

Utility-Scale Solar 2015

An Empirical Analysis of Project Cost, Performance, and Pricing Trends in the United States

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August 2016

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ENERGY TECHNOLOGIES AREA

Project Site: <http://utilityscalesolar.lbl.gov>



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Part of broader solar work in the Electricity Markets and Policy Group

◆ Solar Cost-Related Work:

- Annual solar “state of the market” reports
 - Residential/commercial systems: <http://trackingthesun.lbl.gov>
 - Large ground-mounted systems: <http://utilityscalesolar.lbl.gov>
- Derivative analyses (e.g., Academic Partnership Program)

◆ Renewable Energy Valuation and Grid Integration

◆ Rate-Design Impacts on the Economics and Deployment of DPV

◆ Impact of DPV on Traditional Utility Business Models

◆ Impact of Utility-Scale and Distributed PV on Real Estate Assets

◆ Technical Assistance and Policy Evaluations (e.g., RPS analyses)

Presentation Outline

Strong growth of the utility-scale solar market offers increasing amounts of project-level data that are ripe for analysis.

1. Introduction and description of broader technology trends

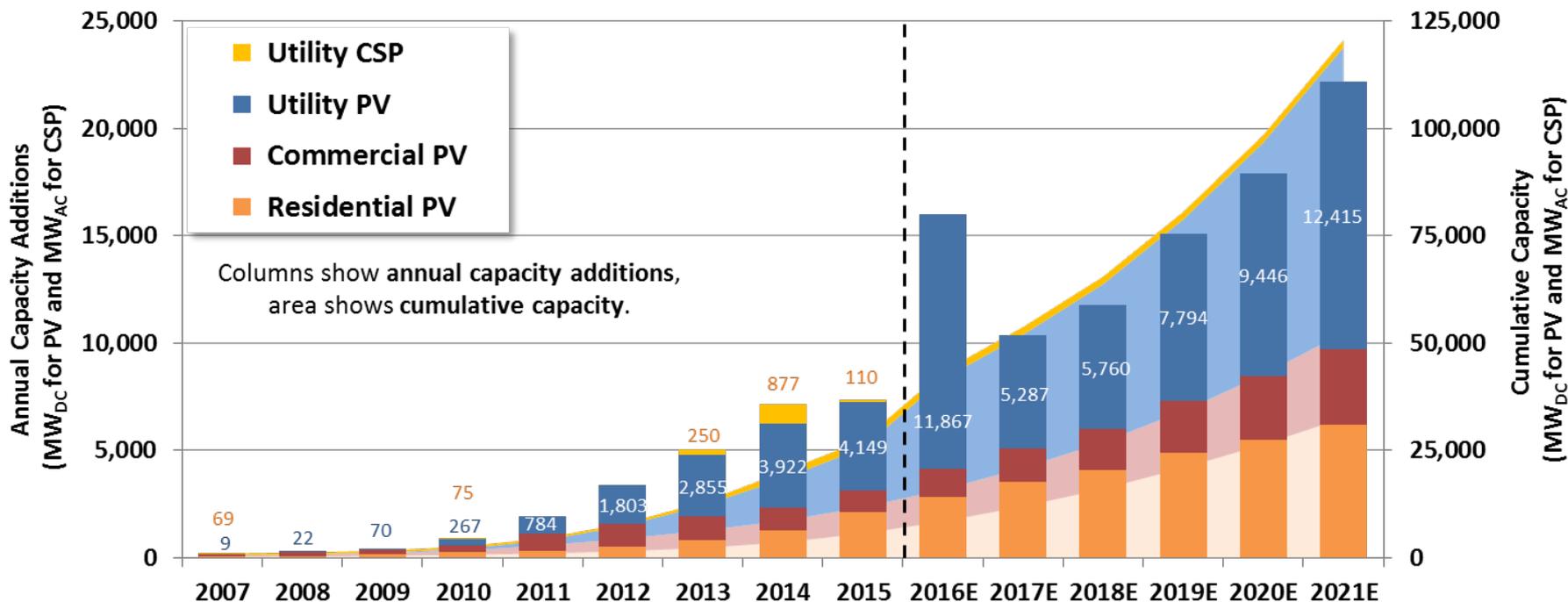
Key findings from analysis of the data samples

*(We discuss **PV projects** first, then focus on **CSP projects**):*

2. Installed project prices
 3. Operation and maintenance (O&M) costs
 4. Performance (capacity factors)
 5. Power purchase agreement (“PPA”) prices
6. Future outlook

Utility-scale projects have the greatest capacity share in the U. S. solar market

- ◆ Utility-scale solar had a 57% capacity share of 2015 installations and a 54% share of cumulative installations at the end of 2015

