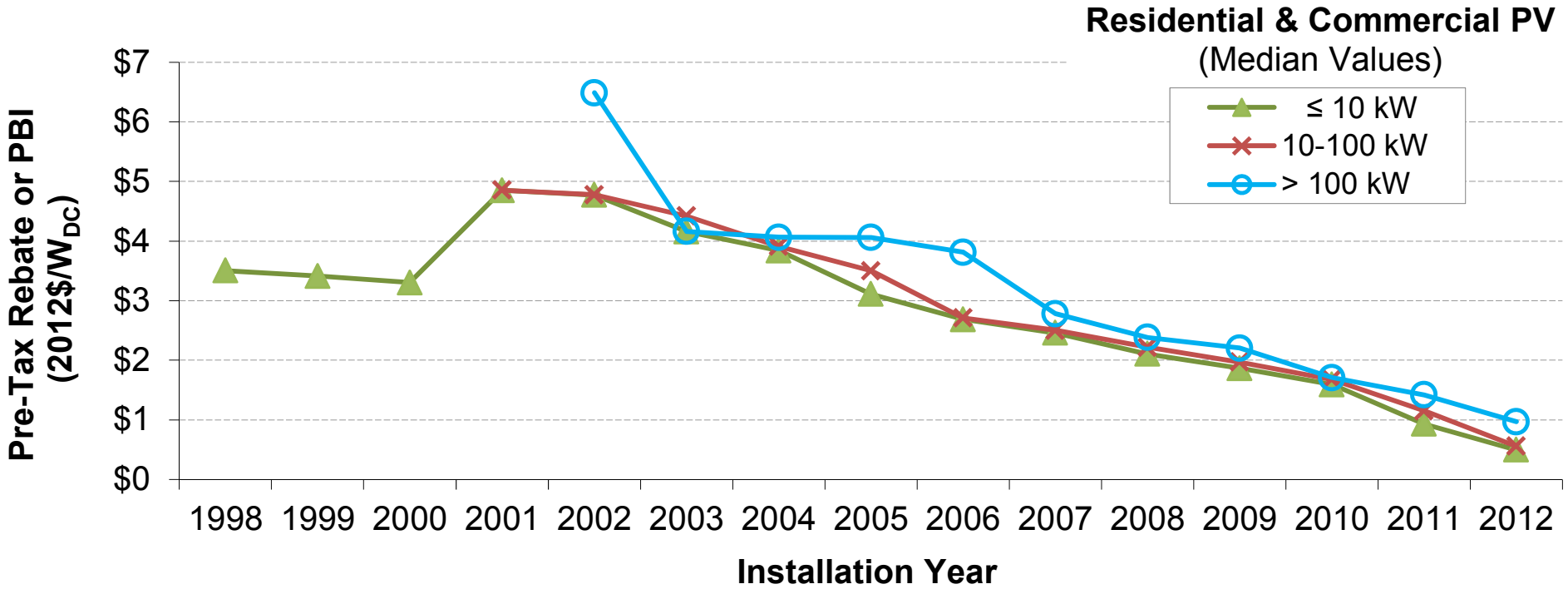
Global average module prices fell by $2.6/W from 2008 to 2012, equal to 80% of the total installed price decline for ≤10 kW systems; implied non-module costs have remained relatively flat in recent years, but have fallen by $2.5/W since 1998



Notes: The Global Module Price Index is Navigant Consulting's module price index for large-quantity buyers (Mints 2012) and the successor index for first-buyer ASPs published by Paula Mints Solar PV Market Research (Mints 2013). "Implied Non-Module Costs" are calculated as the Total Installed Price minus the Global Module Price Index.

Installed price declines have occurred in concert with falling state/utility cash incentives for PV

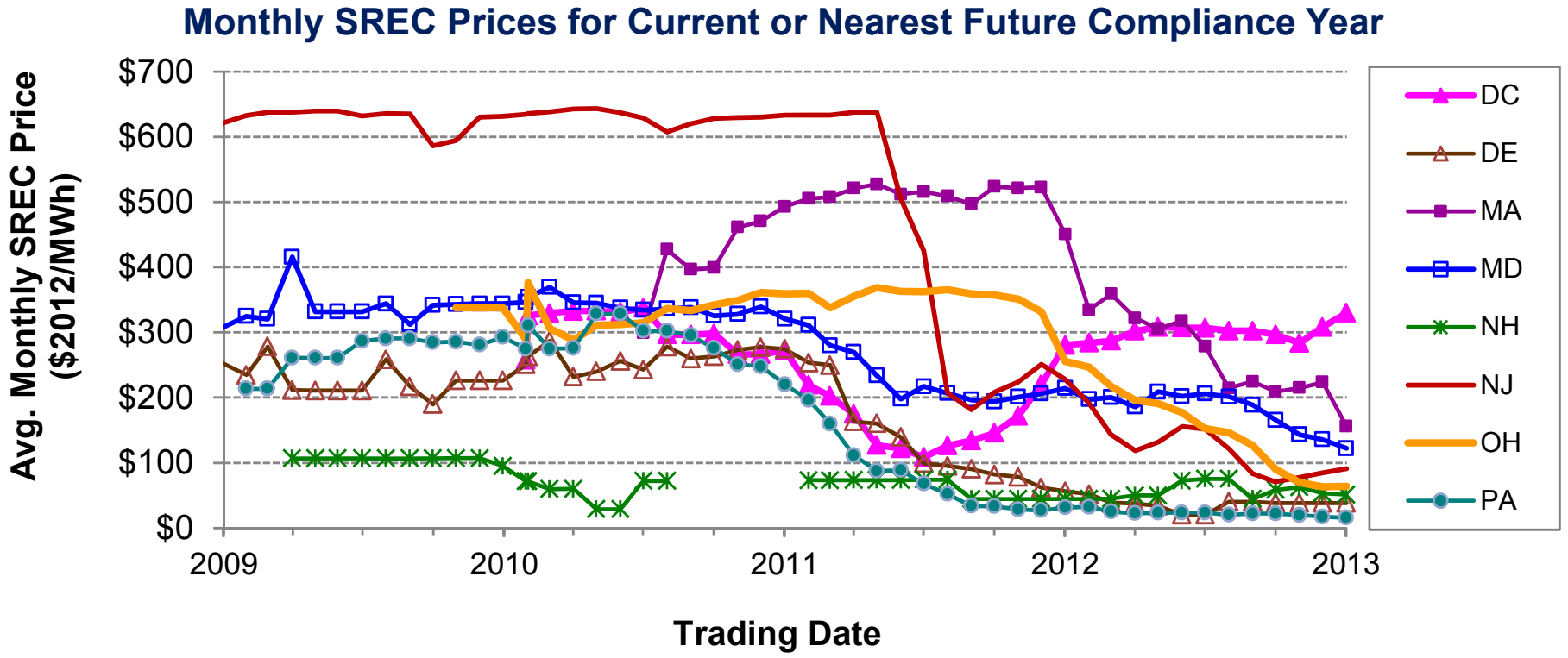
The decline in cash incentives (rebates and performance-based incentives) is equal to 50-150% of the drop in installed prices from 2011-2012, and 82-88% of the price decline over the past decade, depending on system size



Notes: The figure depicts the pre-tax value of rebates and performance-based incentives provided through state/utility PV incentive programs, excluding systems that received incentives solely in the form of ongoing SREC payments over time. Results are excluded if fewer than 15 observations are available. The high median incentive for >100 kW systems in 2002 reflects the large percentage of systems that received an incentive through LADWP's PV incentive program, which provided especially lucrative incentives in that year.

SREC prices in many RPS solar set-aside markets have also declined significantly

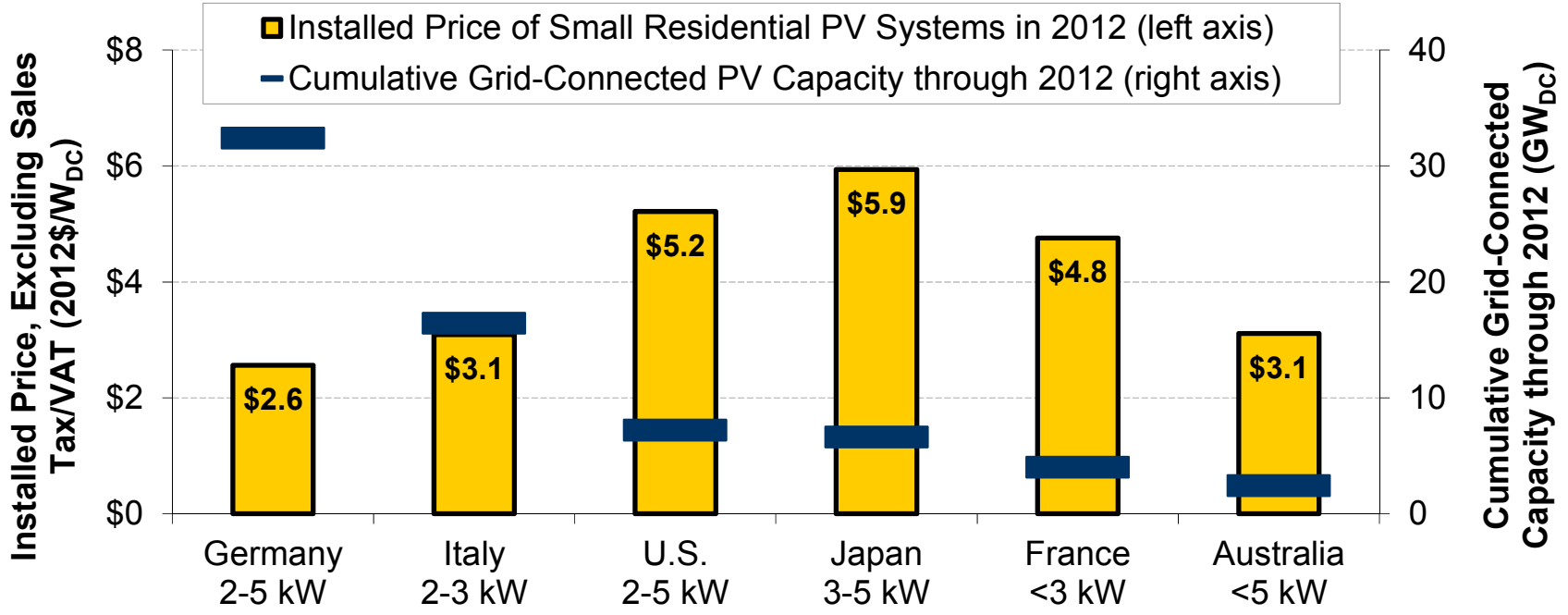
Solar renewable energy certificate (SREC) prices fell precipitously in most markets during 2011 and 2012, with short-term contract prices dropping below $100/MWh in many major markets



Notes: Data sourced from Spectron, SRECTrade, and Flett Exchange (data averaged across available sources). Plotted values represent SREC prices for the current or nearest future compliance year traded in each month. Data for Ohio are for in-state SRECs.

