Tracking the Sun

The Installed Cost of Photovoltaics in the U.S. from 1998-2007

Ryan Wiser, Galen Barbose, Carla Peterman

Lawrence Berkeley National Laboratory

- Report Summary -

February 2009

Thanks to the U.S. DOE's Solar Energy Technologies Program and Office of Electricity Delivery and Energy Reliability, and to the Clean Energy States Alliance, for supporting this work

Project Overview

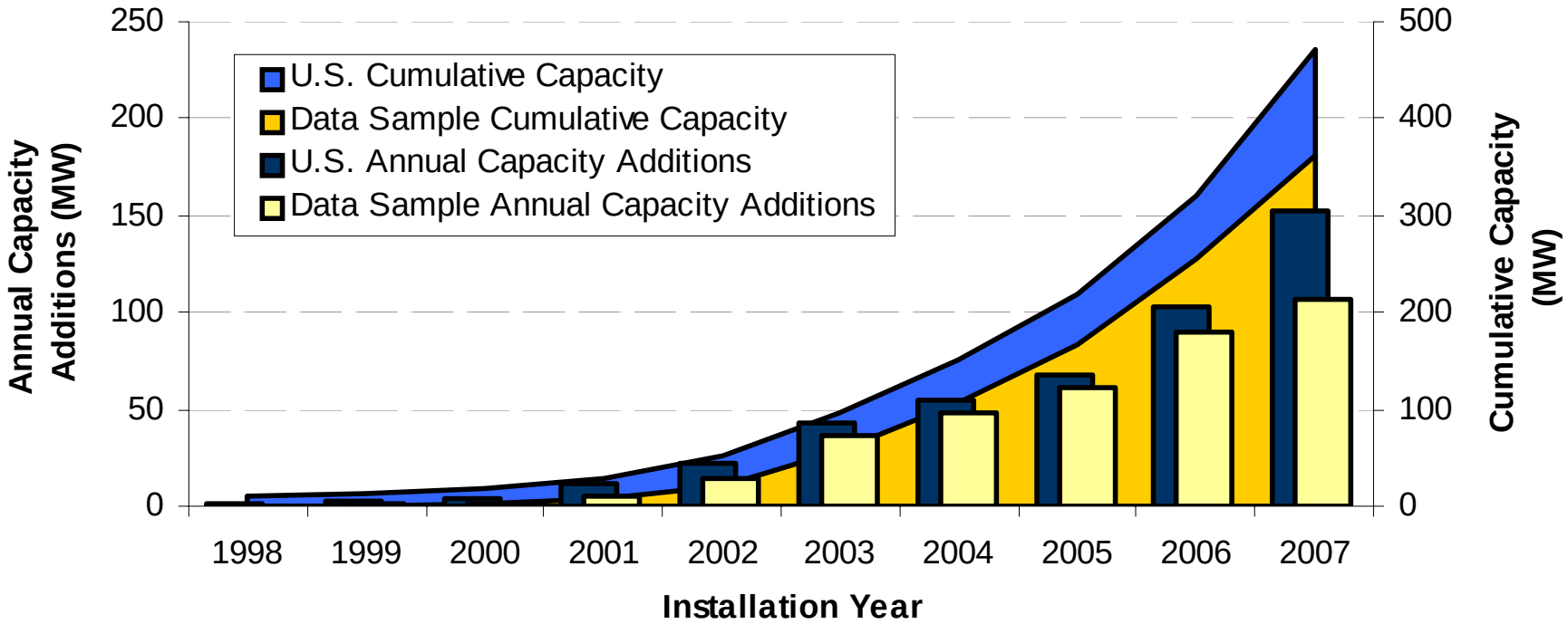
Objective: Using project-level data, evaluate trends in the installed cost of grid-connected PV systems throughout the U.S. to answer the following:

- How have installed PV costs changed over time?
- To what extent are these trends associated with module vs. non-module costs?
- To what extent do installed costs decline with system size?
- To what extent have costs varied country, by state, and by incentive program?
- How do costs differ between applications and technologies:
  - new construction vs. retrofit?
  - building-integrated vs. rack-mounted?
  - thin-film vs. crystalline silicon?
- What are the trends in component-level costs?
- How have PV incentives changed over time, and how do they vary across states?
- How have net installed costs for residential and commercial PV changed over time, and how do they vary across states?

Data and Methodology

- Sought project-level cost data from as many PV incentive programs in the U.S. as reasonably feasible, with some focus on larger programs
- Ultimately, data were obtained from 16 solar incentive programs spanning 12 states, with PV system sizes ranging from 100 W_{DC} to 1.3 MW_{DC}
- Primary sample includes roughly **37,000 grid-connected PV systems** installed from 1998-2007, totaling **363 MW_{DC}**
  - All systems in the primary sample are installed on the utility-customer-side of the meter
  - Additional cost data for five 2+ MW systems, several of which are installed on the utility-side of the meter, were obtained from press releases and other public sources
- Reported costs are those paid by the system owner, before any incentives
- All cost data are expressed in real 2007$, and all size data are converted to $W_{DC\text{-}STC}$ (denoted as W_{DC} in slides)
- Data were cleaned to only include system costs of \$3-30/W_{DC}, systems where installed cost > total incentive, and only systems with installed cost, size, and incentive level reported

Primary Sample Represents 76% of All Grid-Connected PV Installed through 2007



Source for U.S. Capacity Data: Sherwood, L. 2008. U.S. Solar Market Trends 2007. Interstate Renewable Energy Council.

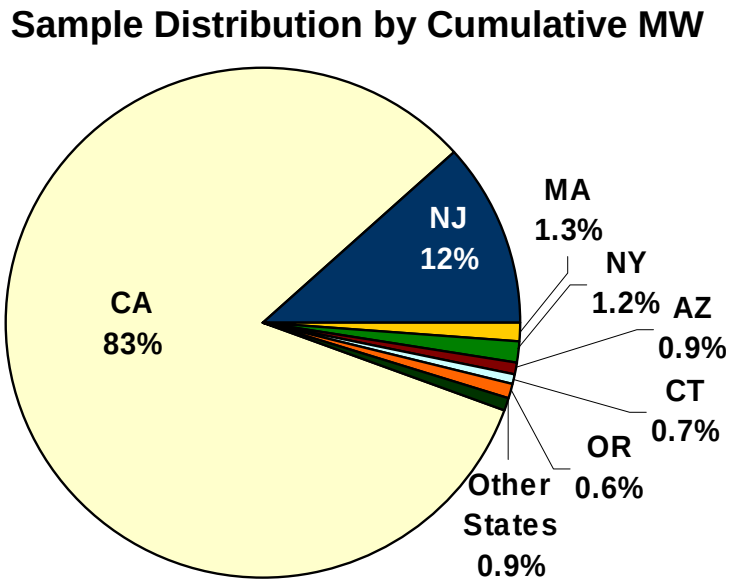
- Estimated $990 million investment in grid-connected PV installations in the U.S. in 2007; primary data study sample represents $810 million
- Including the additional five >2 MW projects (for which cost data were obtained from press releases and other public sources) in the tally brings the sample to **89%** of cumulative U.S. grid-connected PV capacity through 2007

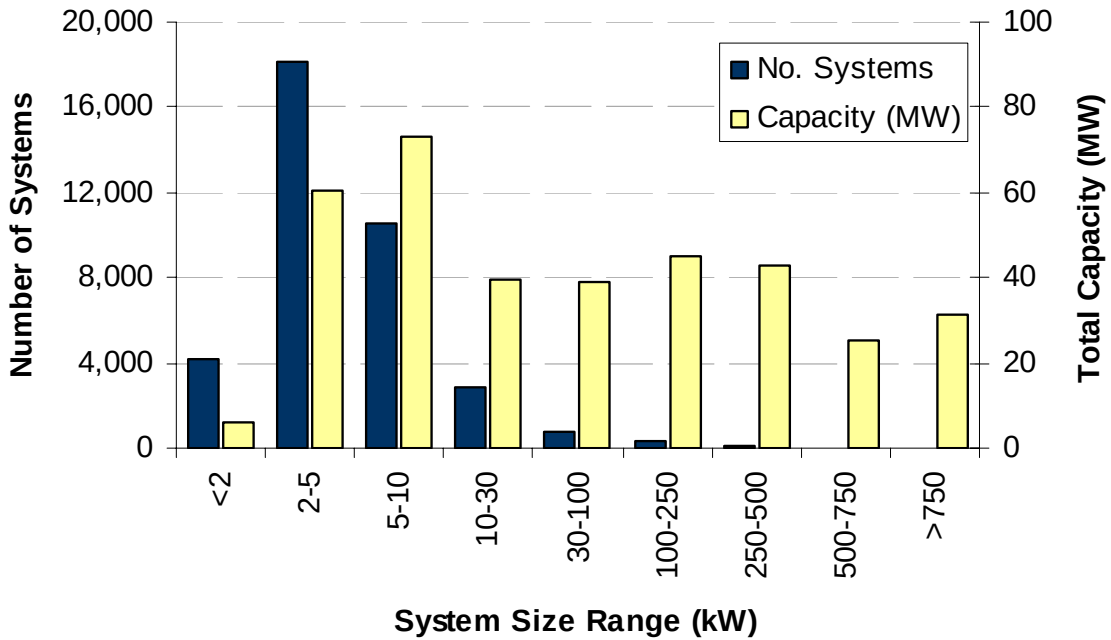
Summary of PV Incentive Program Data

State	PV Incentive Program	No. of Systems	Total MW	% of Total MW	Size Range (kW)	Year Range
AZ	Solar Partners Incentive Program (APS)	540	3.1	0.9%	0.4 – 255	2002 - 2007
CA	Emerging Renewables Program (CEC)	27,267	143.0	39.4%	0.1 – 670	1998 - 2007
	Self Generation Incentive Program (PG&E, SCE, CCSE)	801	132.6	36.5%	34 – 1,265	2002 - 2007
	California Solar Initiative (PG&E, SCE, CCSE)	2,303	14.3	3.9%	1.2 – 1,182	2007
	Solar Incentive Program (LADWP)	592	10.6	2.9%	0.3 – 467	1999 - 2006
CT	Solar PV and Onsite Renewable DG Programs (CT Clean Energy Fund)	311	2.7	0.7%	1.0 – 434	2003 - 2007
IL	Renewable Energy Grant Programs (Illinois Clean Energy Community Foundation)	21	0.6	0.2%	1.0 – 110	2002 - 2005
	Renewable Energy Resources Rebate Program (IL DCEO)	145	0.7	0.2%	0.8 – 60	1999 - 2007
MA	Small Renewables Initiative (MTC)	702	4.7	1.3%	0.2 – 432	2002 - 2007
MD	Solar Energy Grant Program (MEA)	78	0.2	0.1%	0.5 – 45	2005 - 2007
MN	Solar Electric Rebate Program (MN State Energy Office)	105	0.4	0.1%	0.9 – 40	2002 - 2007
NJ	Customer Onsite Renewable Energy Program (NJCEP)	2,395	42.1	11.6%	0.8 – 702	2003 - 2007
NY	PV Incentive Program (NYSERDA)	755	4.4	1.2%	0.7 – 51	2003 - 2007
OR	Solar Electric Program (Energy Trust of Oregon)	600	2.3	0.6%	0.8 – 67	2003 - 2007
PA	Solar PV Grant Program (Sustainable Development Fund)	137	0.5	0.1%	1.2 – 10	2002 - 2007
WI	Cash Back Rewards Program (WI Focus on Energy)	240	0.9	0.2%	0.2 – 19	2002 - 2007
	Total	***36,992***	***363.1***	***100%***	***0.1 – 1,265***	***1998 - 2007***