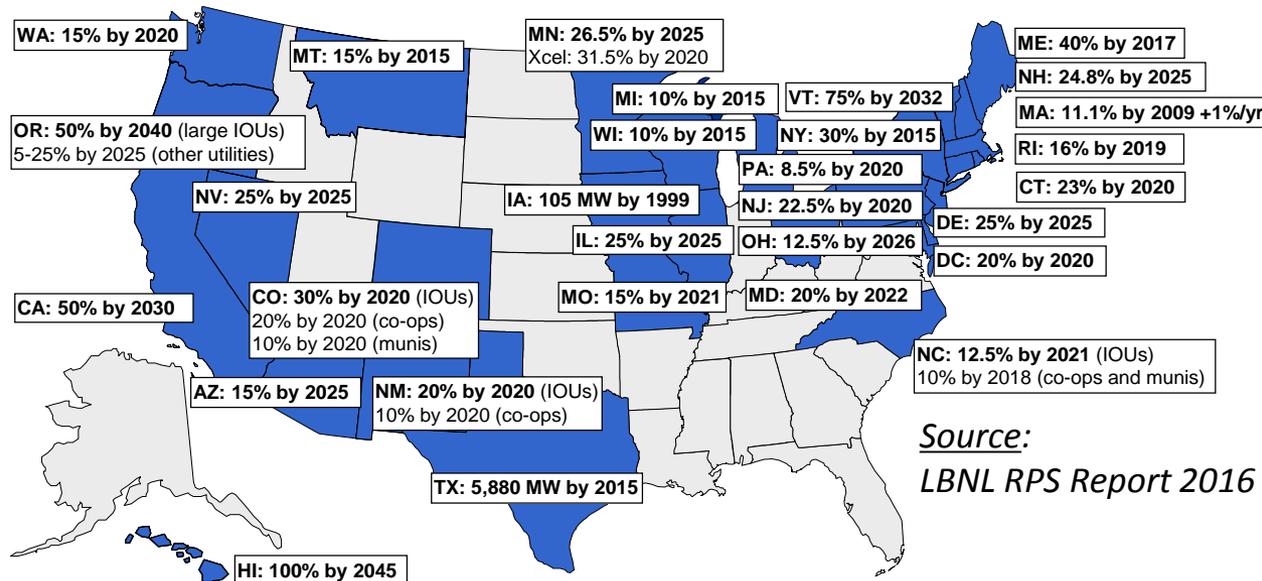


Sources: GTM / SEIA Solar Market Insight Reports, LBNL Database

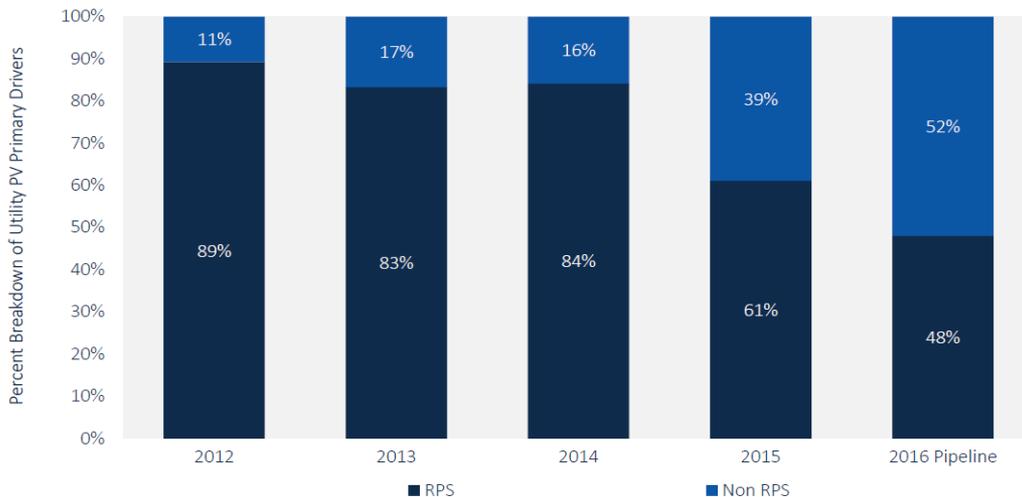
We define “utility-scale” as any ground-mounted project that is larger than 5 MW_{AC}.
Smaller systems are analyzed in LBNL’s “Tracking the Sun” series.

Drivers of the utility-scale market: RPS

- ◆ RPS has historically been a significant driver of utility-scale solar, particularly in the Southwest and Northeast
- ◆ Recent RPS expansions (e.g., in CA, OR) will ensure future RPS relevance for utility-scale solar markets
- ◆ Increasingly, utility-scale solar expansion into non-RPS states (Southeast) or continued deployment where RPS goals have been reached (e.g., Texas)



Source:
LBNL RPS Report 2016



Source:
GTM 2016: The Next Wave of Utility-Solar

Non-RPS drivers of utility-scale solar

◆ Voluntary Procurement:

- 3rd party-ownership with competitive PPA deals (+ Hedge Value)
- Utility-Owned Generation (Florida Power & Light, Georgia Power, Dominion, Duke, PNM)

◆ PURPA (“avoided cost” rates for “Qualifying Facilities”)