The installed price of small residential PV in the United States is higher than in other countries

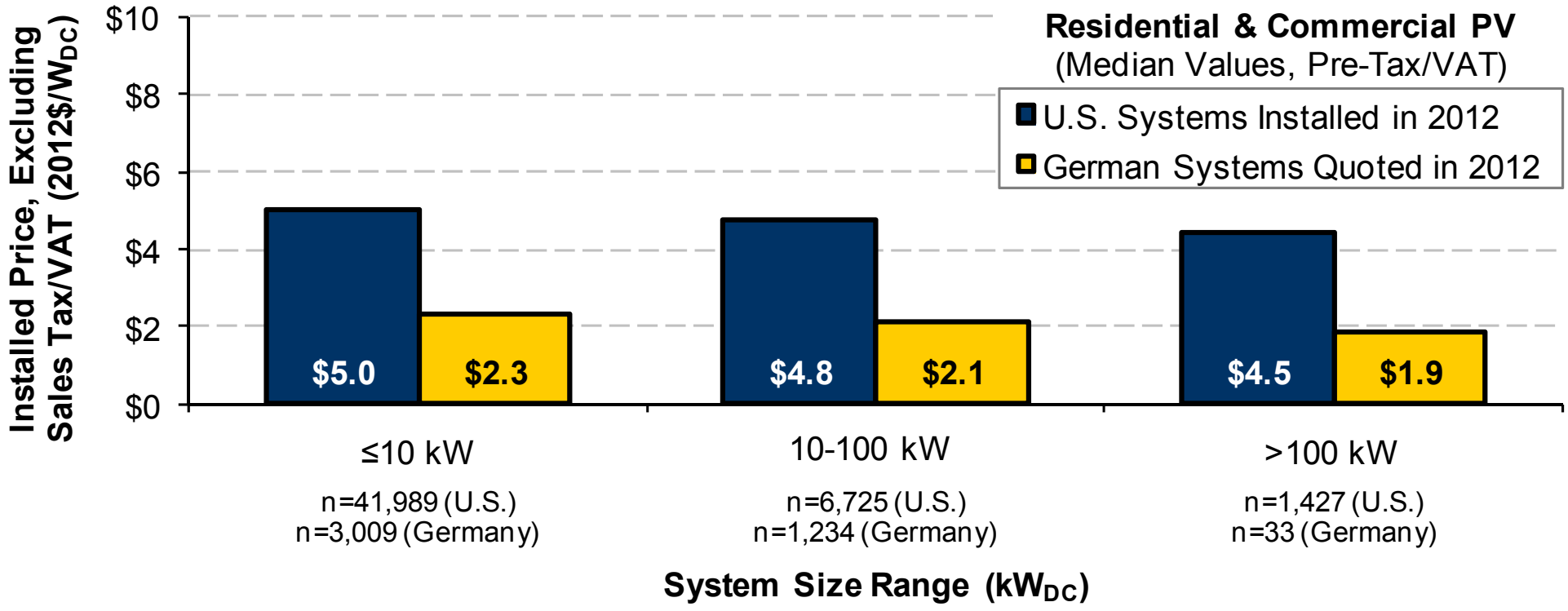
Lower installed prices in other major PV markets largely reflects differences in "soft costs," which may be driven partly by differing levels of deployment scale, though other factors are also likely important



Notes: The U.S. data point represents the median price of 2-5 kW residential systems installed in 2012, and unlike other figures presented in this report excludes sales tax. Data for Germany are based on price quotes for individual systems, collected by EuPD (2013). All other installed price data represent the "turnkey price of typical PV applications" for the particular size range shown, as reported in each country's IEA PVPS Country Report (Castello et al. 2013, Durand 2013, Watt and Passey 2013, Yamada and Ikki 2013). Cumulative installed capacity data for each country derive from REN21 (2013).

The pricing disparity between the United States and Germany persists across system sizes

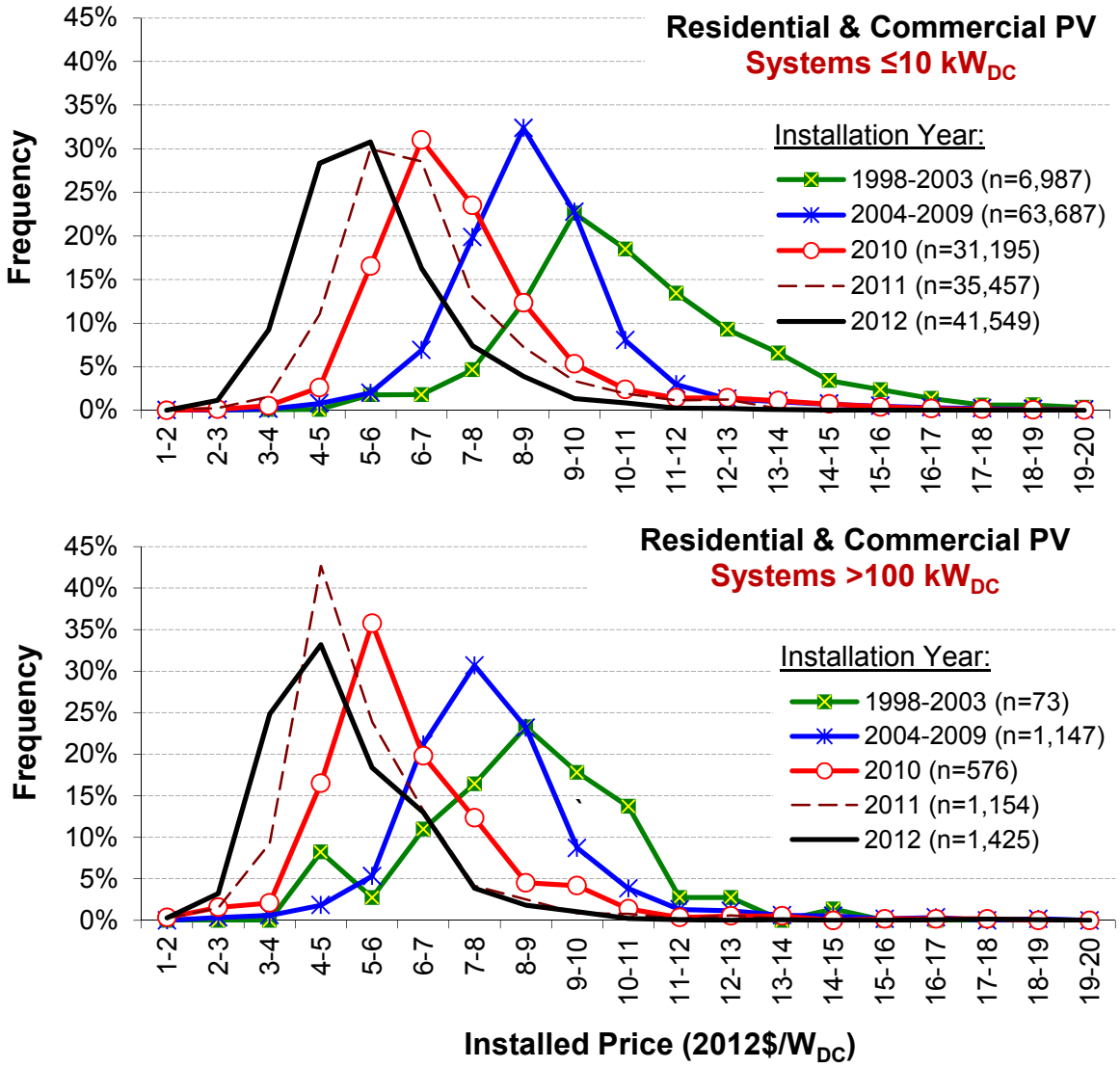
The pricing disparity is particularly stark in comparison to Germany, where installed prices (on a pre-tax/VAT basis) are lower than in the United States by $2.6/W to $2.7/W (53% to 58%) across the three size ranges shown



Notes: This figure relies upon price quotes for individual German PV systems obtained by EuPD through its quarterly survey of German installers and provided to LBNL (EuPD 2013).