Note: Dates used in this report are the system completion dates, or whatever date is provided that best approximates that date

Summary Information on Dataset:
States, System Size, Temporal Distribution





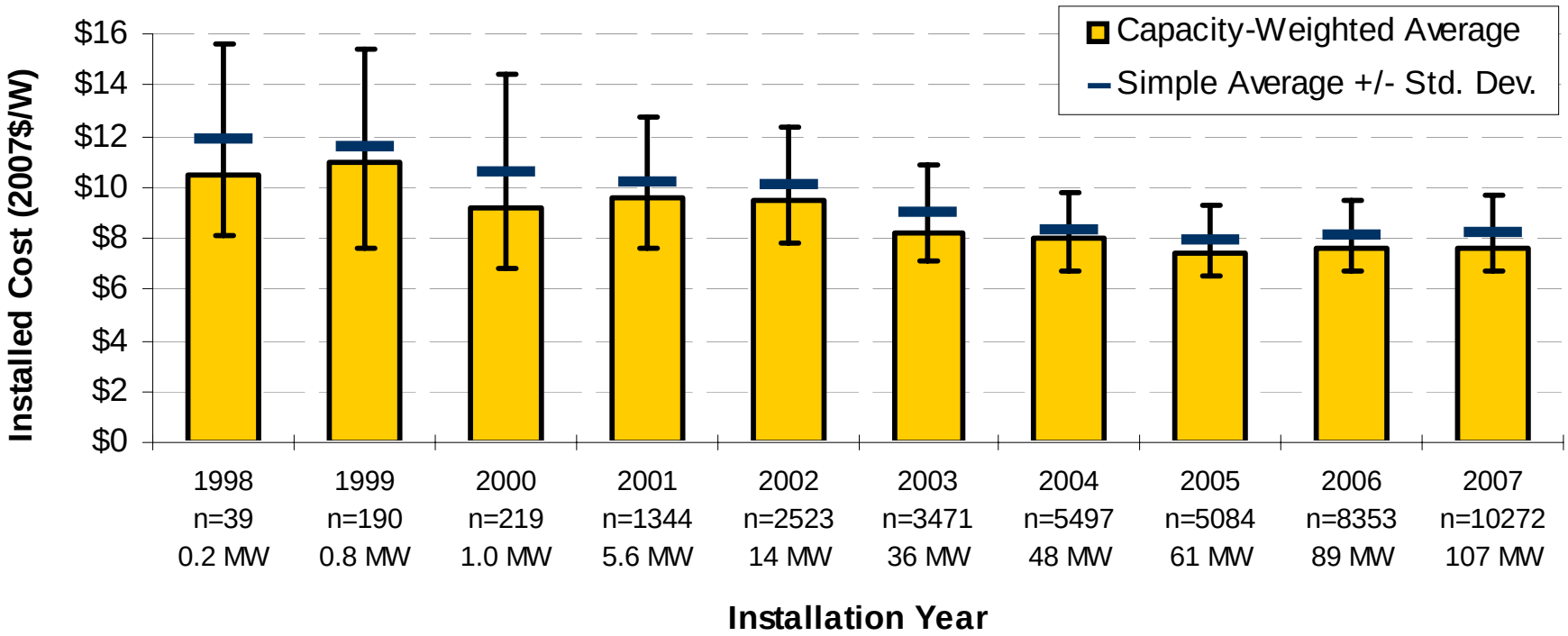
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Total
No. of Systems	39	190	219	1,344	2,523	3,471	5,497	5,084	8,353	10,272	**36,992**
% of Total	0.1%	0.5%	0.6%	3.6%	6.8%	9.4%	14.9%	13.7%	22.6%	27.8%	**100%**
Capacity (MW)	0.2	0.8	1.0	5.6	14.0	36.0	47.9	61.2	89.3	107.0	**363.1**
% of Total	0.1%	0.2%	0.3%	1.6%	3.9%	9.9%	13.2%	16.9%	24.6%	29.5%	**100%**

PV Installed Cost Trends

(Prior to Receipt of Financial Incentives, Tax Credits, Renewable Energy Certificate Revenues, etc.)

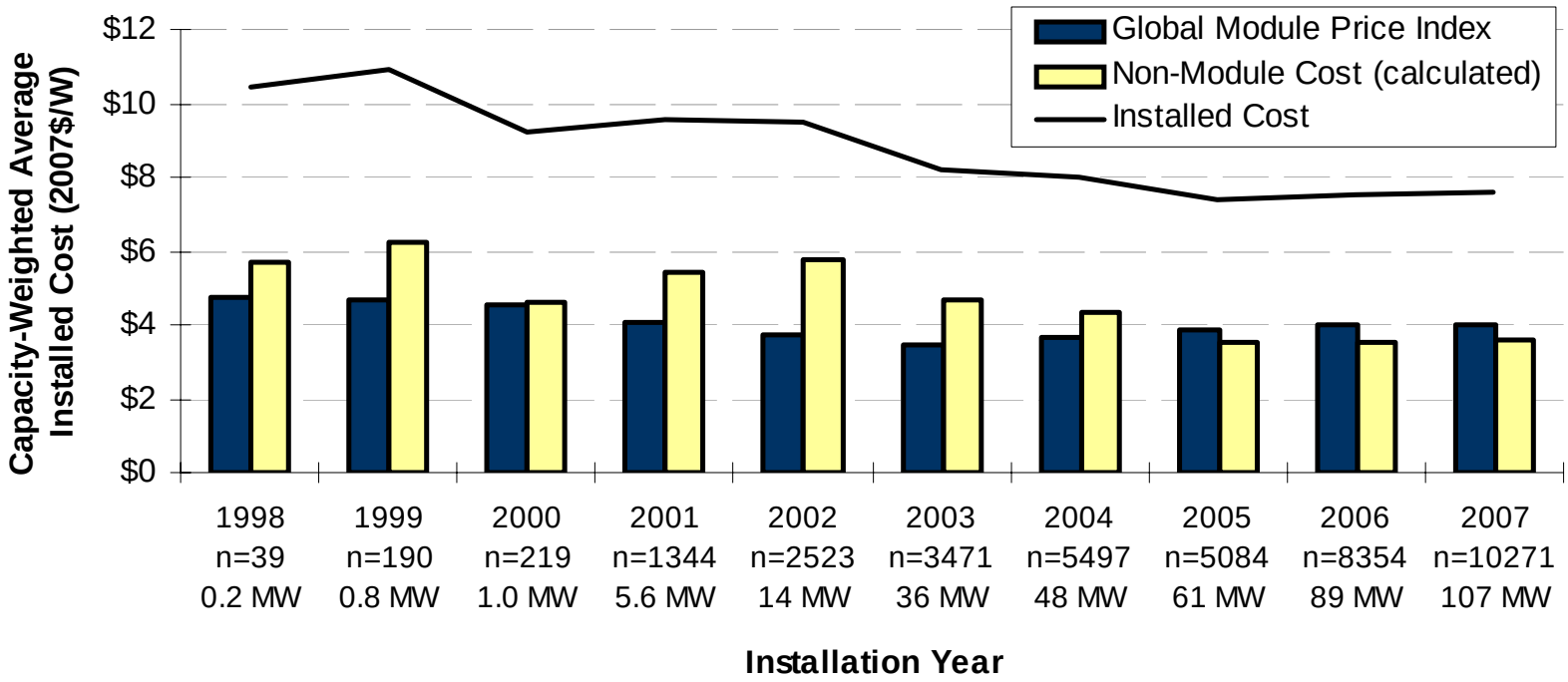
Installed Costs Declined from 1998-2007, but Were Stable from 2005-07

Average annual reduction of **$0.3/W$_{DC}$** in real 2007$ (3.5%/yr) from 1998-2007 (but no apparent reduction in costs from 2005-2007)



Installed Cost Reductions Are Primarily Associated with Non-Module Costs

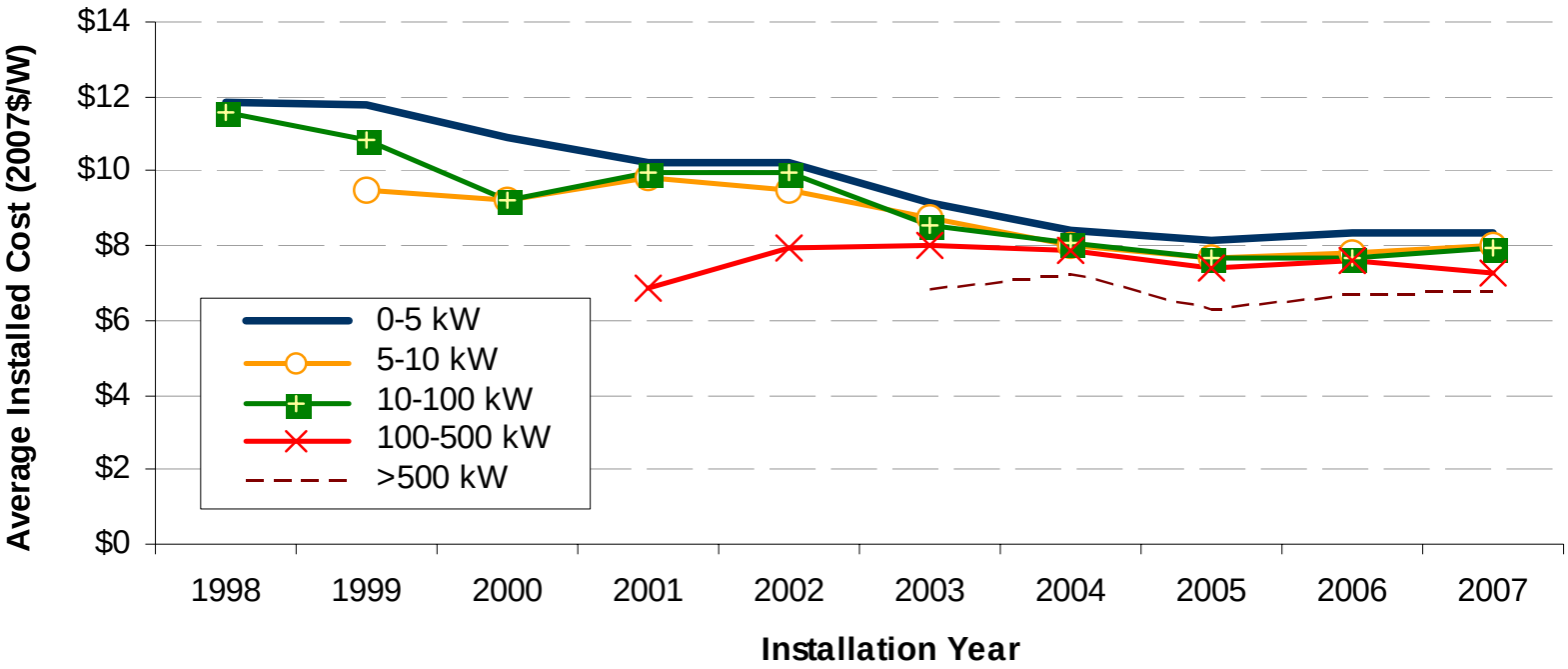
Module costs are largely set in a worldwide market; reductions in *non-module* costs suggest that state/local PV programs have had some success in driving down installed costs (though again, there is little evidence of cost reductions from 2005-2007)