- e.g., North Carolina (~2700 MW), Utah (~700 MW), Idaho (~500 MW), Oregon
- Potential for boom and bust cycles

◆ Retail Procurement

- Green tariffs / community solar
- Direct access (e.g., Apple 130 + 150 MW California Flats PPA)
- Community Choice Aggregation

◆ Merchant Solar

- e.g., Barilla Solar in Texas

◆ *Clean Power Plan???*

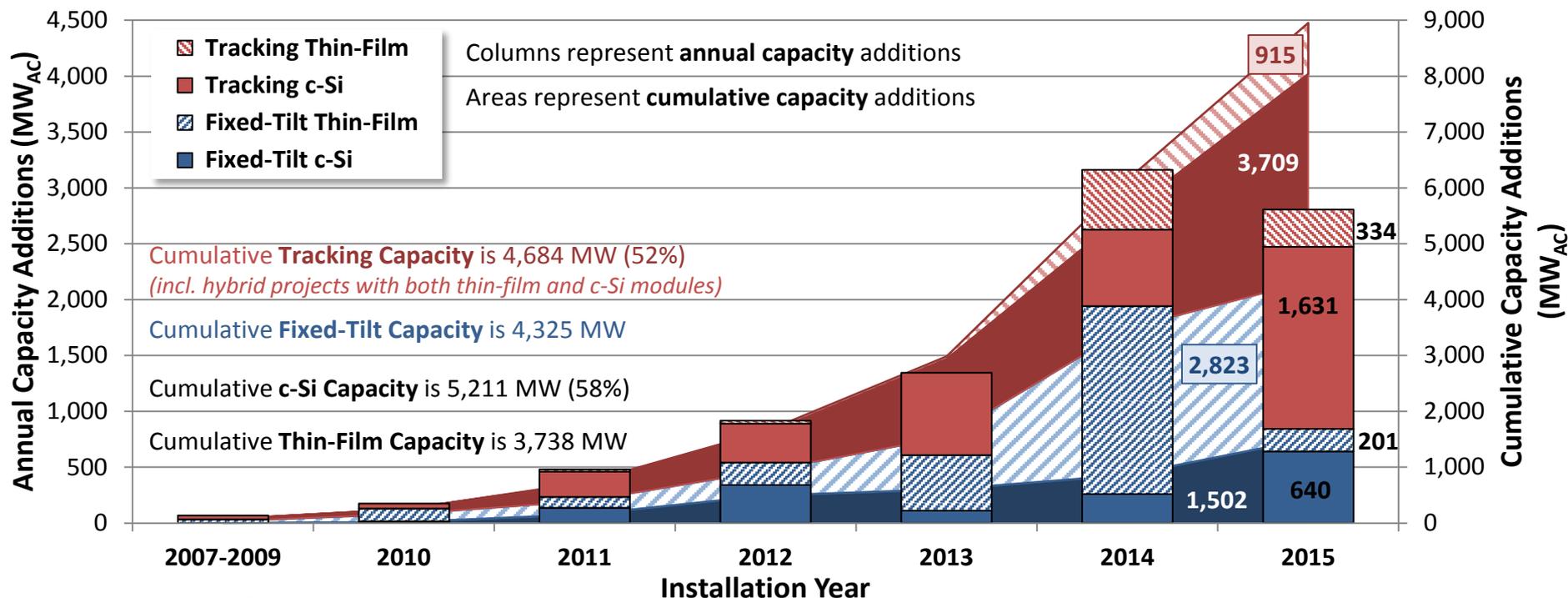
PV projects



Photo Credit: sPower SEPV Palmdale East

PV project population broken out by tracking vs. fixed-tilt, module type, and installation year