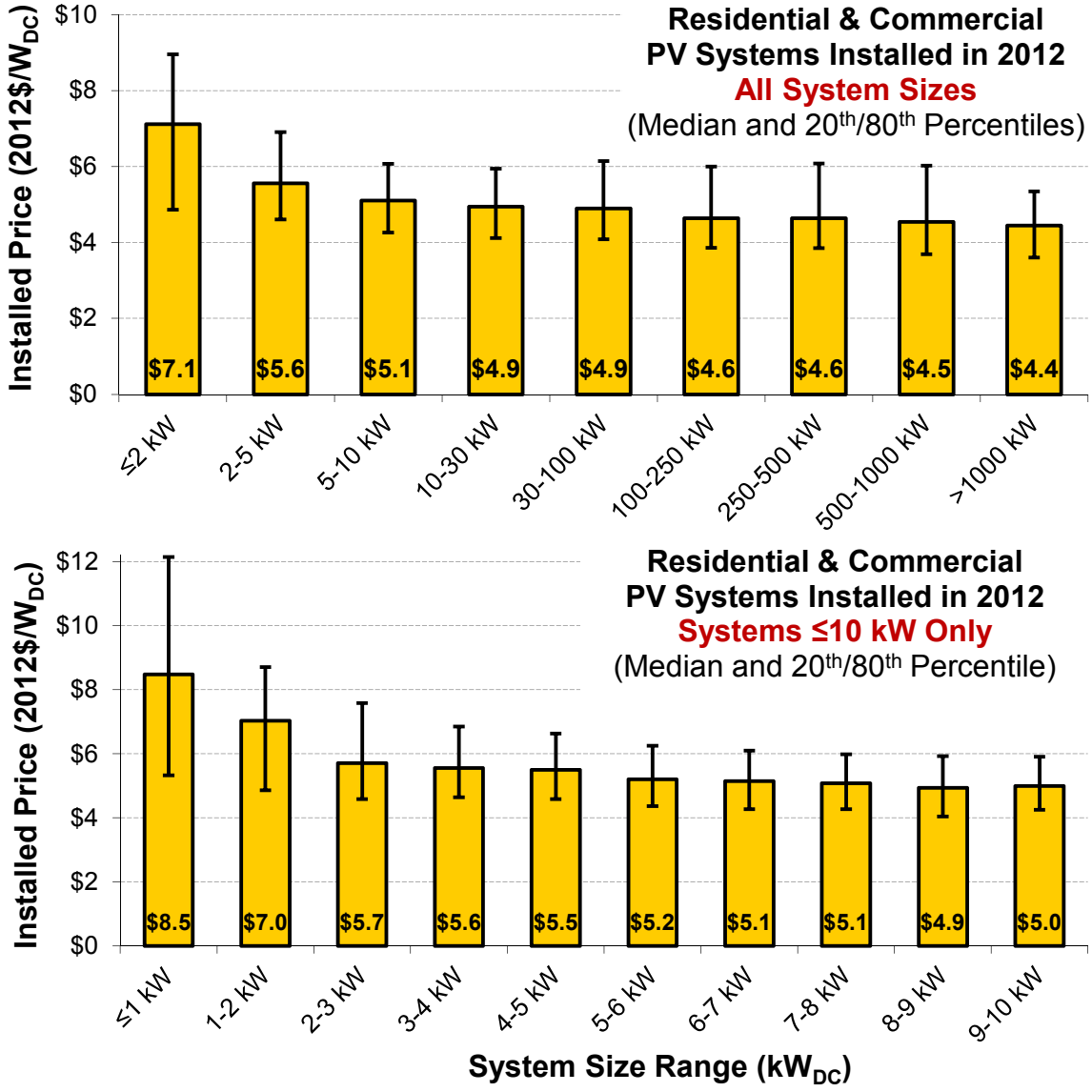
Installed prices vary widely across individual projects

- Over time, installed price distributions have both shifted to the left and narrowed, suggestive of a maturing market with greater competition and better informed consumers
- Narrowing trends have ceased in recent years, and high degree of variability in pricing persists, reflecting differences in local markets, system design, component choice, etc.
- Among ≤10 kW systems installed in 2012, 20% of systems were priced <$4.5/W while a similar percentage was >$6.5/W



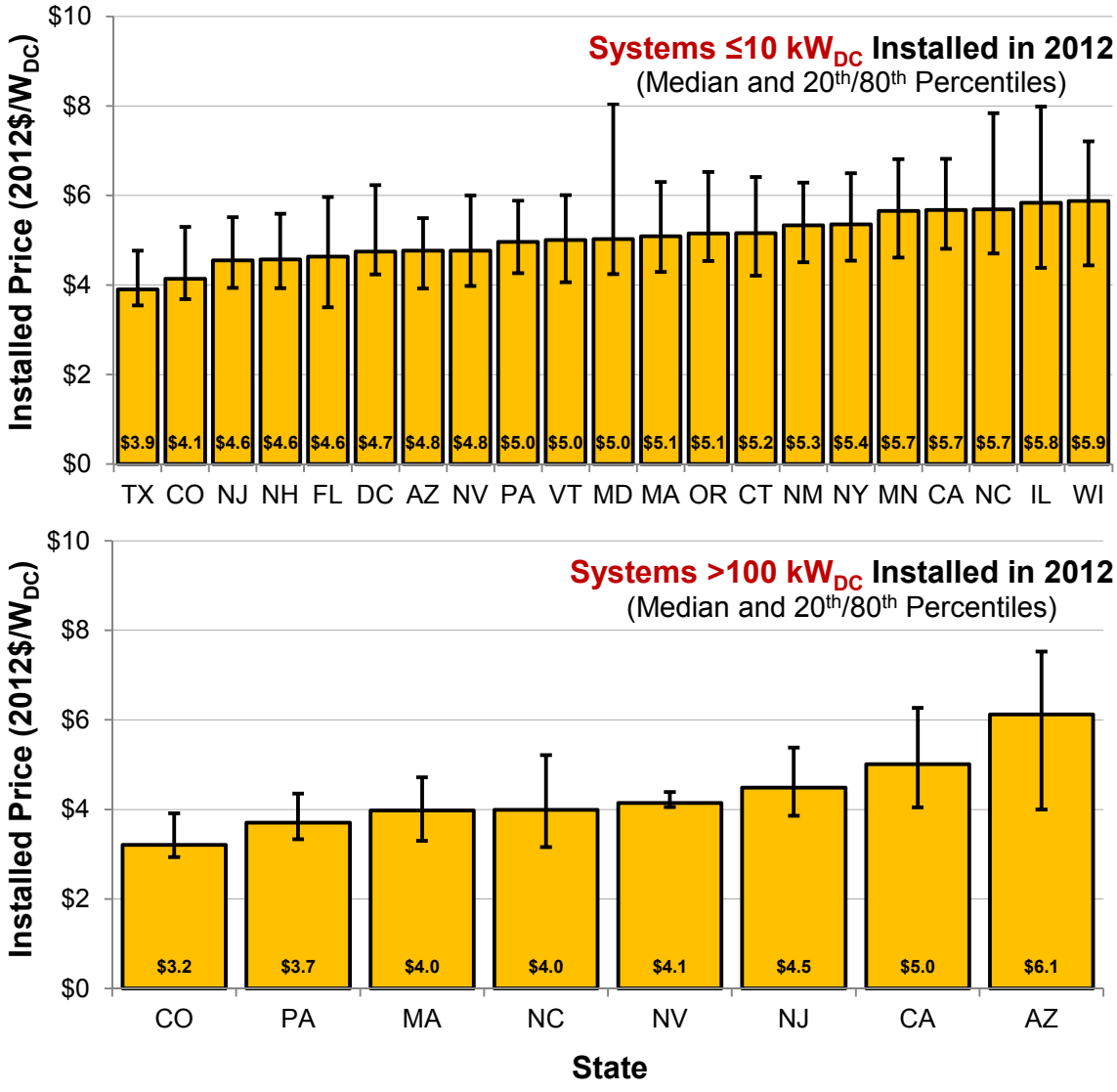
Installed prices exhibit economies of scale

- Across all residential and commercial systems installed in 2012, systems >1,000 kW had 38% lower median installed price than the systems ≤2 kW
- Returns to scale are particularly pronounced at low end of the size spectrum (bottom figure)
- Economies of scale, in combination with increasing system sizes, have contributed to the long-term decline in installed prices for ≤10 kW systems, which grew in median size from 2.4 kW in 1998 to 5.2 kW in 2012



Installed prices differ significantly across states

- Cross-state variation potentially reflects differences in market size and maturity, labor costs, installer competition, incentives and retail rates, administrative costs, customer and system characteristics, and sales taxes, among other factors
- California is a relatively high-priced state, pulling the overall sample median upward by virtue of its large fractional share
- Significant intra-state variability exists, often wider than cross-state differences