Note: Non-module costs are calculated as the reported total installed costs minus the global module price index.

Historical Cost Reductions Are Most Evident Among Smaller Systems

Average annual reduction of **$0.4/W$_{DC}$** in real 2007$ from 1998-2007 for systems < 5 kW; no significant change in cost of systems > 100 kW since 2001



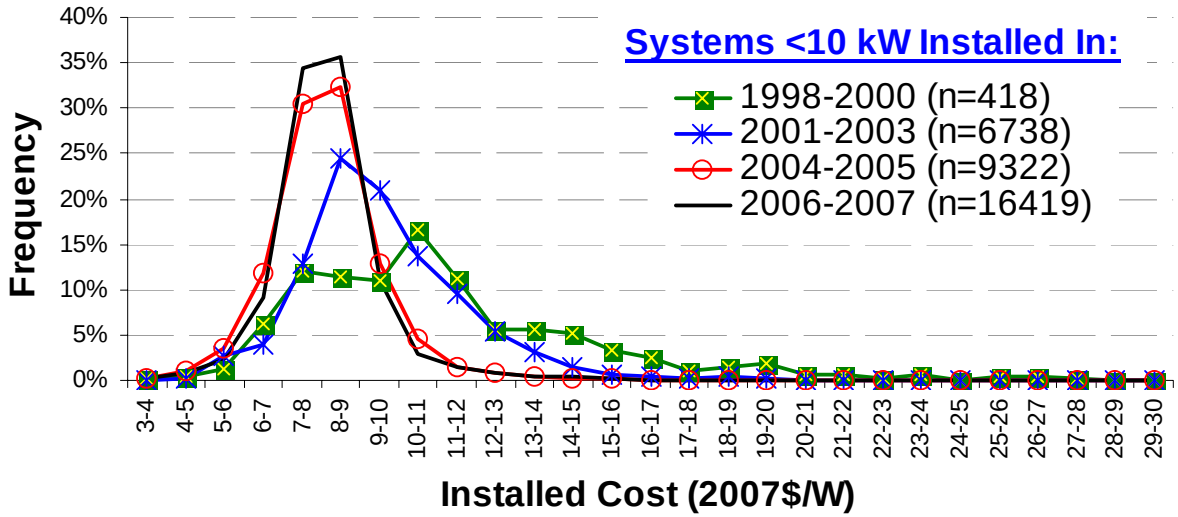
Note: Averages shown only if more than five observations were available for a given size category in a given year.

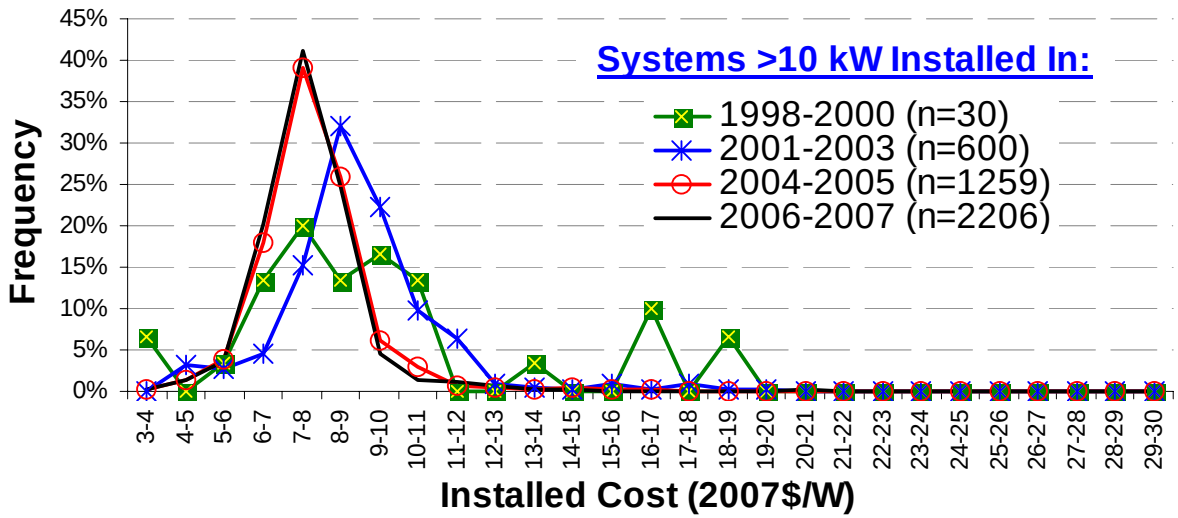
Cost Distributions Have Narrowed and Shifted With Time

Average Costs Declining Due To:

Shifting: Overall shift of the cost distributions toward lower costs, until 2004 when stabilized

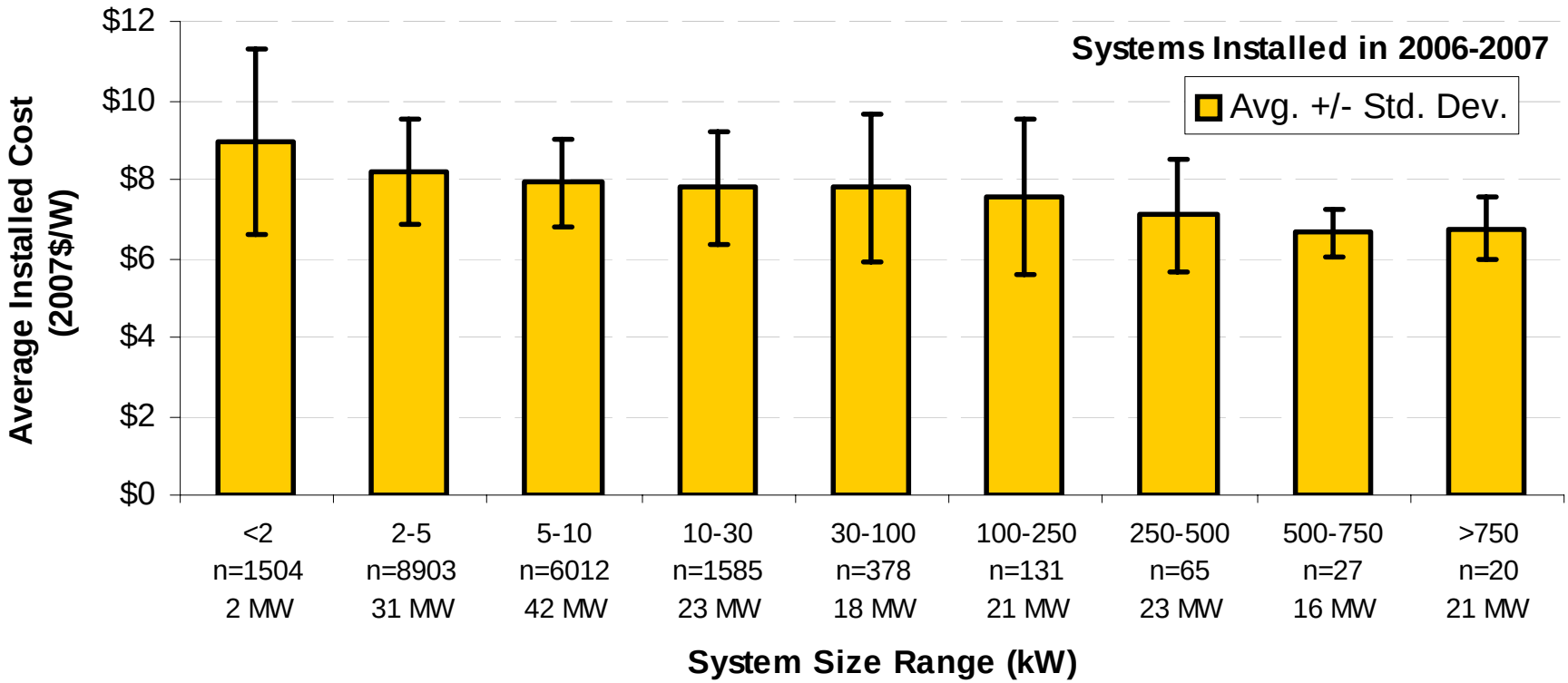
Narrowing: Reduction in high-cost outliers, demonstrating a maturing market in which competition has become more robust





Economies of Scale Drive Down Costs as System Size Increases

Largest systems are **~$2.2/W$_{DC}$** (~25%) cheaper, on average, than smallest installations; most significant economies of scale occur up to 5 kW, and from 100-750 kW