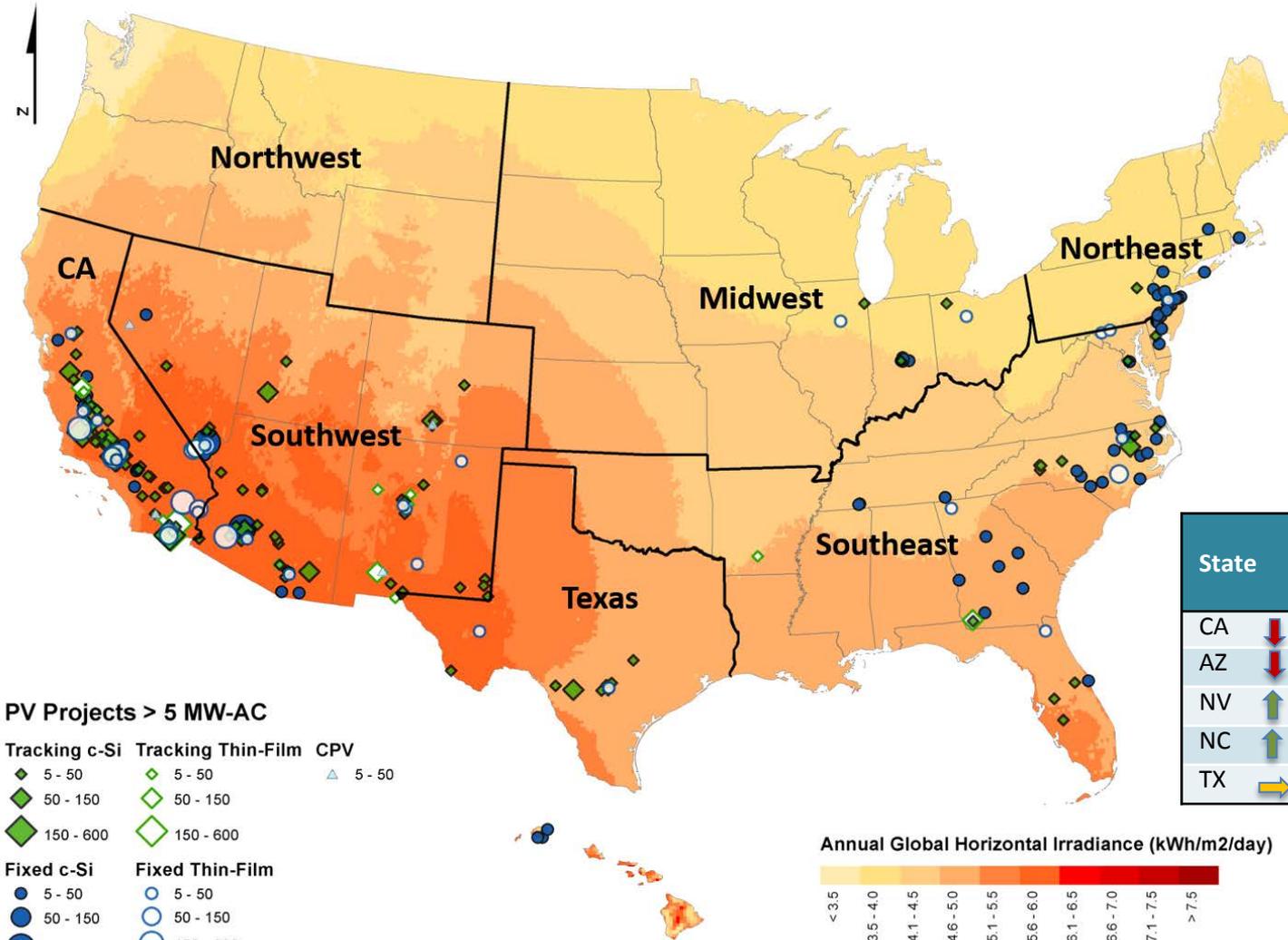
PV project population: 278 projects totaling 9,016 MW_{AC}



◆ 2015 Trends:

- Strong growth in c-Si capacity (81%) relative to thin-film capacity (19%), driven in part by the completion of the very large Solar Star project (594 MW_{AC}). Largest c-Si manufacturers are SunPower (33% of c-Si market), Trina (20%), and Jinko (16%), while the thin-film market is dominated by First Solar (93% of the installed capacity).
- Increasing dominance of tracking projects (70% of newly installed capacity) relative to fixed-tilt projects (30%)

Historically heavy concentration in the Southwest and mid-Atlantic, but now spreading to Southeast



- Primarily fixed-tilt c-Si projects in the East
- ◆ Tracking (c-Si and, increasingly, thin-film) is more common in the Southwest

State	Cumulative Capacity MW-AC %	
	2015	2014
CA	56%	59%
AZ	13%	17%
NV	7%	5%
NC	6%	2%
TX	3%	3%