Note: Results shown only if 15 or more observations are available for the state

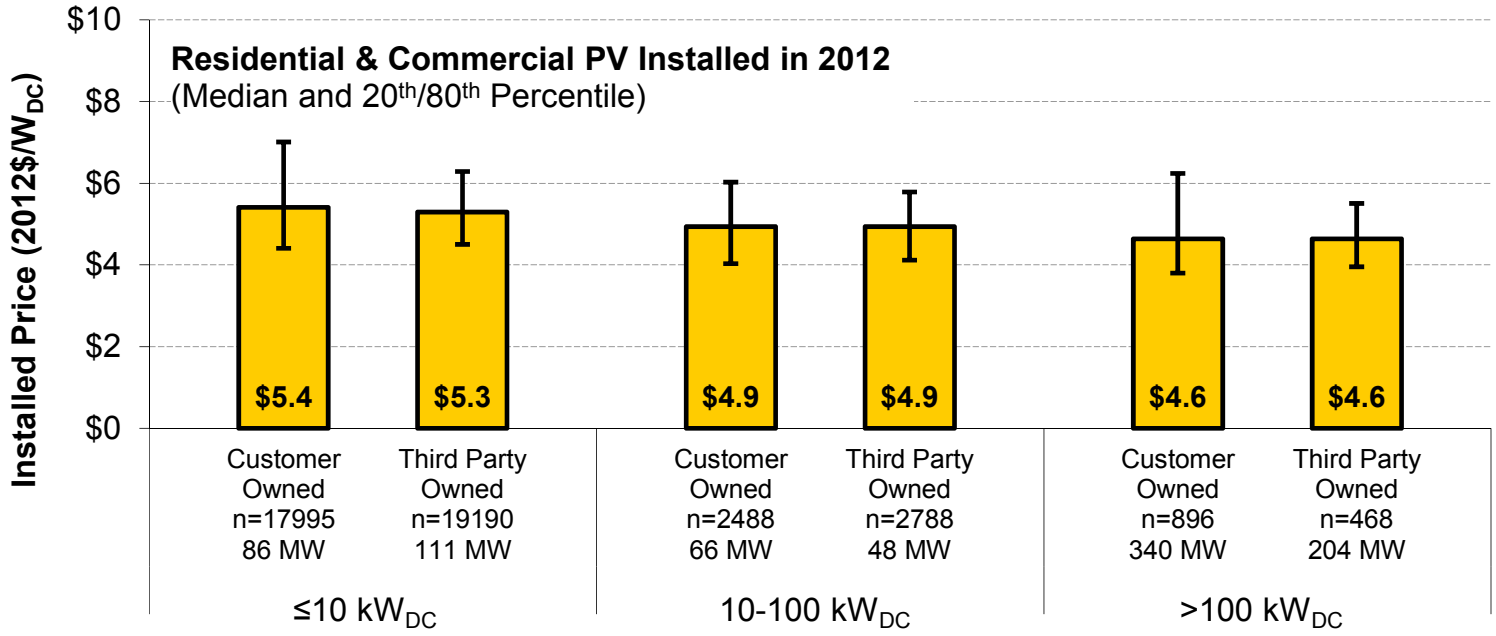
Installed price reporting for third-party owned systems complicates the analysis of price trends

Installed price reporting for third party owned (TPO) systems depends on the type of customer finance provider

- For TPO systems financed by *integrated* companies that provide both installation and customer financing:
  - Installed price data reported to PV incentive program administrators typically represent an appraised value (in some cases, an assessed "fair market value")
  - To the extent identifiable, these systems were removed from the sample
- For TPO systems financed by *non-integrated* companies that provide customer financing but purchase systems from EPC contractors/installers:
  - Installed price data reported to PV incentive programs generally represent the actual purchase price paid to the EPC contractor
  - These systems were retained in the data sample

TPO systems retained in the sample have similar installed prices to customer-owned systems

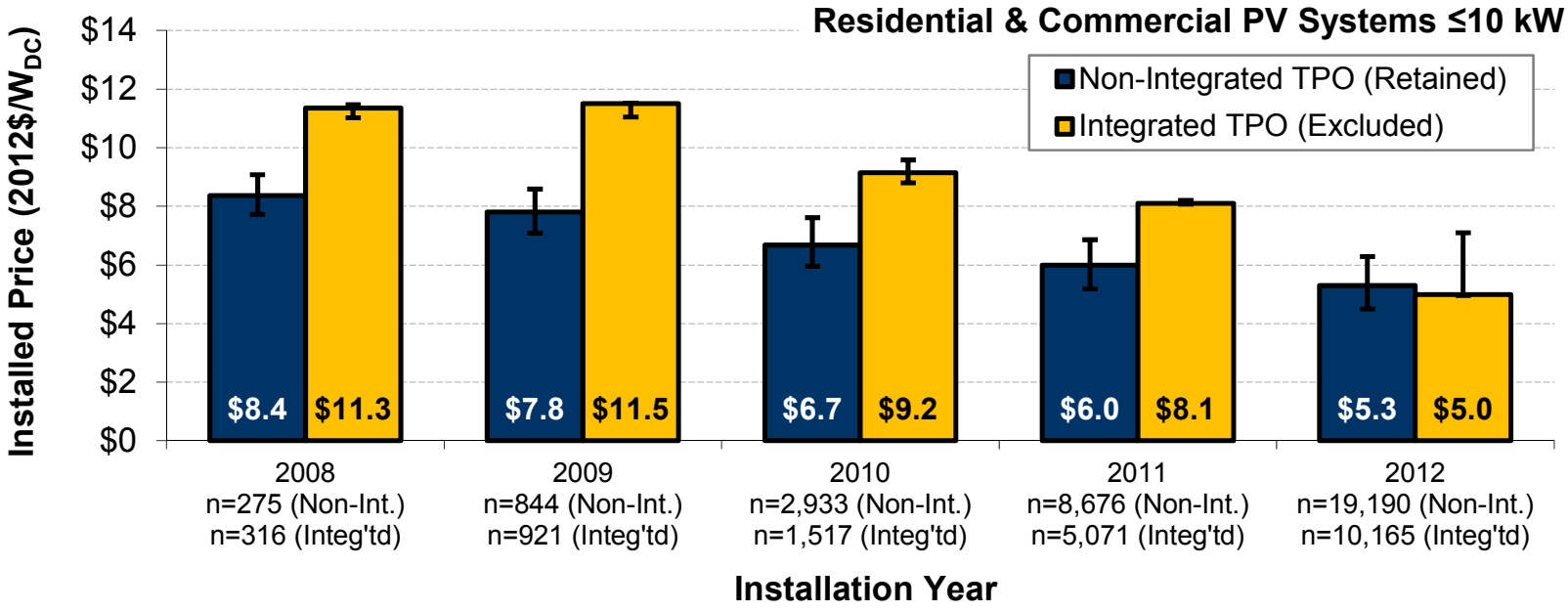
- Growing prominence of TPO systems therefore has not had a material impact on overall installed price trends (given the exclusion of appraised value TPO systems)
- TPO systems do have modestly narrower variability than customer-owned systems, as customer finance providers often purchase groups of systems and are likely relatively well-informed buyers



Notes: As is the case throughout the report, data from TPO systems for which reported installed prices were deemed likely to represent an appraised value were excluded from the sample. The values shown here for TPO systems are based only on systems for which the installed prices reported to state/utility PV incentive programs were deemed likely to represent an actual transaction price between an EPC contractor and a customer finance provider.

In contrast, TPO systems excluded from the data sample historically have had much higher prices

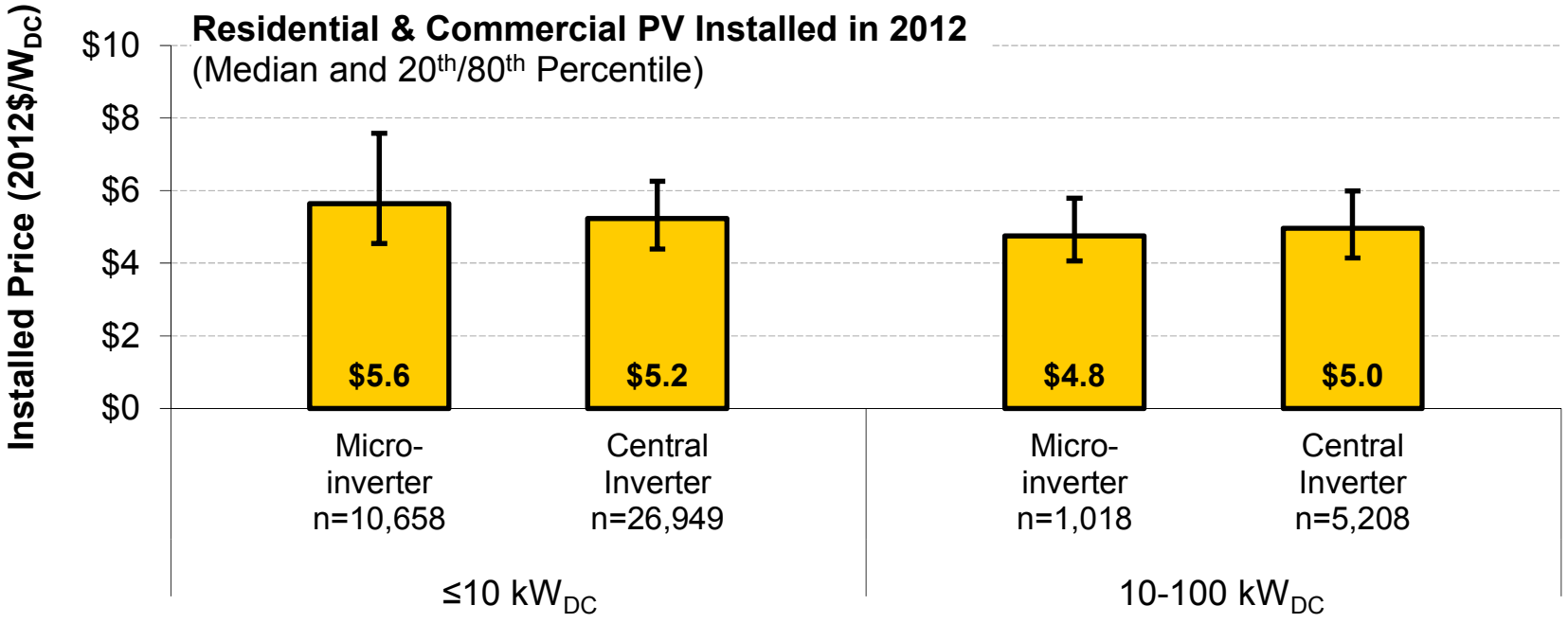
- Through 2011, installed prices reported for TPO systems installed by integrated finance providers (often reflecting an assessed "fair market value") were dramatically higher than for non-integrated TPO systems
- Starting in 2012, one major integrated TPO provider altered its methodology for reporting installed prices to PV incentive programs



Notes: The data for integrated TPO systems are included in this figure but excluded throughout all other elements of this report. The data presented here for both types of TPO systems represent installed prices reported to state and utility PV incentive programs, which may differ from those reported to other entities (e.g., to the U.S. Treasury Dept. or the IRS, for the purposes of the 1603 Grant or federal ITC).