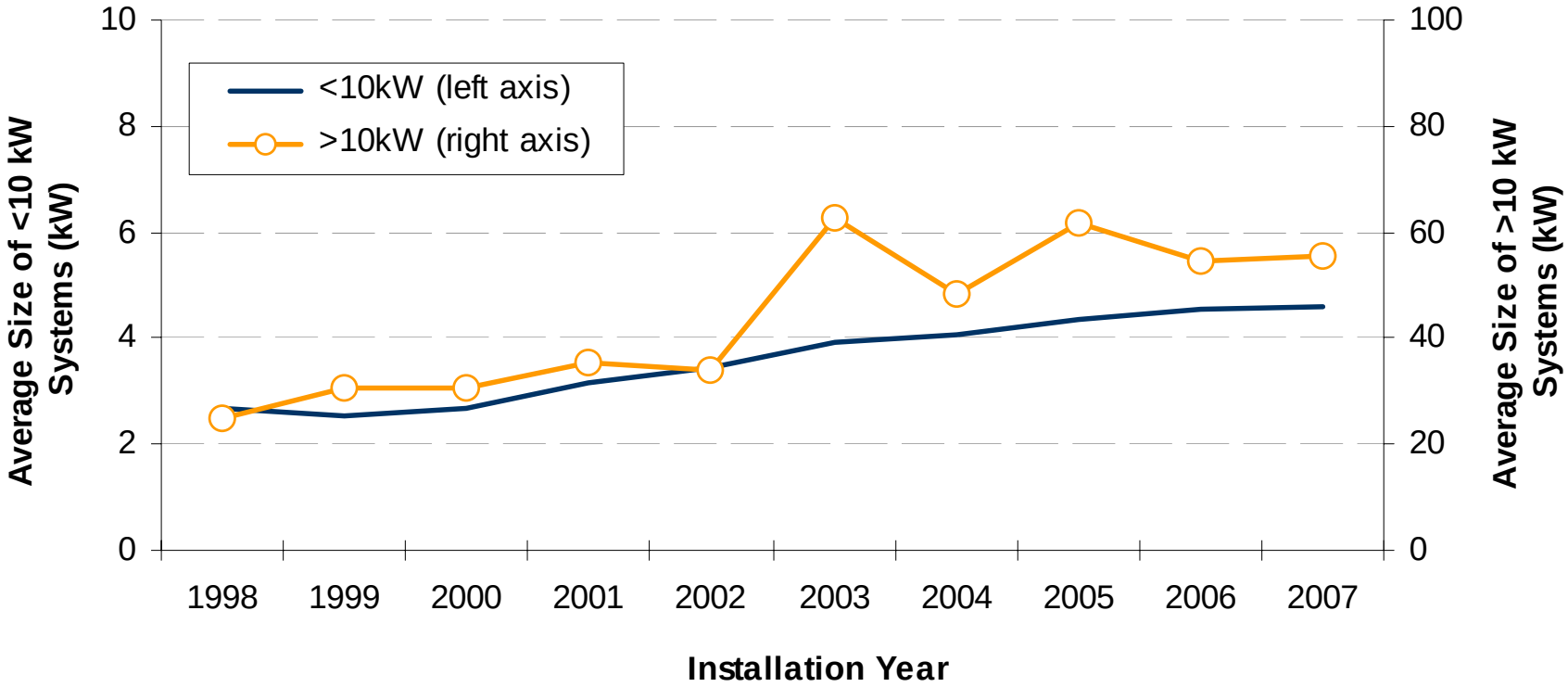
Large Projects *Not* in Our Primary Sample Have Similar Installed Costs to the >750 kW Systems in the Sample

Location	Year of Installation	Plant Size (kW)	Installed Cost (2007$/W)	Actual or Expected Capacity Factor	Tracking System Design
Nellis, NV	2007	14,200	7.0	24%	single axis
Alamosa, CO	2007	8,220	7.3	24%	fixed, single axis, and double axis
Fort Carson, CO	2007	2,000	6.5	18%	fixed
Springerville, AZ	2001-2004	4,590	5.9	19%	fixed
Prescott Airport, AZ	2002-2006	3,388	5.4	21%	single axis and double axis

Notes: Cost for Springerville is for capacity added in 2004. Cost for Prescott is for single-axis capacity additions in 2004.

- A number of these large projects, however, have tracking systems, and are therefore likely to attain higher performance, and a lower levelized cost of electricity
- Though not reported here, a number of utility-scale projects installed in 2008 are reported to have *substantially* lower installed costs

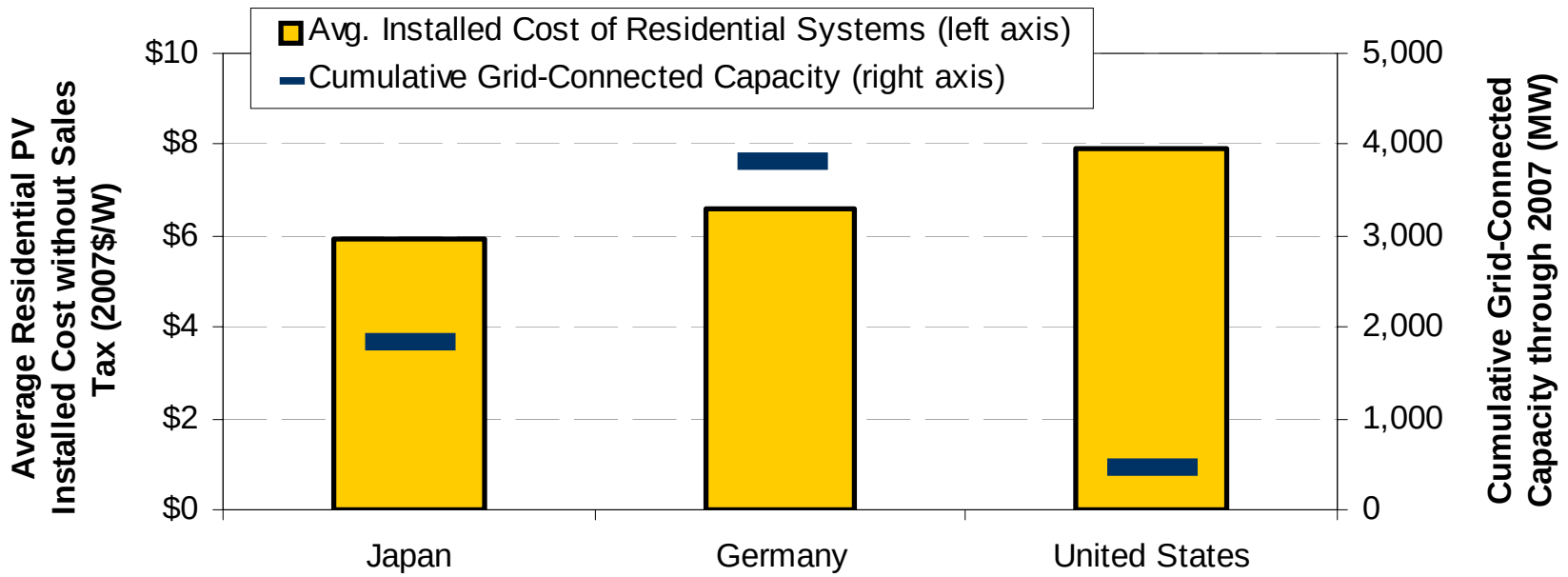
Temporal Cost Reductions Partially Reflect Increasing Average System Size



- Average system size approximately doubled from 1998-2007, both for systems <10 kW and for systems >10 kW
- 10 kW used as a rough proxy to differentiate residential and non-residential systems, because several programs do not report customer type

Avg. Cost for Residential PV In the U.S. Exceeds that in Japan and Germany

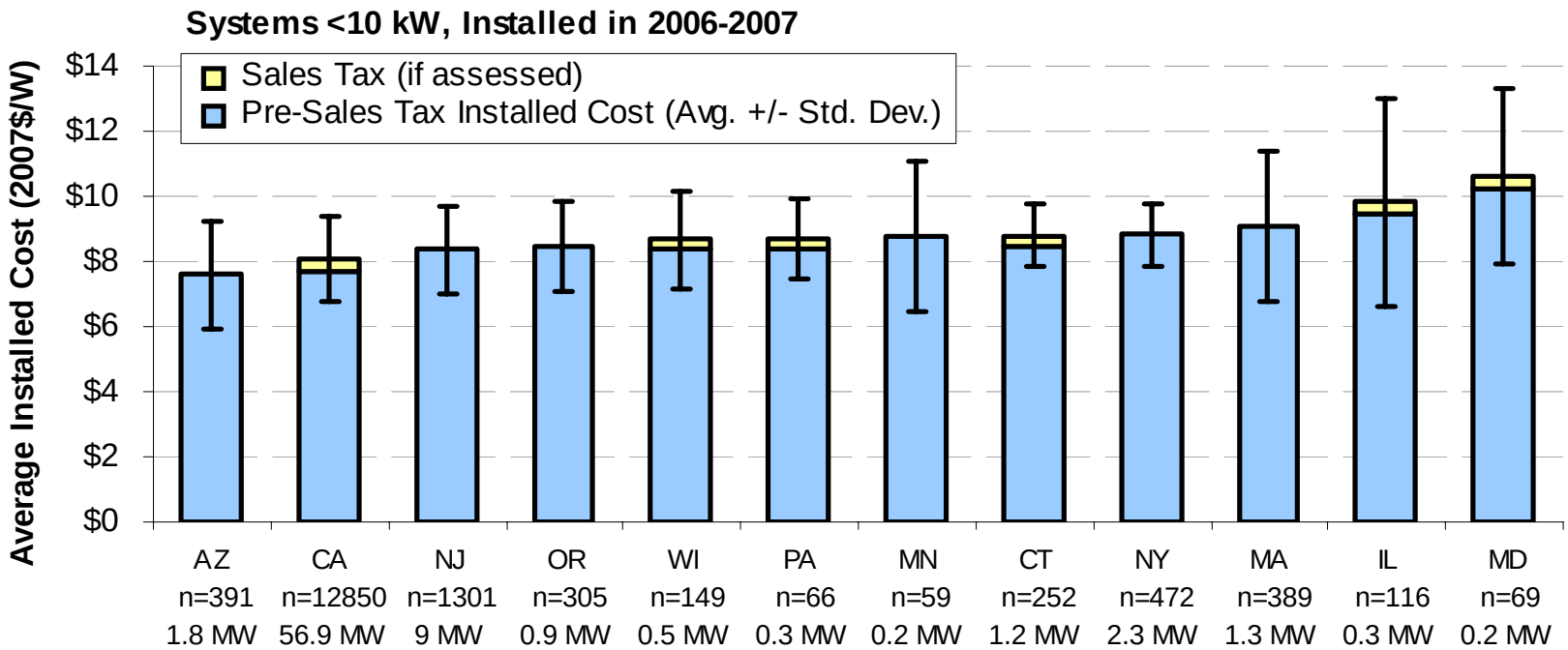
Figure presents average cost of residential systems installed in 2007, excluding sales tax and VAT, and cumulative grid-connected PV capacity