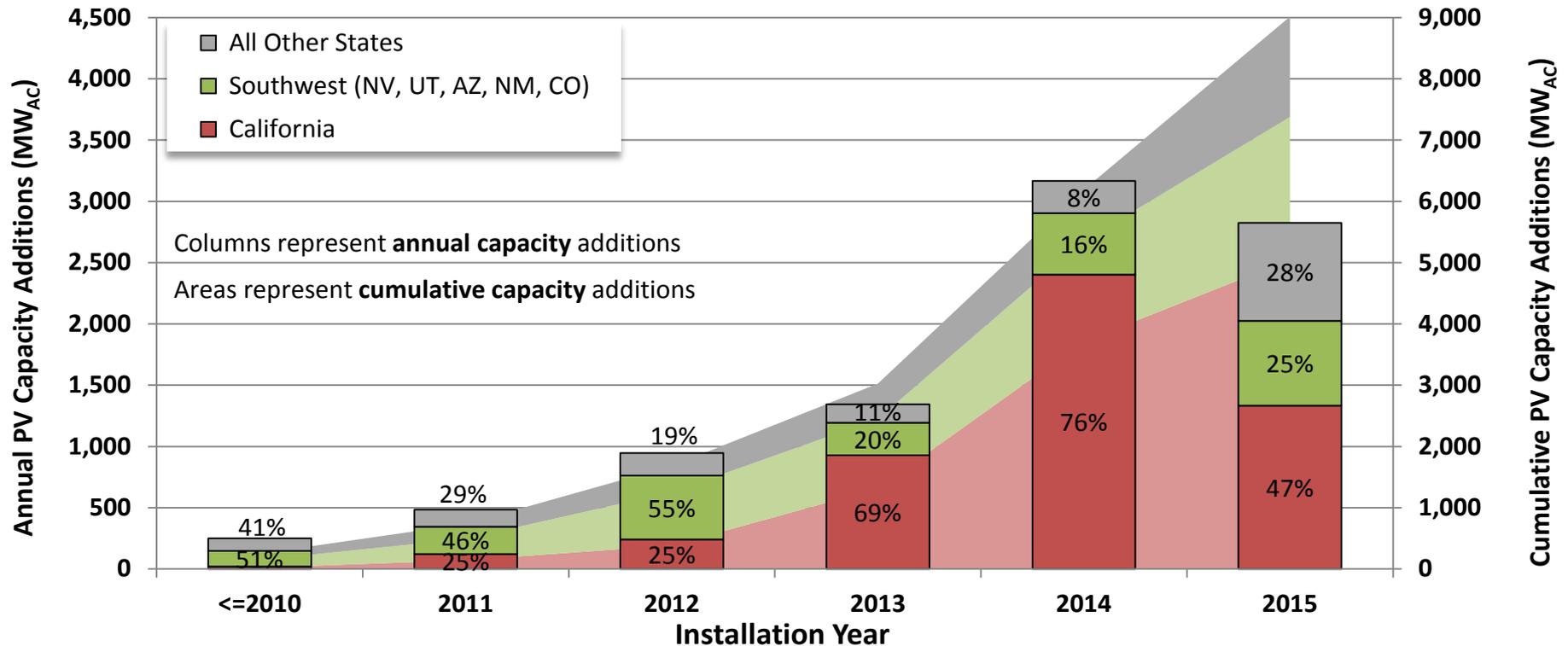
PV Projects > 5 MW-AC



Annual Global Horizontal Irradiance (kWh/m2/day)



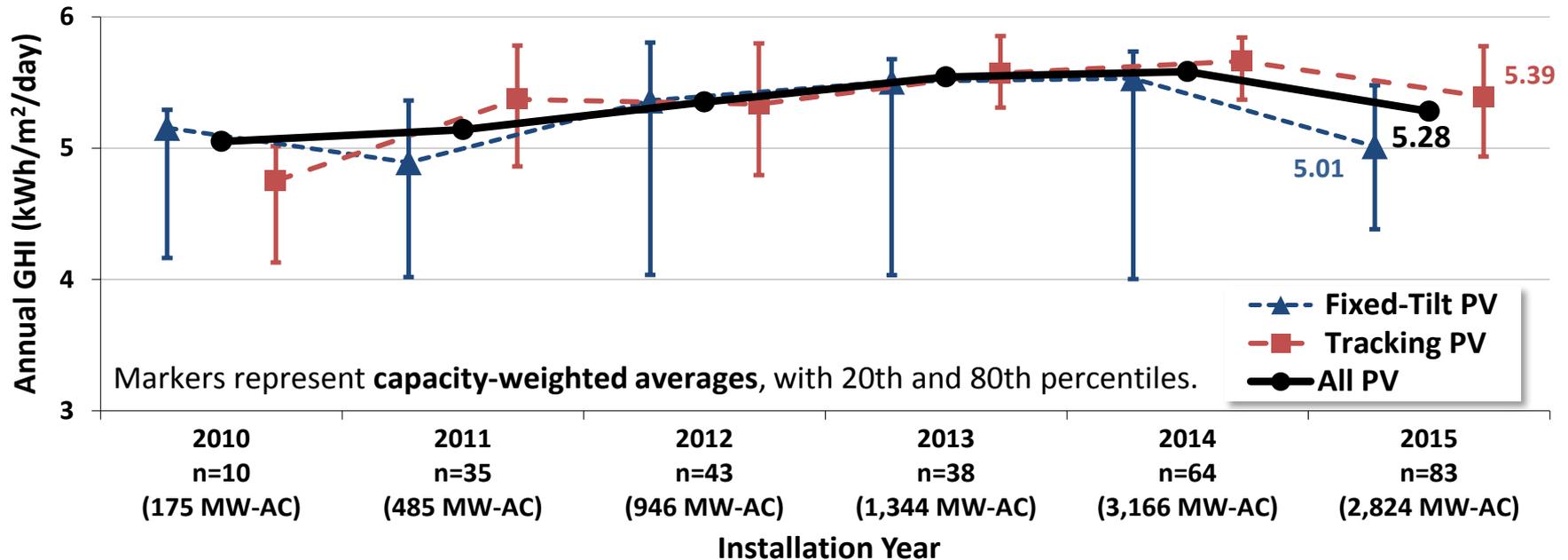
Utility-scale PV continues to expand beyond California and the Southwest



◆ Strong percentage growth outside the established markets:

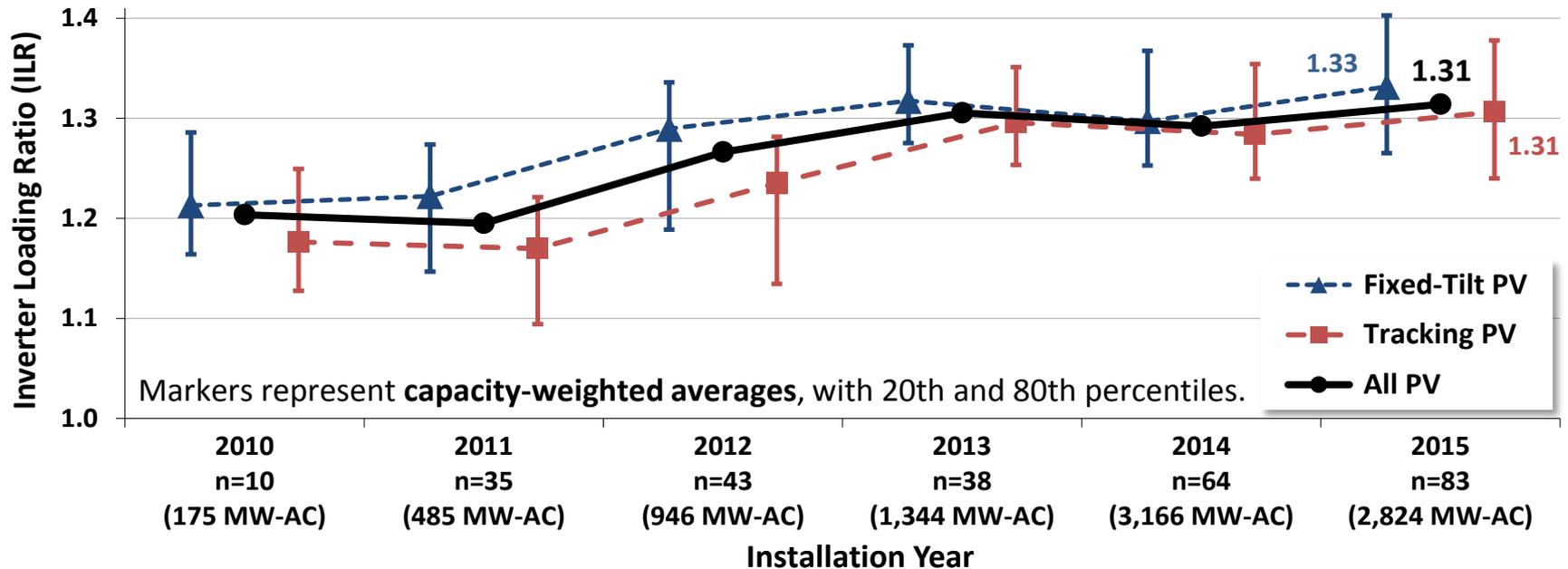
- North Carolina (quadrupling previous capacity with 15 new projects)
- Georgia (nearly tripling previous capacity with 6 new projects totaling 177 MW_{AC})
- Nevada (more than doubling previous capacity with 4 new projects totaling 349 MW_{AC})