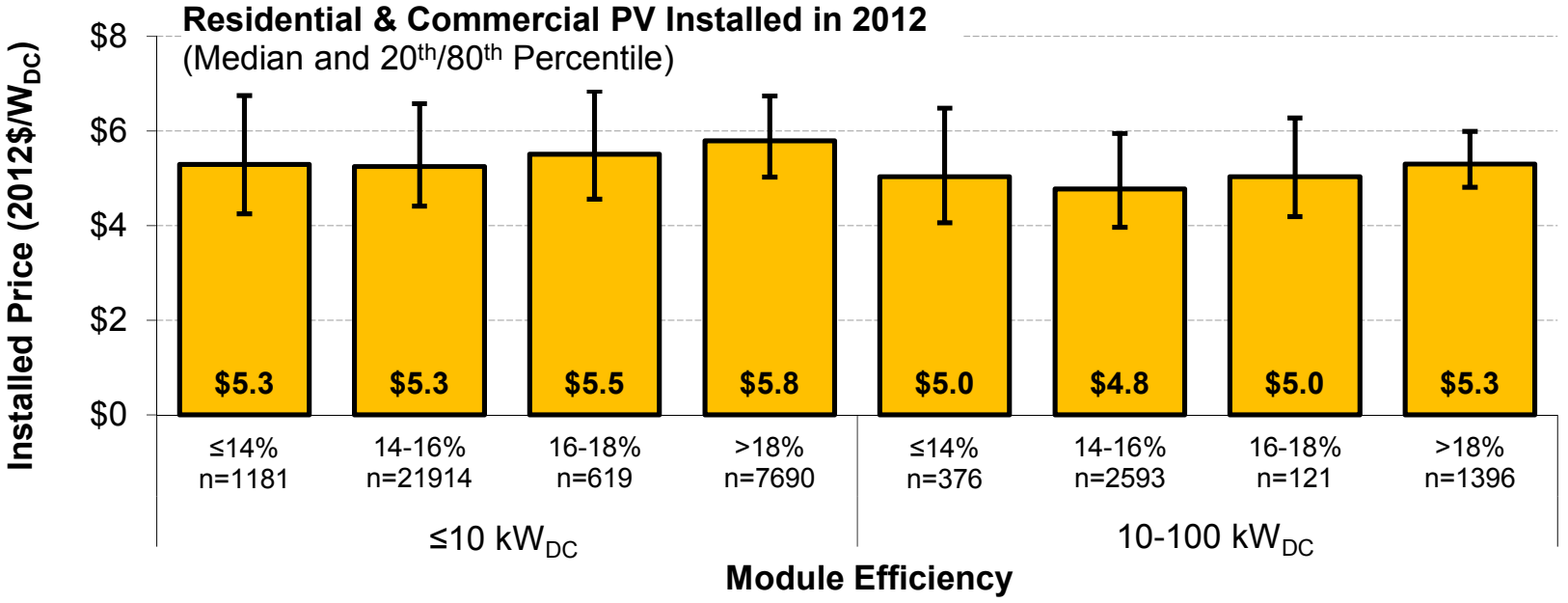
Microinverters are associated with higher installed prices among small systems

- Microinverters improve system performance but, for small systems at least, entail a higher installed price ($0.4/W higher in 2012 and a similar amount in 2011)
- Increasing penetration of microinverters has thus modestly dampened the installed price decline for ≤10 kW systems
- The installed price differentials for larger systems are smaller and less consistent over time



Installed prices increase moderately with higher module efficiencies

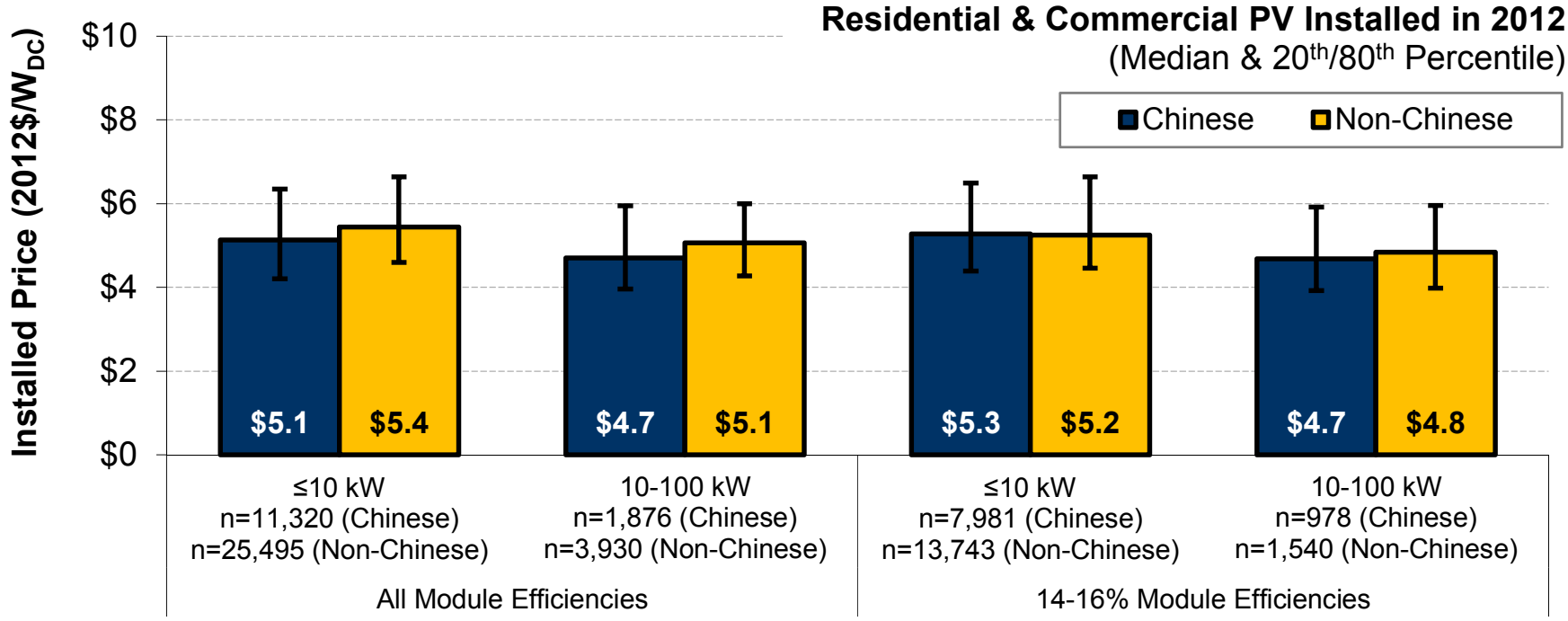
- Within both size ranges, systems with premium-efficiency module efficiencies (>18%) had a median installed price $0.5/W higher than that of systems with 14-16% module efficiencies (typical of standard polysilicon modules)
- Suggests that the cost premium for high-efficiency modules has, thus far at least, generally outweighed associated reduction in balance of systems costs



Notes: The figure excludes building-integrated PV (BIPV) systems, in order to avoid any bias associated with a higher incidence of BIPV systems with particular module efficiency levels.

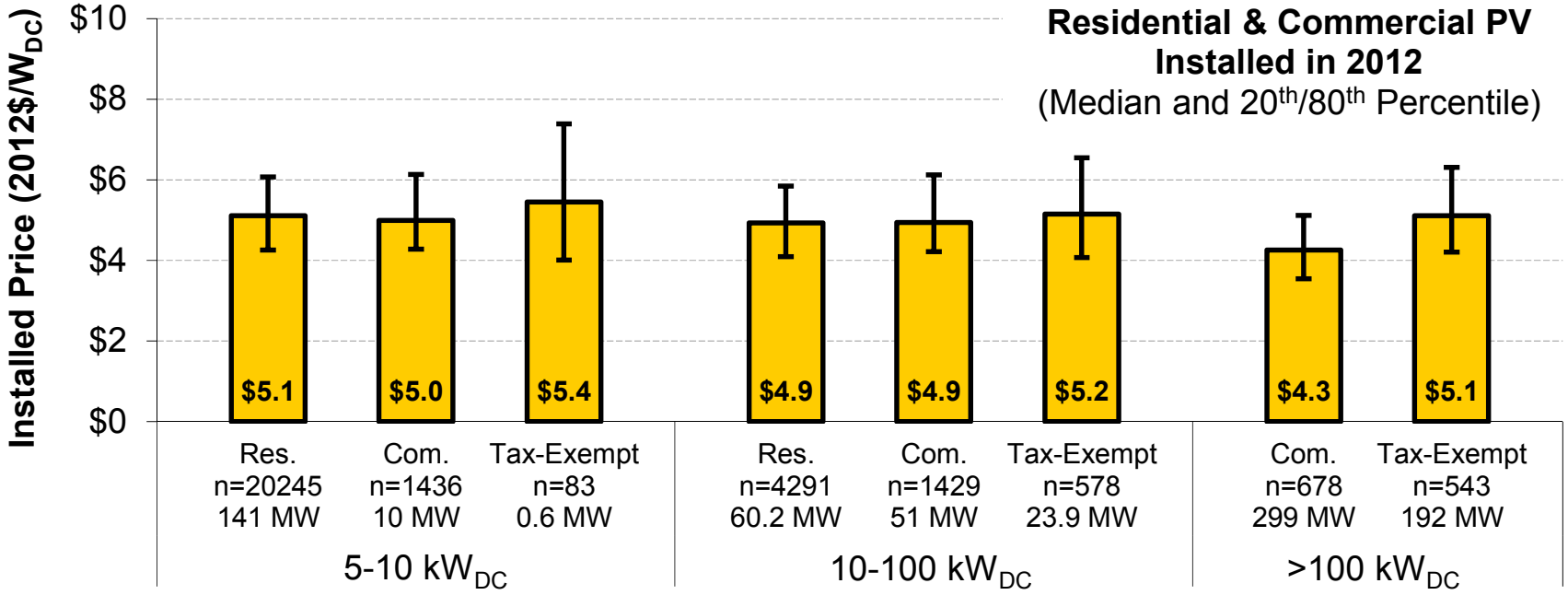
Systems with Chinese-brand modules generally have lower installed prices