- Lower costs in Japan and Germany suggest that further near-term cost reductions in the U.S. may be possible
- Lower costs may be partly attributable to greater deployment scale, but other factors also likely play an important role

Average Cost for PV Systems < 10 kW Vary Widely Across States

Two largest markets, California and New Jersey, are among the lowest cost; suggests that larger PV markets stimulate greater competition and hence greater efficiency in the delivery chain for PV, but other factors clearly also play an important role in determining average installed costs



A small portion of the cost difference reflects varying sales tax incentives

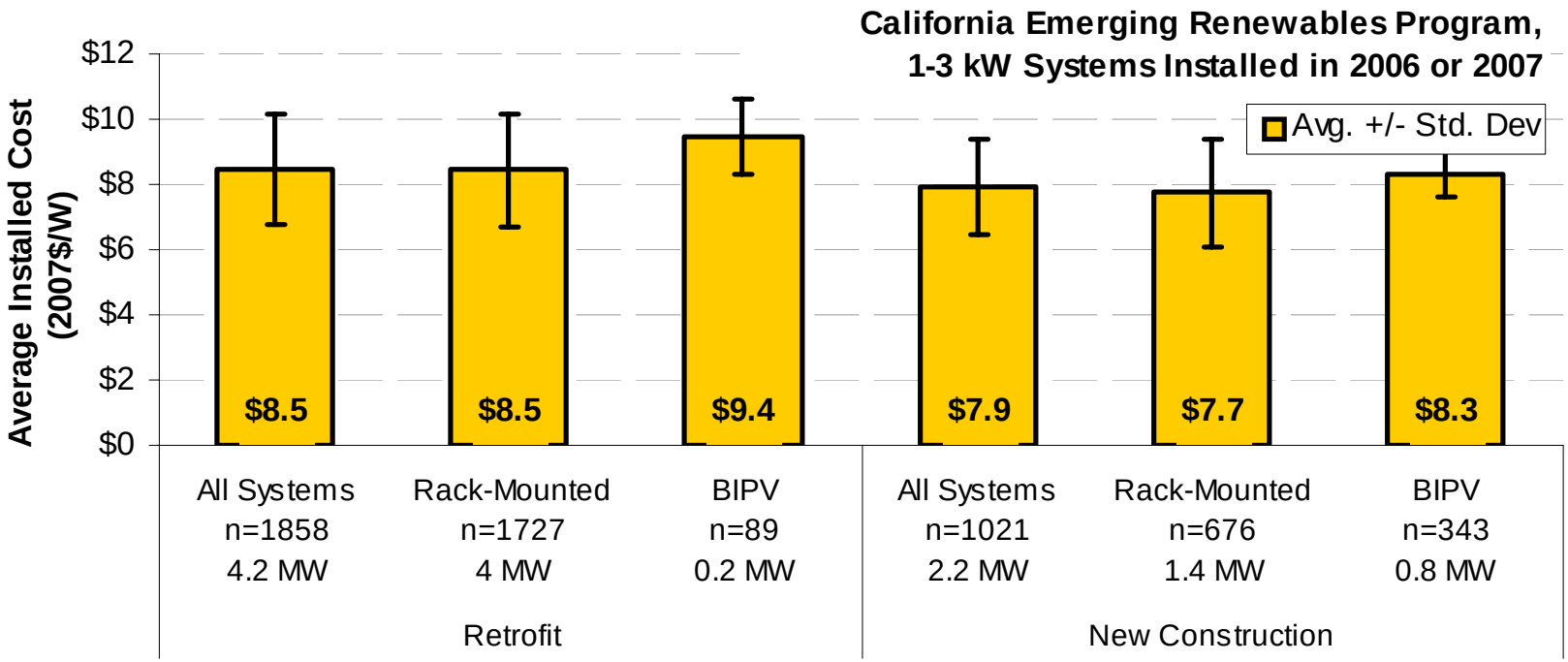
Note: Sales tax, if assessed on customer-sited PV installations in 2006-07, was assumed to be applied to only hardware costs, which were assumed to constitute 60% of the total pre-sales-tax installed cost.

Cost Variation Across States Persists Across System Sizes

State	Total Sample Capacity-Weighted Average Cost		2006-2007 Systems									
			Capacity-Weighted Average Cost (all sizes)		Simple Average Cost							
					0 - 10 kW		10 - 100 kW		100 - 500 kW		>500 kW	
AZ	$7.8	(n=540)	$7.6	(n=413)	$7.6	(n=391)	$8.1	(n=20)	$9.1	(n=2)	n/a	(n=0)
CA	$7.7	(n=30963)	$7.5	(n=14614)	$8.1	(n=12850)	$7.6	(n=1607)	$7.3	(n=136)	$6.7	(n=33)
CT	$8.4	(n=311)	$8.3	(n=274)	$8.8	(n=252)	$8.1	(n=19)	$7.9	(n=3)	n/a	(n=0)
IL	$12.4	(n=166)	$8.5	(n=118)	$9.8	(n=116)	$3.3	(n=2)	n/a	(n=0)	n/a	(n=0)
MA	$9.7	(n=702)	$9.6	(n=415)	$9.1	(n=389)	$10.1	(n=24)	$8.8	(n=5)	n/a	(n=0)
MD	$9.8	(n=78)	$9.7	(n=71)	$10.6	(n=69)	$8.5	(n=2)	n/a	(n=0)	n/a	(n=0)
MN	$8.4	(n=105)	$8.5	(n=60)	$8.8	(n=59)	$8.7	(n=3)	n/a	(n=0)	n/a	(n=0)
NJ	$7.7	(n=2395)	$7.5	(n=1588)	$8.4	(n=1301)	$8.4	(n=272)	$7.6	(n=50)	$6.7	(n=15)
NY	$8.8	(n=755)	$8.8	(n=519)	$8.8	(n=472)	$8.9	(n=52)	n/a	(n=0)	n/a	(n=0)
OR	$8.0	(n=600)	$8.4	(n=324)	$8.4	(n=305)	$8.4	(n=19)	n/a	(n=0)	n/a	(n=0)
PA	$9.0	(n=137)	$8.7	(n=67)	$8.7	(n=66)	$8.4	(n=1)	n/a	(n=0)	n/a	(n=0)
WI	$8.4	(n=240)	$8.3	(n=162)	$8.7	(n=149)	$7.9	(n=16)	n/a	(n=0)	n/a	(n=0)

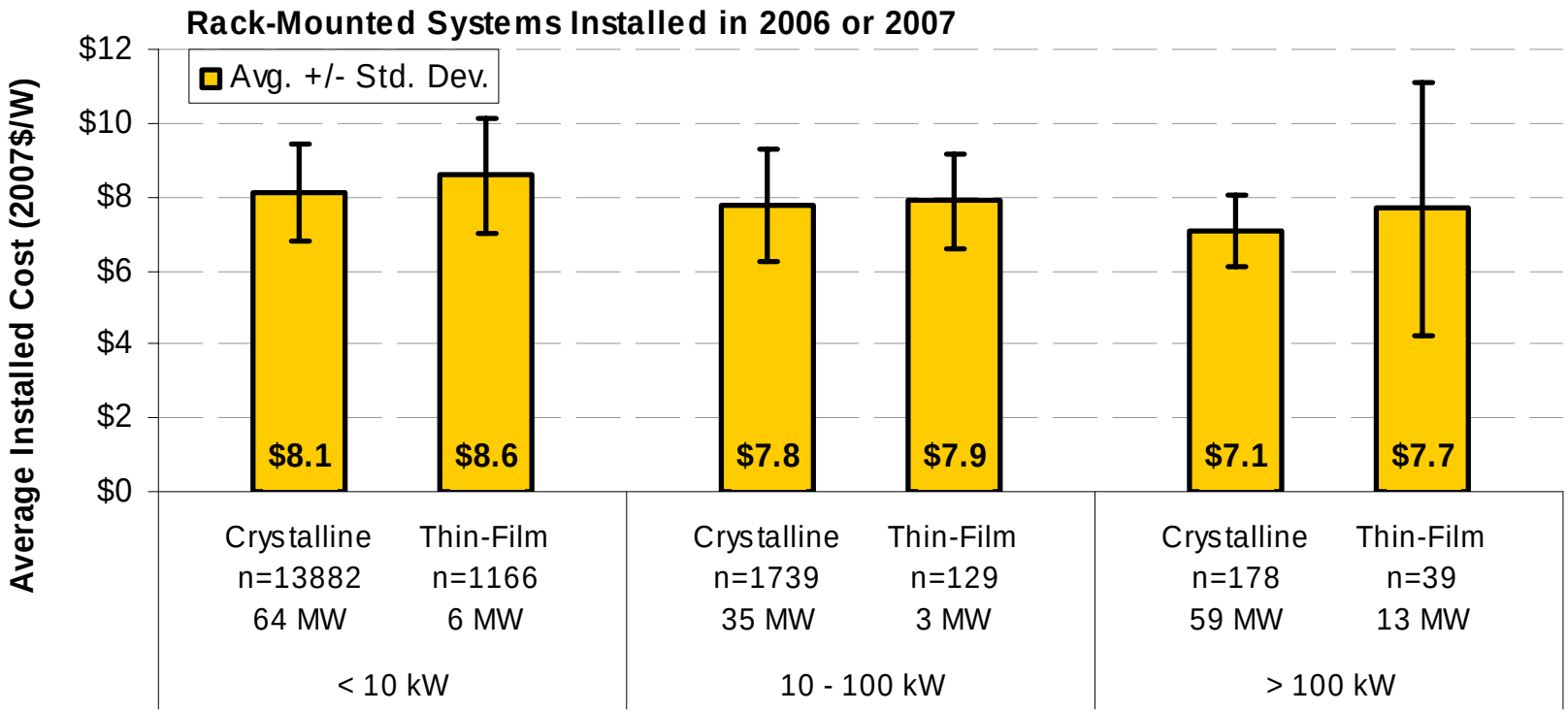
The New Construction Market Offers Cost Advantages for Residential PV

In 2006-2007, residential new construction systems cost **$0.6/$W_{DC}$** less, on average, than similar-sized retrofit systems (**$0.8/$W_{DC}$** if only rack-mounted systems are compared)