The eastward expansion is reflected in the buildout of lower-insolation sites



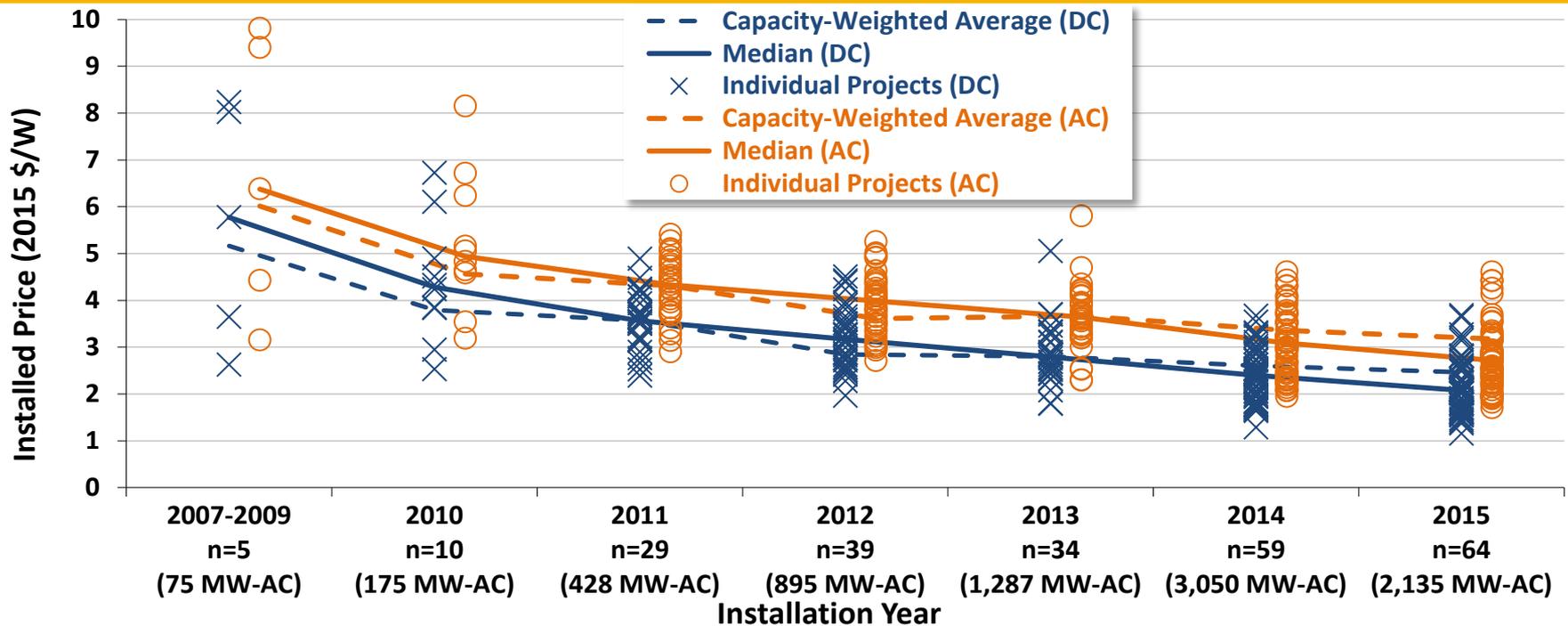
- ◆ Historical trend of increasing solar resource quality for the average project site did not continue in 2015 – the first year where the Global Horizontal Irradiance declined
- ◆ The wide 80/20 distribution of fixed-tilt PV reflects deployment throughout the US, whereas tracking PV is concentrated more in the high-GHI Southwest. However, 2015 shows an expansion of tracking into less-sunny areas (note the decline in the 20% percentile)
- ◆ All else equal, higher GHI should boost sample-wide capacity factors (reported later). The effects of the lower GHI for new 2015 projects will be evaluated in next year's report once they have been operational for a full year

The average inverter loading ratio (ILR) has increased over time, to 1.31 in 2015



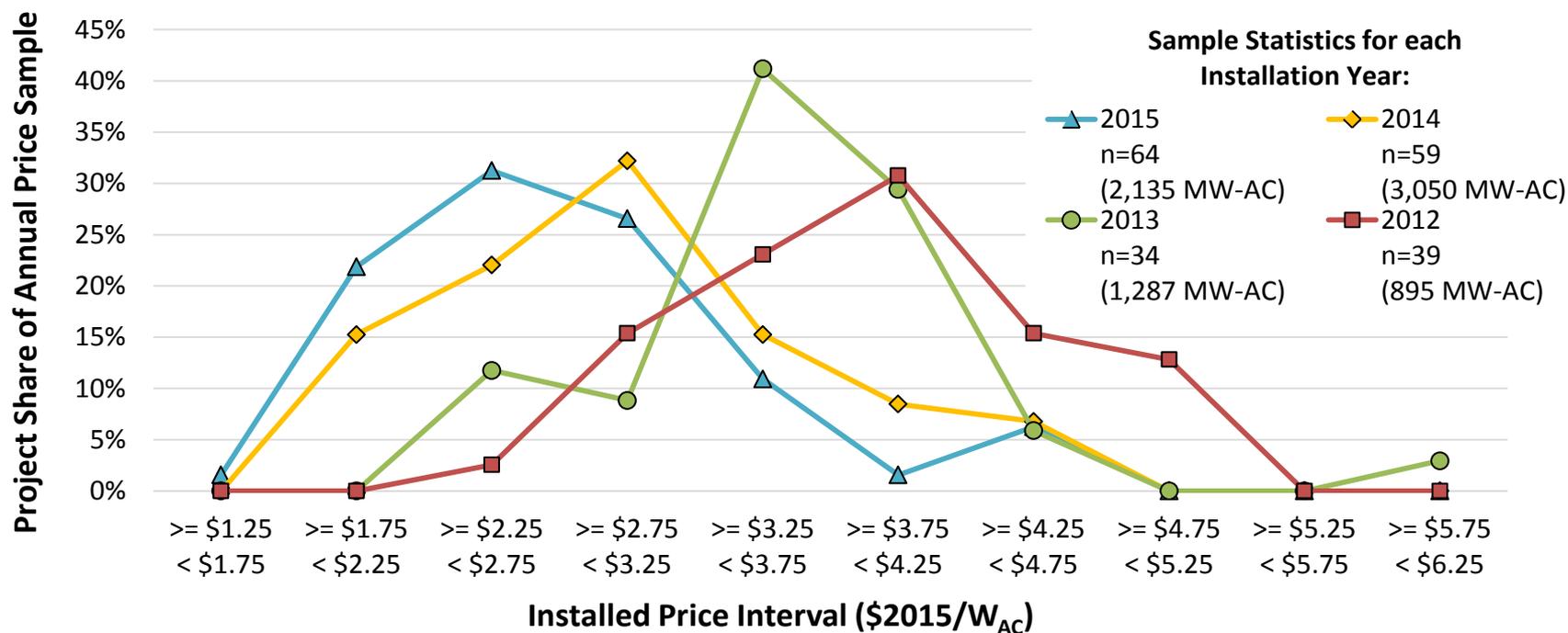
- ◆ As module prices have fallen (faster than inverter prices), developers have oversized the DC array capacity relative to the AC inverter capacity to enhance revenue
- ◆ Fixed-tilt PV generally has a higher average ILR than tracking PV (fixed-tilt has more to gain from boosting ILR), dip in 2014 is skewed by several very large projects
- ◆ The apparent decline in the capacity-weighted average ILR from 2013 to 2014 is related to several large projects – the median ILR held nearly constant in 2014
- ◆ All else equal, a higher ILR should boost sample-wide capacity factors (reported later)