- Across all module efficiencies, the median installed price of systems with Chinese-brand modules was $0.3/W to $0.4/W lower than those with non-Chinese-brand modules, consistent with the associated difference in underlying module prices
- Focusing more narrowly on systems with module efficiencies of 14-16% (the range within which most Chinese-brand modules fall), the installed price differential between systems was considerably smaller



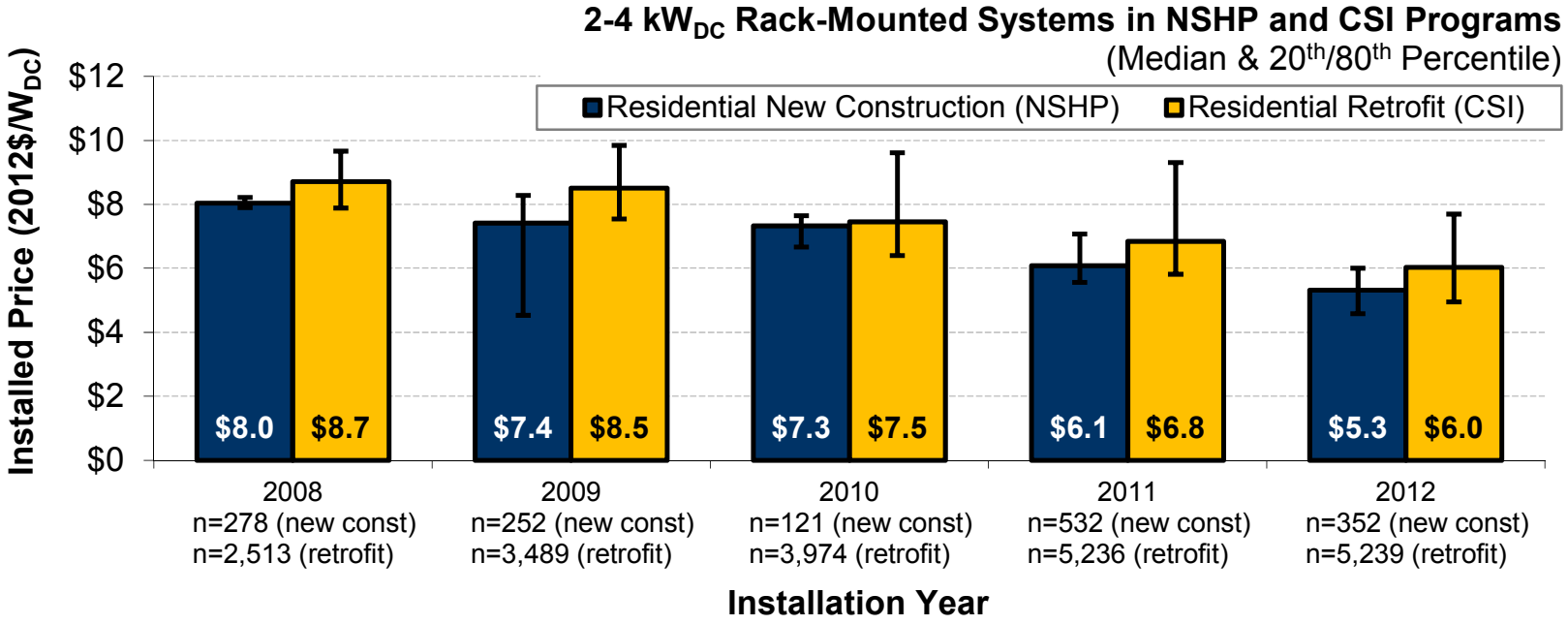
Installed prices for tax-exempt customers are higher than for other customer segments

- The median installed price of tax-exempt systems was $0.3/W to $0.8/W higher than that of residential and commercial systems, across the three size ranges
- The installed price differential may reflect, for example: prevailing wage/union labor requirements, preferences for domestically manufactured components, a high incidence of shade and parking structure PV arrays, additional permitting requirements, and more complex government procurement processes.



The new construction market offers installed price advantages for small residential PV

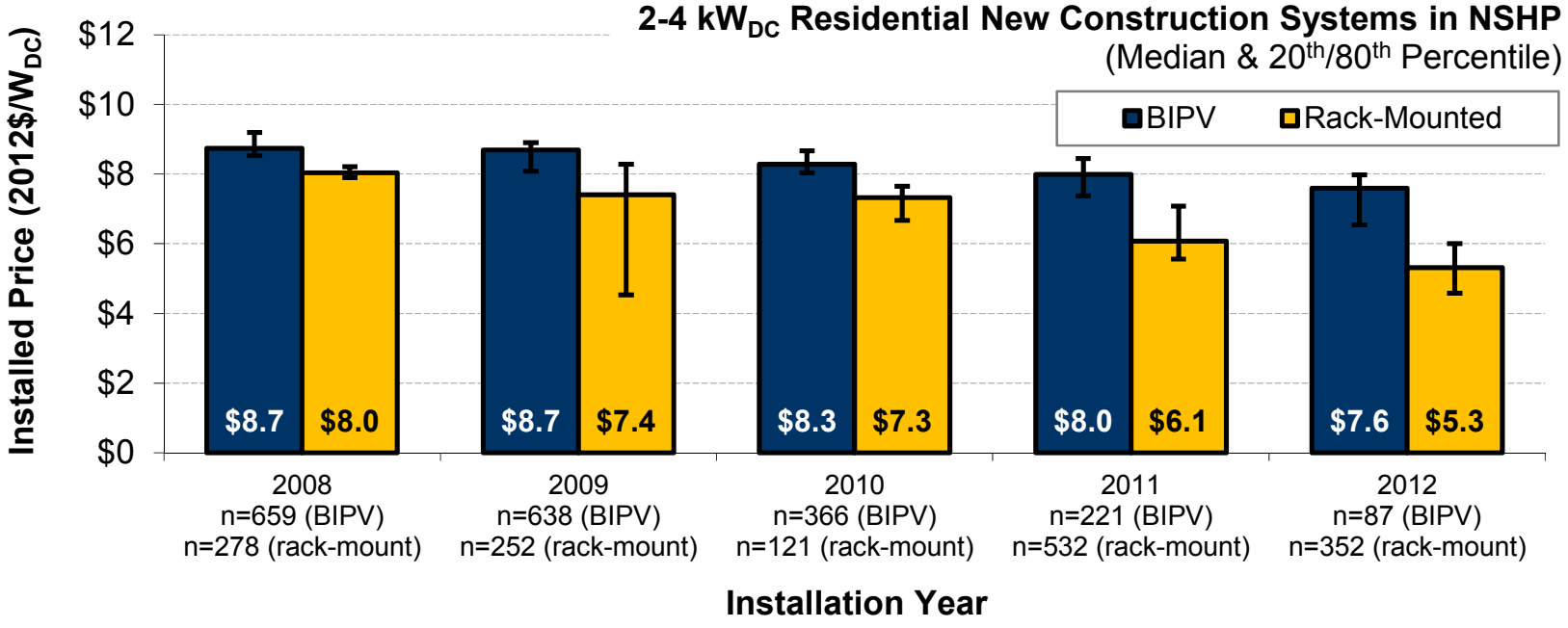
- In each year over the 2008 to 2012 period, median installed prices of *rack-mounted* systems in residential new construction were $0.2/W to $1.1/W lower than those of similarly-sized retrofit systems (see next slide for data on BIPV)
- The trend is consistent with economies of scope and economies of scale that might be anticipated in residential new construction



Notes: The data for retrofits are based on systems installed through the California Solar Initiative (CSI), and data for residential new construction are based on systems installed through California's New Solar Homes Partnership (NSHP) program. The comparison focuses on 2-4 kW systems, the most common size range for residential new construction systems.