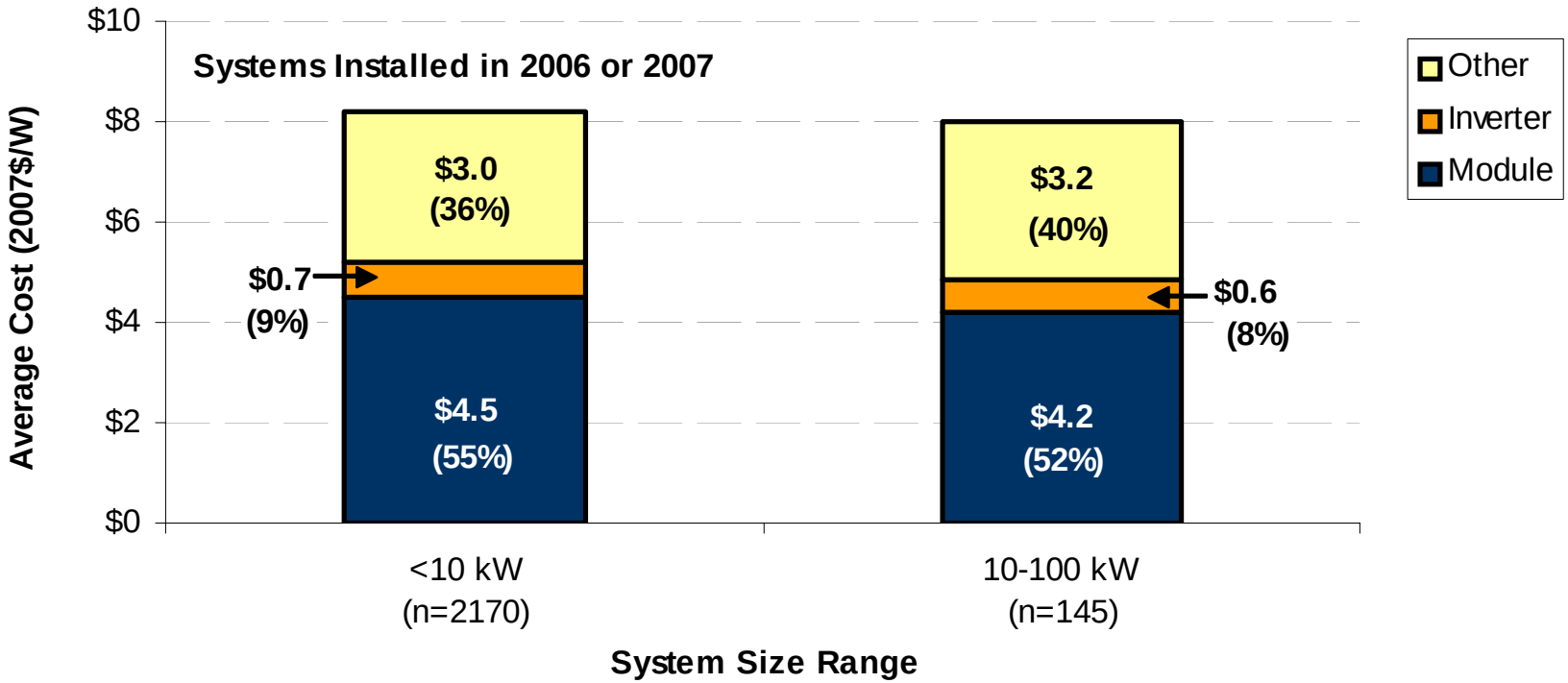
Note : The number of rack-mounted systems plus BIPV systems may not sum to the total number of systems, as some systems could not be identified as either rack-mounted or BIPV.

Thin-Film Systems Had Higher Installed Costs in 2006/07 than Those with Crystalline Modules



- For <10 kW systems, the installed cost of thin-film systems in 2006/07 was $0.5/W higher than systems with crystalline modules
- Average cost for >100 kW thin-film systems reflects a single, high-cost system; if this system is removed, average installed costs are nearly identical between thin-film and crystalline systems >100 kW

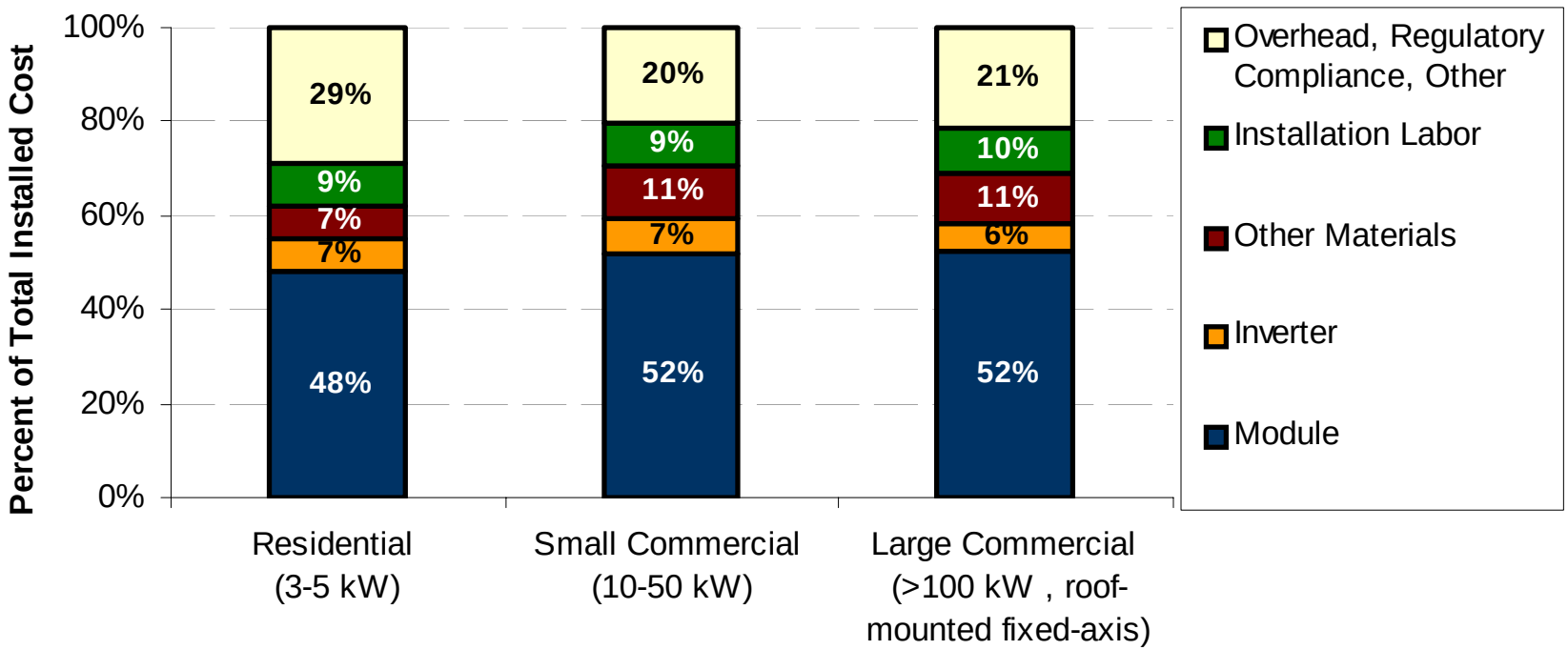
Module Costs Represent Just over 50% of Installed Costs



Of the 196 MW of 2006-2007 PV installations in our dataset, module *and* inverter cost data was provided for only 14 MW (7%), shown in this figure; many programs do not collect or did not provide component cost information

Non-Module Costs Consist of a Diversity of Components

Figure shows the results of a Berkeley Lab component-cost survey of PV installers, conducted in 2008 (i.e., the data presented below are based on a survey of installers, not the project-level data collected for this report)



Sample size: six installers provided survey responses for residential and large commercial systems, and five installers provided survey responses for small commercial systems.

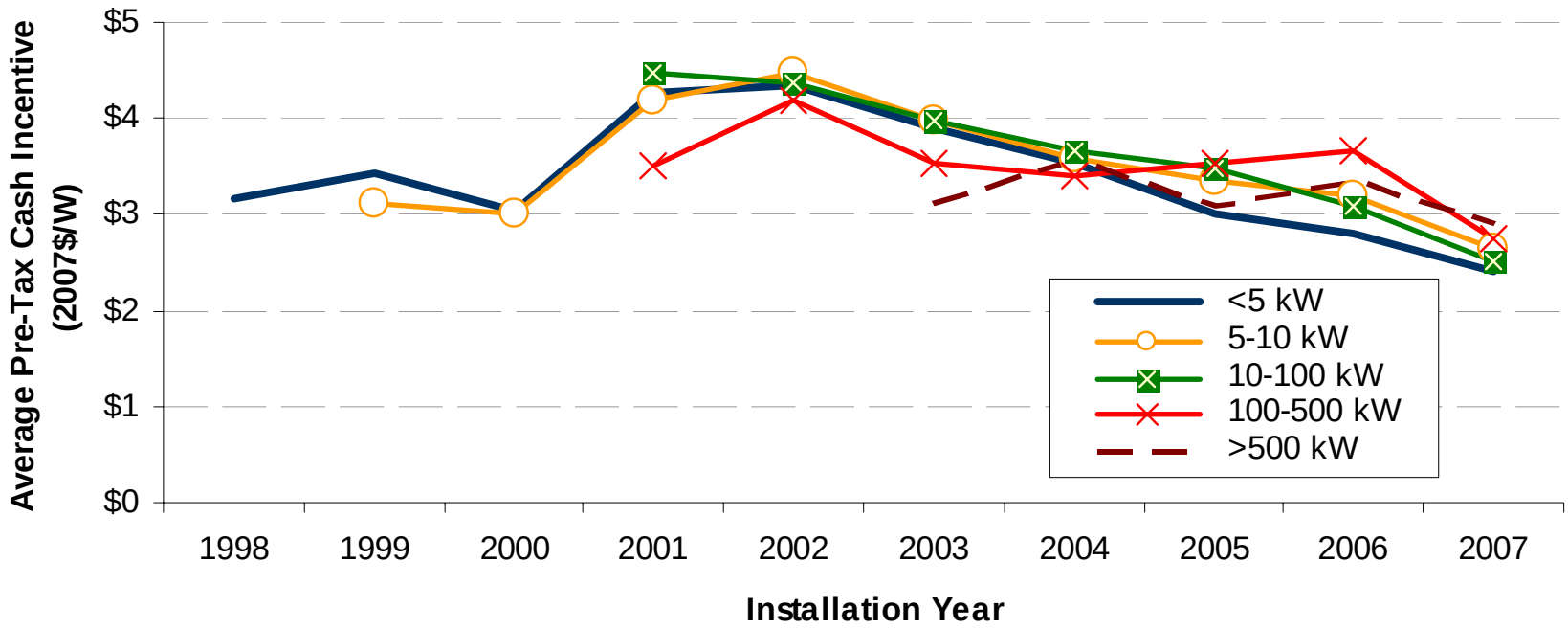
PV Incentive and Net Installed Cost Trends

Key Assumptions Used to Derive Incentive Trends and Net Installed Costs

- Incentives and net installed costs (i.e., customer cost after receipt of incentives) are calculated and account for:
  - Cash incentives provided by the 16 PV incentive programs in the data sample
  - State and Federal investment tax credits (ITCs)
- But do not account for:
  - Cash incentives potentially provided by other PV incentive programs
  - Revenue from renewable energy certificates (RECs)
  - The value of accelerated depreciation (applicable to commercial PV only)
- 10 kW was used to delineate between residential and commercial PV if no other information was available on customer type
- See the full report for details on the calculation of after-tax incentives

State/Utility Cash Incentives Have Declined since 2002

Figure shows the average **cash incentive** on a pre-tax basis



Note: Averages shown only if more than five observations available for a given size range in a given year.

- Cash incentives from PV programs in dataset declined by $1.9/W from 2002-07 for <100 kW systems, and by $1.4/W for 100-500 kW systems
- Trends largely reflect incentive levels under CA and NJ programs

REC Revenues Add to Overall Incentives, But Impact Varies Widely

In general, the revenue potential from the sale of RECs depends on where the system is located and what REC markets are available:

1. **Voluntary REC Markets**: prices averaged about $20/MWh in 2007, which, extrapolated over a 20-year period, are equivalent to $0.23/W on a pre-tax present-value basis
2. **Traditional RPS Markets** (no solar set-aside): the highest prices in 2007 occurred in Massachusetts, where Class I RECs averaged $55/MWh, equivalent to $0.63/W (if extrapolated over a 20-year period)
3. **RPS Solar Set-Aside Markets**: Solar REC prices in New Jersey averaged $253/MWh in 2007, equivalent to $2.9/W (if extrapolated over a 20-year period)

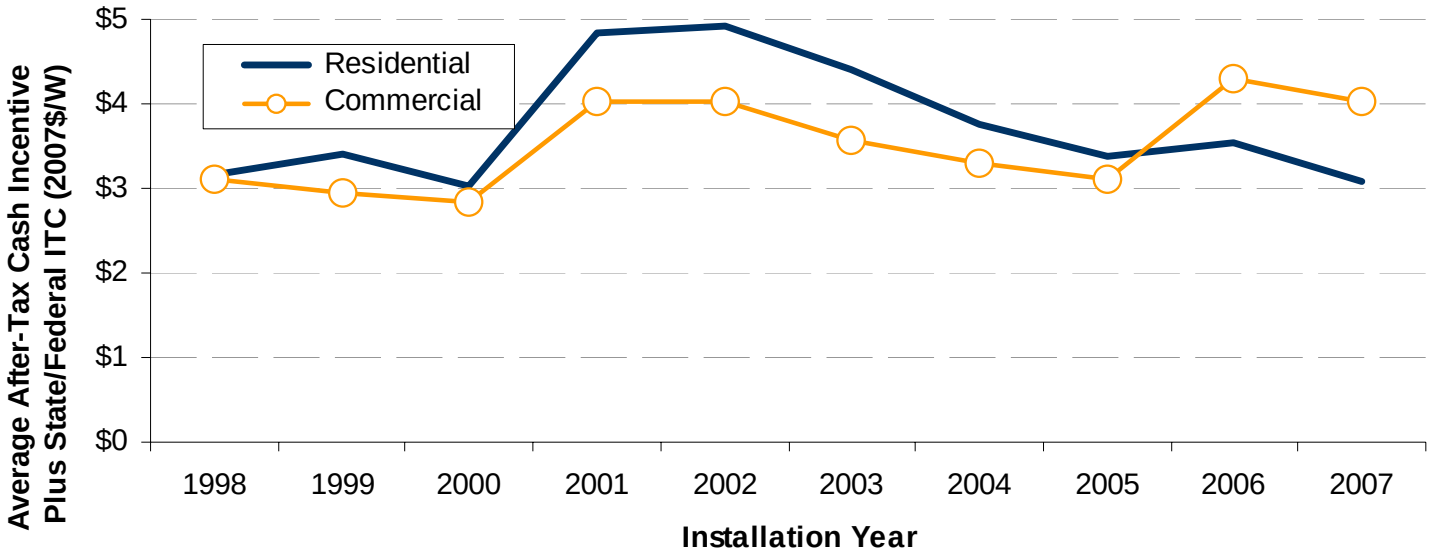
** Source of historical REC price data: Evolution Markets*

*** $/W estimates calculated assuming 10% nominal discount rate and 14% capacity factor*

Because the present-value of REC revenue is uncertain and variable, this value is **not** included in the slides that follow

Including Federal and State ITCs, Financial Incentives Rose for Commercial PV from 2002-2007, But Fell for Residential PV

Figure shows the combined value, on an after-tax basis, of direct **cash incentives** plus **state/Federal ITCs** (excludes RECs and accelerated depreciation)

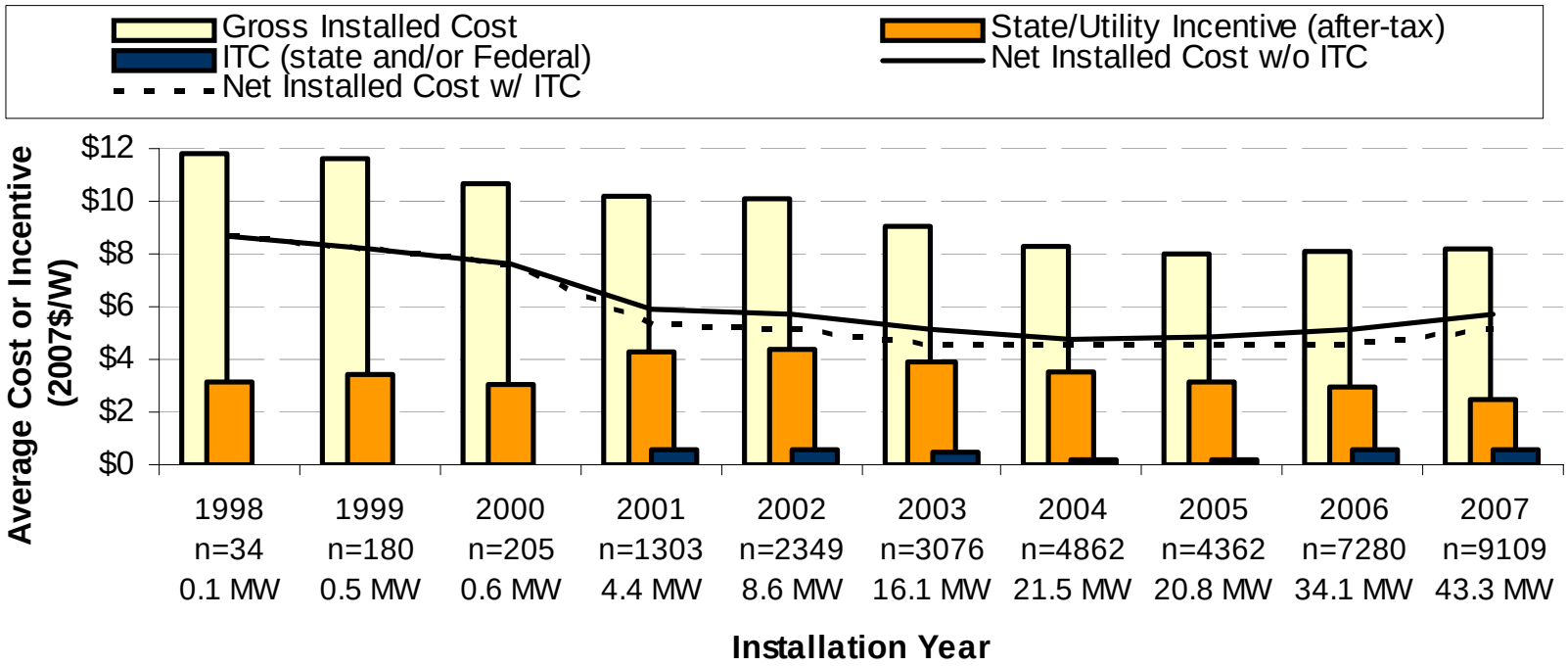


Shift towards commercial PV installations from 2005-07 likely partially explained by these trends

- Increase in Federal ITC in 2006 for commercial PV provided a significant boost; consequently, incentives for commercial PV were at a near-high in 2007
- Residential PV will see a similar benefit starting in 2009, as a result of the lifting of the $2,000 cap on the Federal ITC for residential PV

Declining Financial Incentives for Residential PV Offset Much of the Cost Reductions from 2001-07, Yielding Relatively Flat Net Installed Costs...

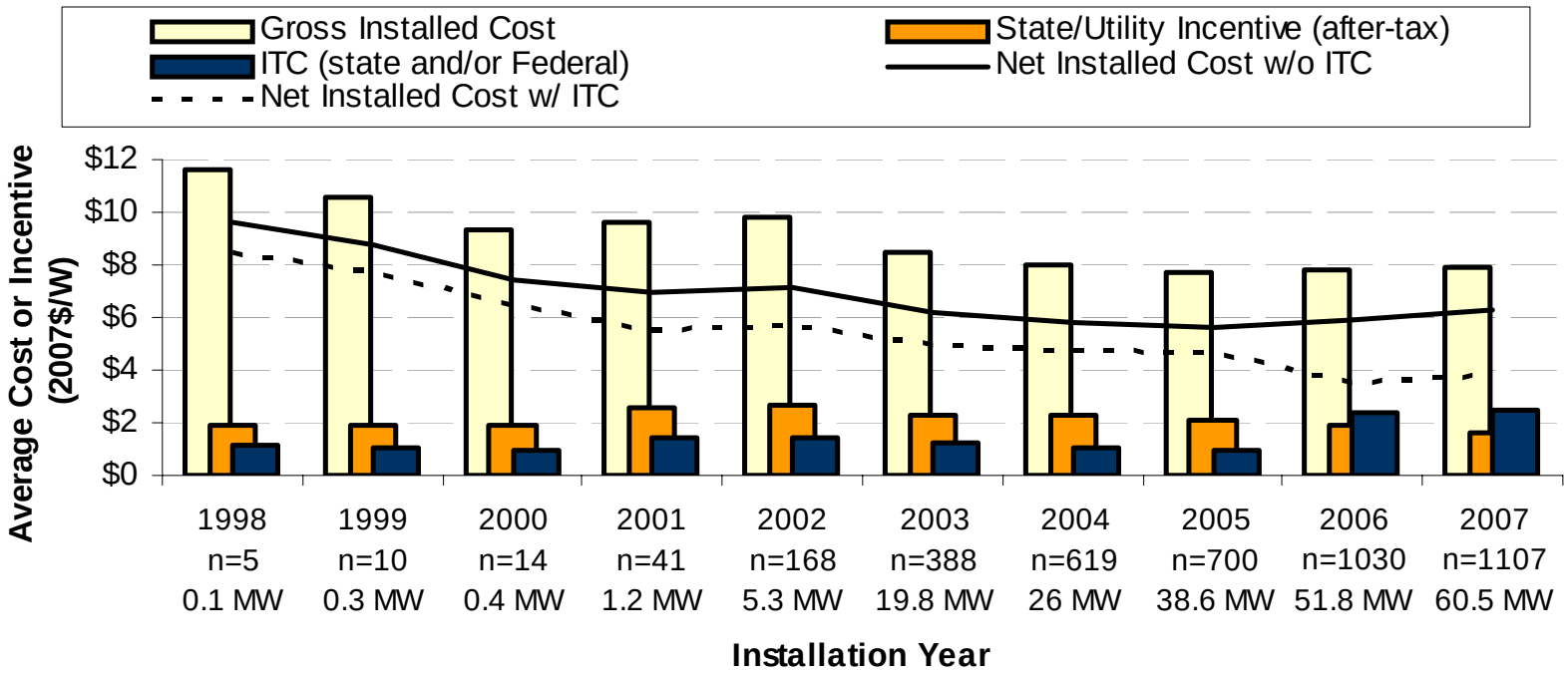
Calculated Net Installed Cost of Residential PV