BIPV systems have shown substantially higher installed prices than rack-mounted systems in new construction

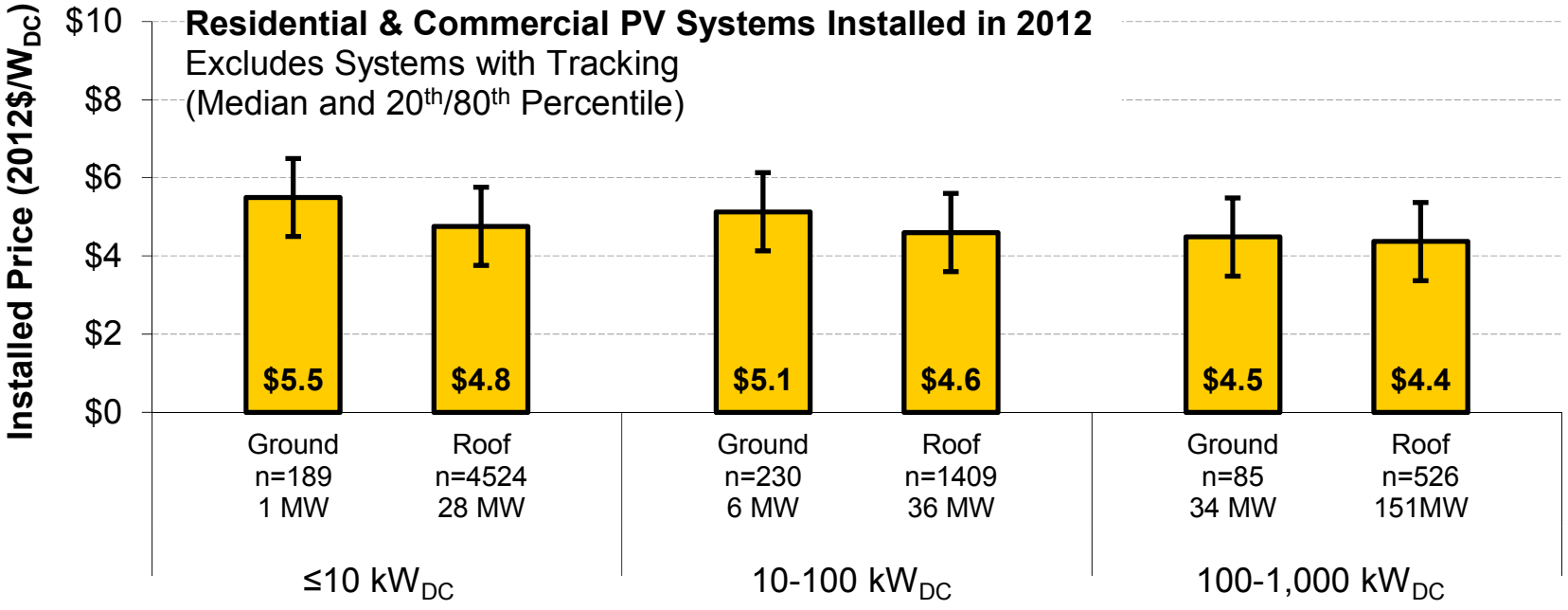
- Among systems installed in residential new construction over the 2008 to 2012 period, median installed prices of BIPV systems were $0.7/W to $2.3/W higher than those of rack-mounted systems
- Comparison does not account for avoided roofing materials cost associated with BIPV or performance differences, both of which also impact LCOE



Notes: Data are based on systems installed through California's New Solar Homes Partnership (NSHP) program. The comparison focuses on 2-4 kW systems, the most common size range for residential new construction systems.

Installed prices for ground-mounted systems are typically higher than for roof-mounted systems

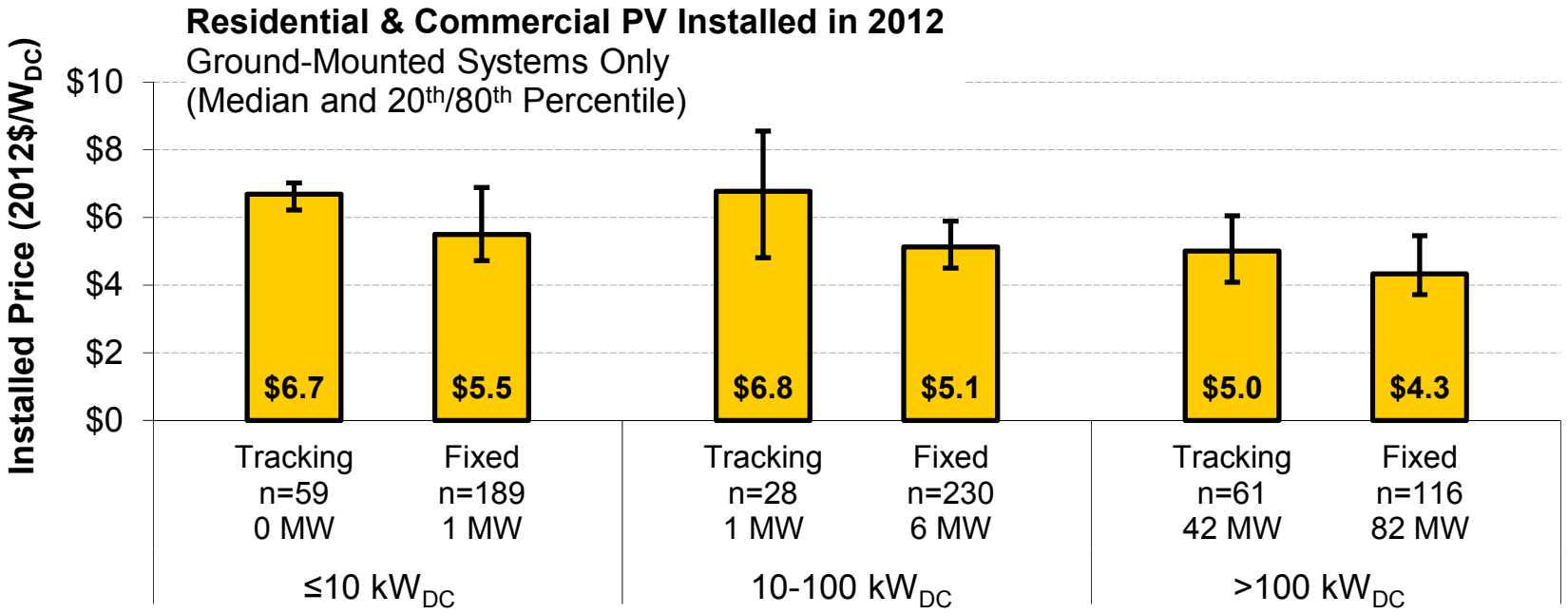
- Among residential and commercial PV systems installed in 2012, the median installed price of *fixed-tilt*, ground-mounted systems was $0.1/W to $0.7/W higher than that of similarly sized roof-mounted systems, depending system size
- Higher installed prices of ground-mounted systems may be (partially) offset by higher performance (e.g., due to more-optimal orientation)



Notes: The figure is derived from the relatively small subsample of systems for which data were available indicating whether the system is roof- or ground-mounted, and excludes systems with tracking or BIPV.

Systems with tracking have notably higher installed prices than fixed-tilt systems

- Among residential and commercial PV systems installed in 2012, the median installed price of systems with tracking was $0.7/W to $1.7/W (15% to 32%) higher than that of fixed-tilt, ground-mounted systems, depending system size
- This installed price differential is roughly on par with the increased performance of tracking systems, depending on location and type of tracking



Notes: The figure is derived from the relatively small subsample of systems for which data were available indicating whether the system is roof- or ground-mounted.

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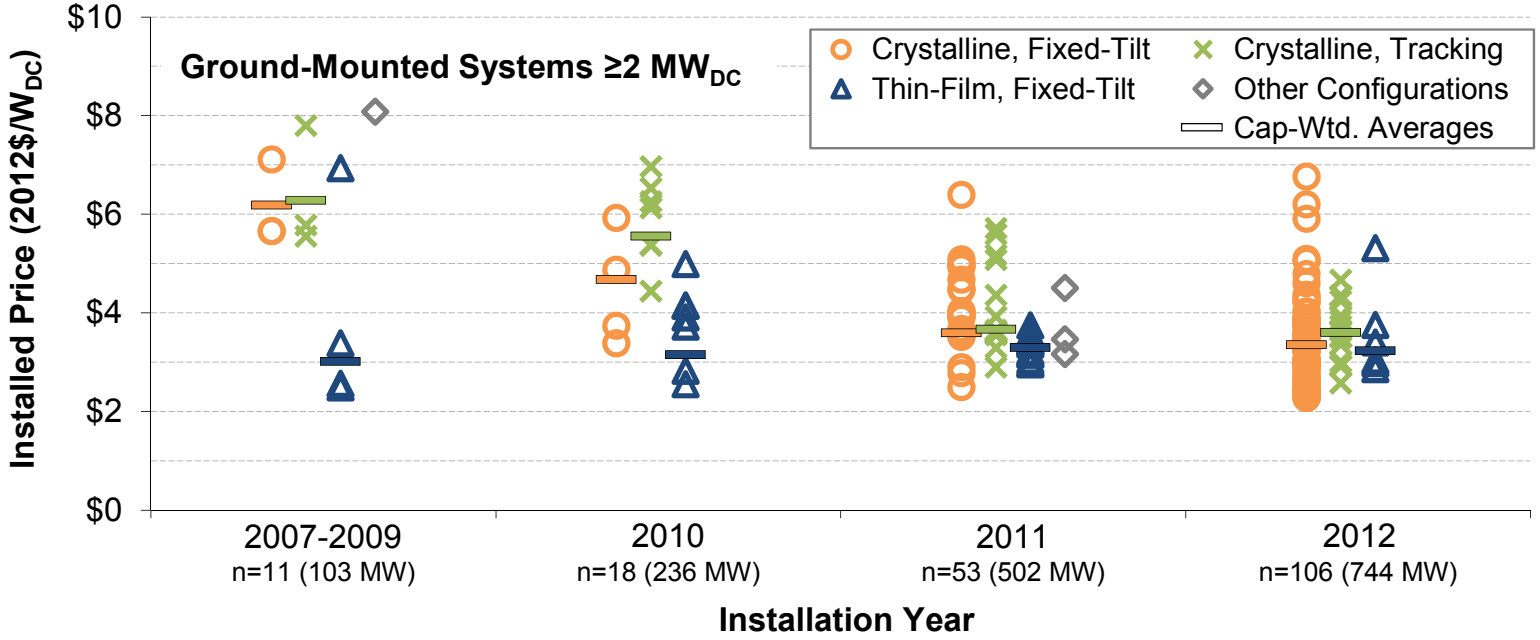
Specific caveats for utility-scale data

The utility-scale installed price data presented here must be interpreted with a certain degree of caution, for several reasons:

- **Small sample size including atypical utility-scale PV projects:** The sample is relatively small (190 systems) and includes a number of relatively small (2-10 MW) projects as well as a number of "one-off" projects with atypical project characteristics
- **Lag in component pricing and market conditions:** The installed price of some projects may reflect component pricing (and/or the market conditions under which power sales agreements were signed) one or two years prior to project completion, and therefore the data sample may not fully capture the recent decline in component prices or other changes in market conditions
- **Reliability of data sources:** The data are derived from varied sources and, in some instances (e.g., trade press articles and press releases), are arguably less reliable than the installed price data presented earlier for residential & commercial systems
- **Focus on installed price rather than levelized cost:** The focus on installed price ignores performance-related differences and other factors that influence the levelized cost of electricity, a more comprehensive cost metric for utility-scale PV

The installed price of utility-scale PV varies considerably but has declined overall

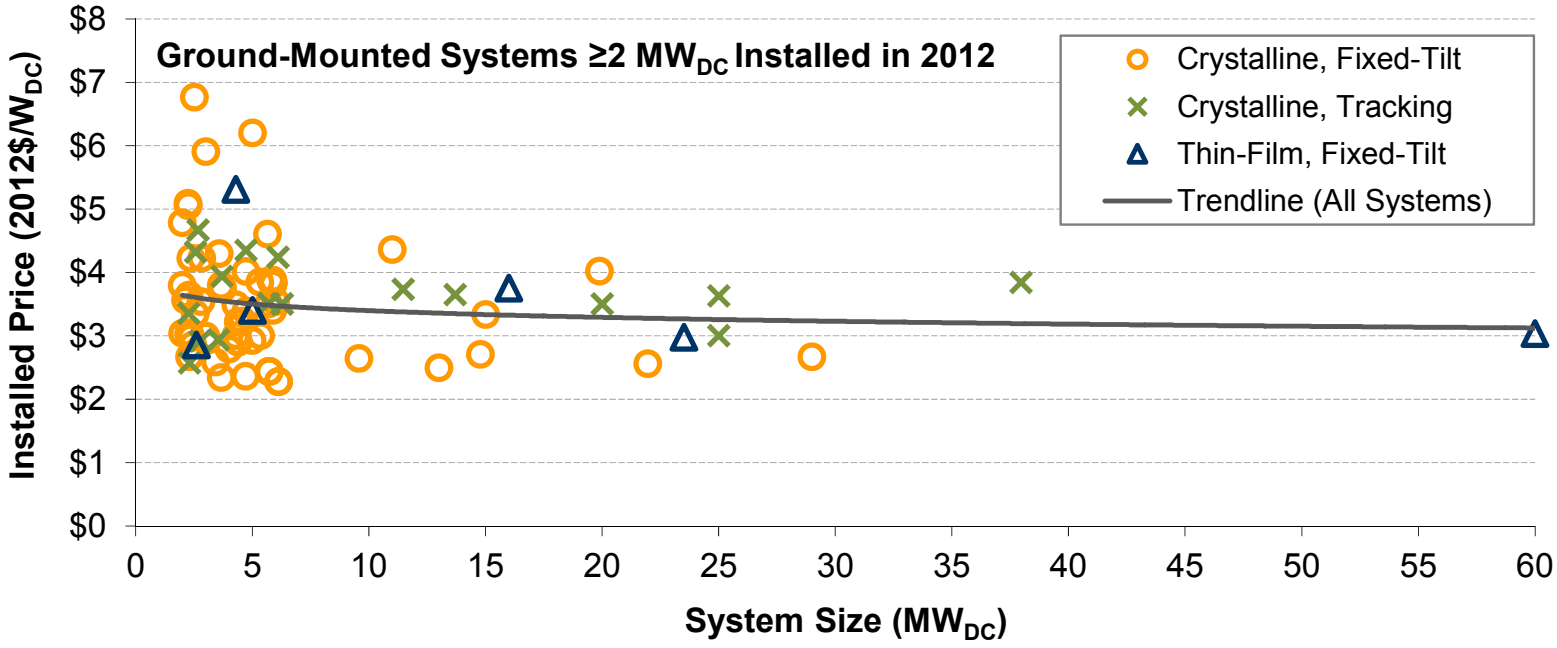
- Among 2012 projects, the capacity-weighted average installed price was $3.3/W for systems with crystalline modules and fixed tilt, compared to $3.6/W for crystalline systems with tracking and $3.2/W for thin-film, fixed-tilt systems
- For crystalline fixed-tilt systems, capacity-weighted average prices fell by $2.8/W over the entire historical period shown, while systems with thin-film modules exhibited almost no change in capacity-weighted installed prices



Notes: Other Configurations includes a thin-film system with tracking, two systems with silicon ribbon modules, and a system with a combination of fixed and tracking arrays.

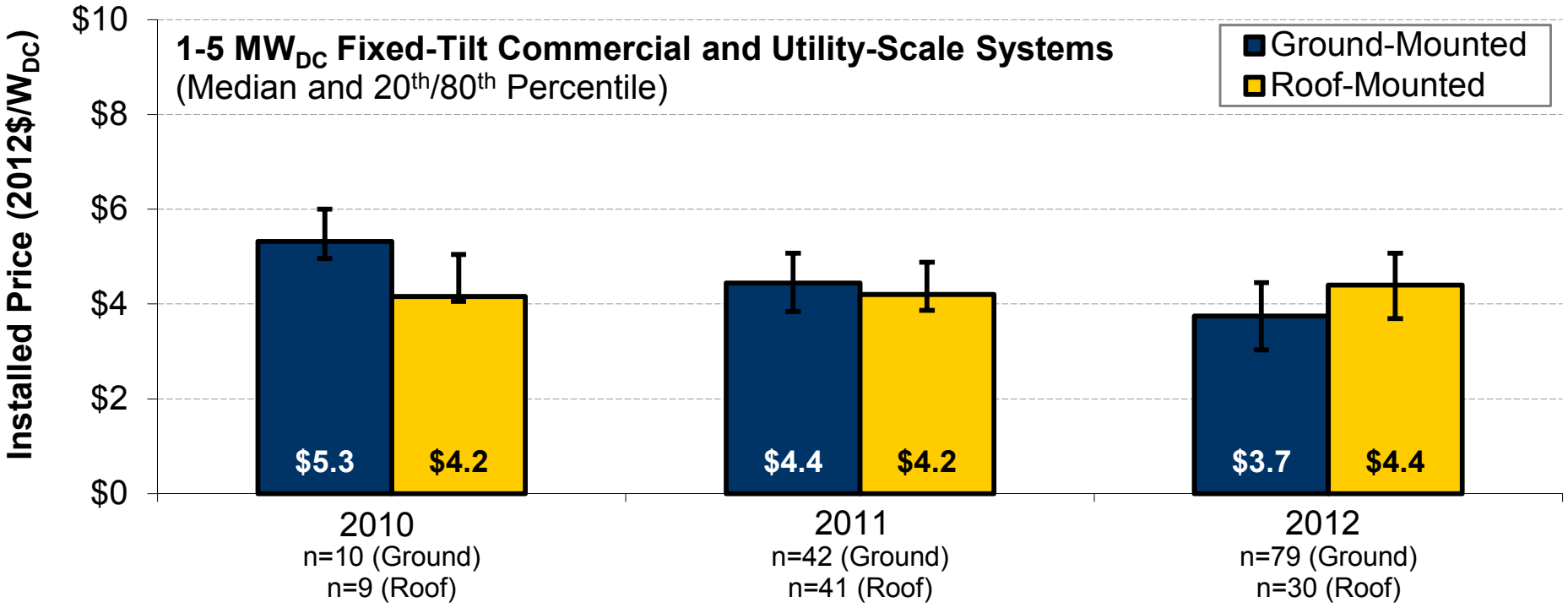
Project size and system configuration impact the installed price of utility-scale PV

- Installed prices are somewhat lower and more uniform for larger utility-scale systems, with most projects >10 MW ranging from $2.5/W to $4.0/W, while projects ≤10 MW exhibit a long tail to the price distribution, with 20% of projects exceeding $4.0/W and several above $5.0/W
- Among systems >10 MW installed in 2012, the capacity-weighted average installed price for crystalline systems with tracking was $0.5/W higher than for crystalline systems with fixed tilt



Installed price differences between small utility-scale and large commercial rooftop systems are inconsistent

- In 2012, the median installed price of 1-5 MW commercial rooftop systems was $0.7/W higher than similarly sized utility-scale (fixed-tilt, ground-mounted) systems
- The directionality of these trends has varied over time (from 2010-2012), which is likely an artifact of small sample size and the idiosyncrasies therein



Outline of presentation

- Data Summary
- Installed Price Trends: Residential and Commercial PV
- Installed Price Trends: Utility-Scale PV
- **Conclusions and Policy Implications**

Conclusions and policy implications

- PV installed prices declined substantially from 1998 through 2012 (and into 2013), but the pace and source of those reductions have varied over time
- Installed price reductions since 2008 are associated primarily with a decline in module costs; given the limits to further reductions in module costs, continued deep reductions in installed system prices will need to come primarily from non-module costs, and in particular from “soft costs”
- Lower installed prices in other major international PV markets (most notably, Germany) and within some U.S. states, as well as the high degree of variability in U.S. system pricing, suggests that deep near-term reductions in PV soft costs are possible and may accompany deployment scale, though other factors are also clearly important
- Achieving deep reductions in soft cost may also require some combination of: incentive policy designs that provide a stable and straightforward value proposition, targeted policies aimed at specific soft costs (for example, permitting and interconnection), and basic and applied research and development

For more information

Download the full report, with appendices and bibliography, along with the companion briefing and data file:

http://emp.lbl.gov/sites/all/files/lbnl-6350e.pdf (full report)

http://emp.lbl.gov/sites/all/files/lbnl-6350e-ppt.pdf (briefing)

http://emp.lbl.gov/sites/all/files/lbnl-6350e-data.xls (data file)

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