- The net installed cost of residential PV was $5.1/W in 2007, just 1% less than in 2001 and approximately 12% higher than in 2006
- The $2000 cap on the Federal ITC for residential PV significantly limited the value of this incentive on a $/W basis

... While Net Installed Costs for Commercial PV Continued to Fall

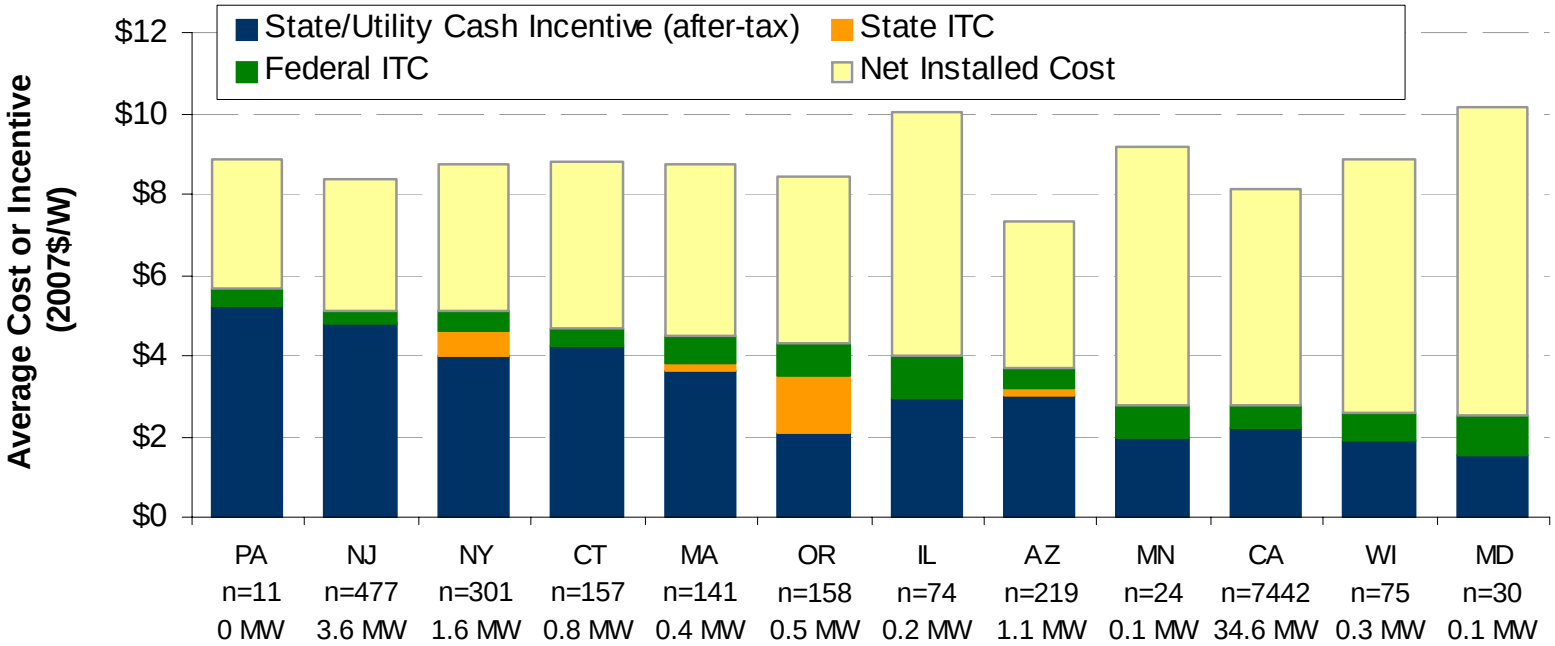
Calculated Net Installed Cost of Commercial PV



- The net installed cost of commercial PV was $3.8/W in 2007, or 32% less than in 2001, and much lower than for residential PV; large decline in net installed costs is due primarily to the increase in the Federal ITC starting in 2006
- Potential impact of incentive levels on gross installed costs illustrated by trends from 2000-02, when gross costs rose with average incentive levels

Incentives Have Diverged Widely Across States for Residential Systems...

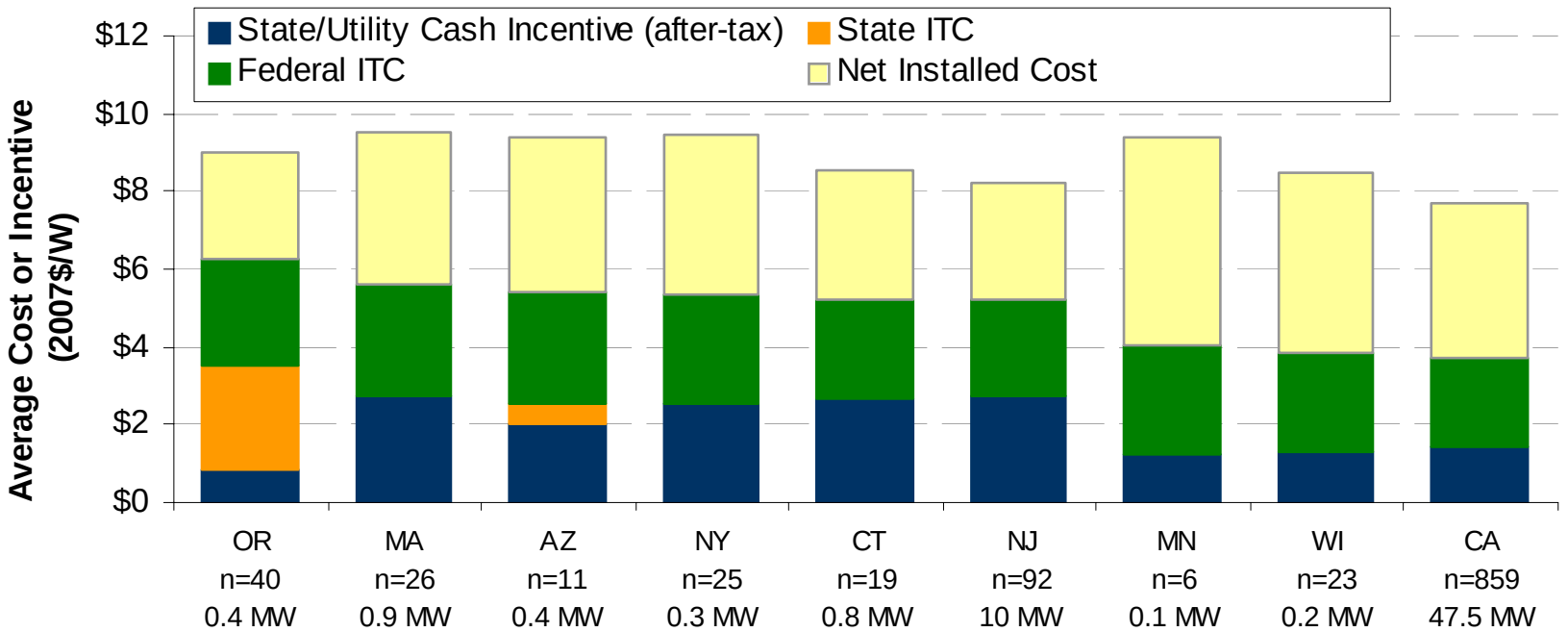
After-Tax Incentives and Net Installed Cost of Residential PV Systems Installed in 2007



- Average combined after-tax incentives (cash incentives plus ITCs) ranged from $5.7/W in Pennsylvania to $2.5/W in Maryland in 2007
- The two largest markets - California and New Jersey - differ substantially in average financial incentives in 2007, at $2.8/W and $5.1/W, respectively

...and for Commercial Systems

After-Tax Incentives and Net Installed Cost of Commercial PV Systems Installed in 2007



- Average combined after-tax incentives (cash incentives plus ITCs) ranged from $6.2/W in Oregon to $3.7/W in California
- Net installed costs ranged from a low of $2.7/W in OR (ignoring NJ solar REC revenues, which are substantial) to a high of $5.4/W in MN

Conclusions and Outlook

Conclusions

- PV costs have declined substantially over time, especially among smaller systems, and primarily as a result of reductions in non-module costs
- This trend, along with the narrowing of cost distributions, suggests that PV deployment policies in the U.S. have achieved some success in fostering competition and spurring efficiencies in the delivery infrastructure
- Lower average costs in Japan and Germany (and among some of the larger PV markets in the US) suggest that deeper near-term installed cost reductions are possible and may accompany deployment scale
- Although costs remained stagnant from 2005-2007, recent developments portend a potentially dramatic shift in the customer-economics of PV over the coming years:
  - Anticipated over-supply of PV modules starting in 2009 will put downward pressure on module prices
  - Lifting of the cap on the Federal ITC for residential PV, also beginning in 2009, will further reduce net installed costs for residential customers

For More Information...

Download the full report from:

http://eetd.lbl.gov/ea/ems/re-pubs.html

Contact the authors:

Ryan Wiser, RHWiser@lbl.gov, 510-486-5474

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

Carla Peterman, cpeterman@berkeley.edu

Thanks to the U.S. DOE's Solar Energy Technologies Program and Office of Electricity Delivery and Energy Reliability, and to the Clean Energy States Alliance, for supporting this work