Median installed price of PV has fallen steadily, by nearly 60%, to around \$2.7/W_{AC} (\$2.1/W_{DC}) in 2015



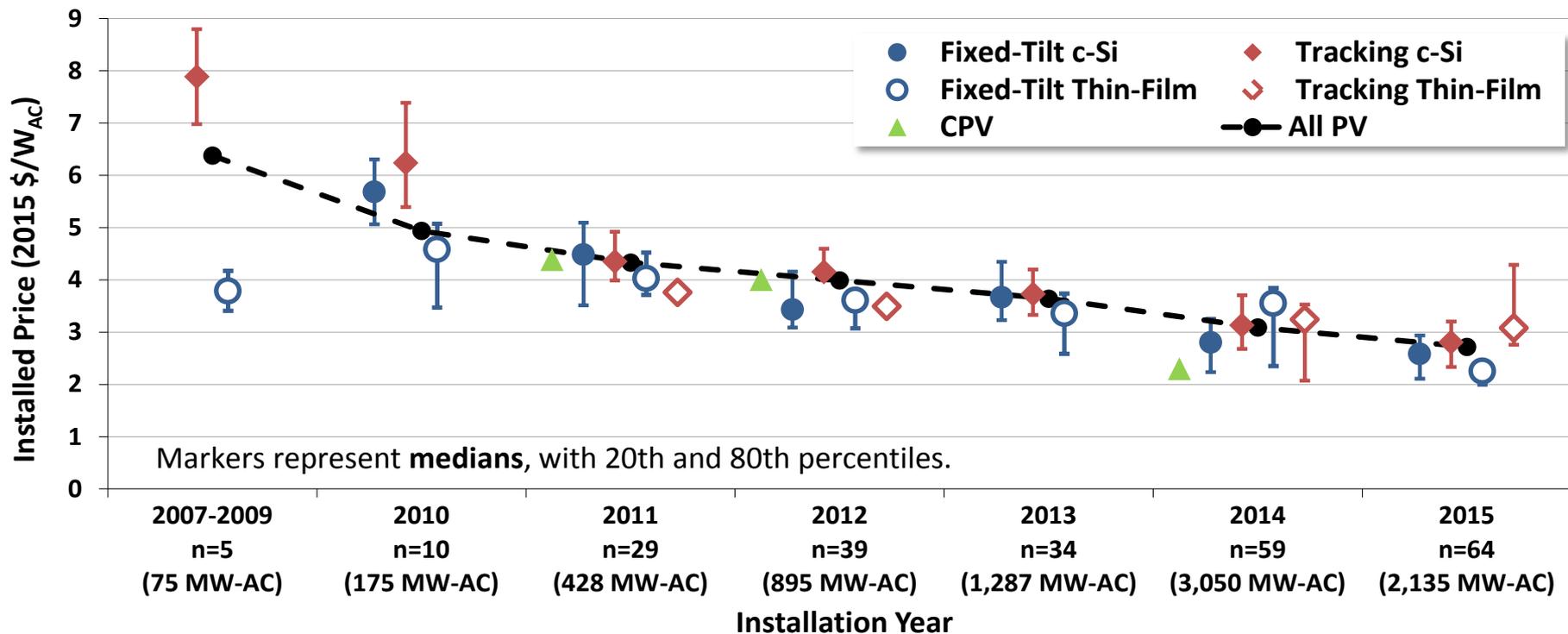
- ◆ Installed prices are shown here in both DC and AC terms, but because AC is more relevant to the utility sector, all metrics used in the rest of this slide deck are expressed solely in AC terms
- ◆ The lowest 20th percentile fell from \$2.3/W_{AC} (\$1.8/W_{DC}) in 2014 to \$2.2/W_{AC} (\$1.6/W_{DC}) in 2015
- ◆ Capacity-weighted average prices were pushed higher in 2014 and 2015 by several very large projects that had been under construction for several years (but only entered our sample once complete)
- ◆ This sample is backward-looking and may not reflect the price of projects built in 2016/2017

Pricing distributions have continuously moved towards lower prices over the last 4 years



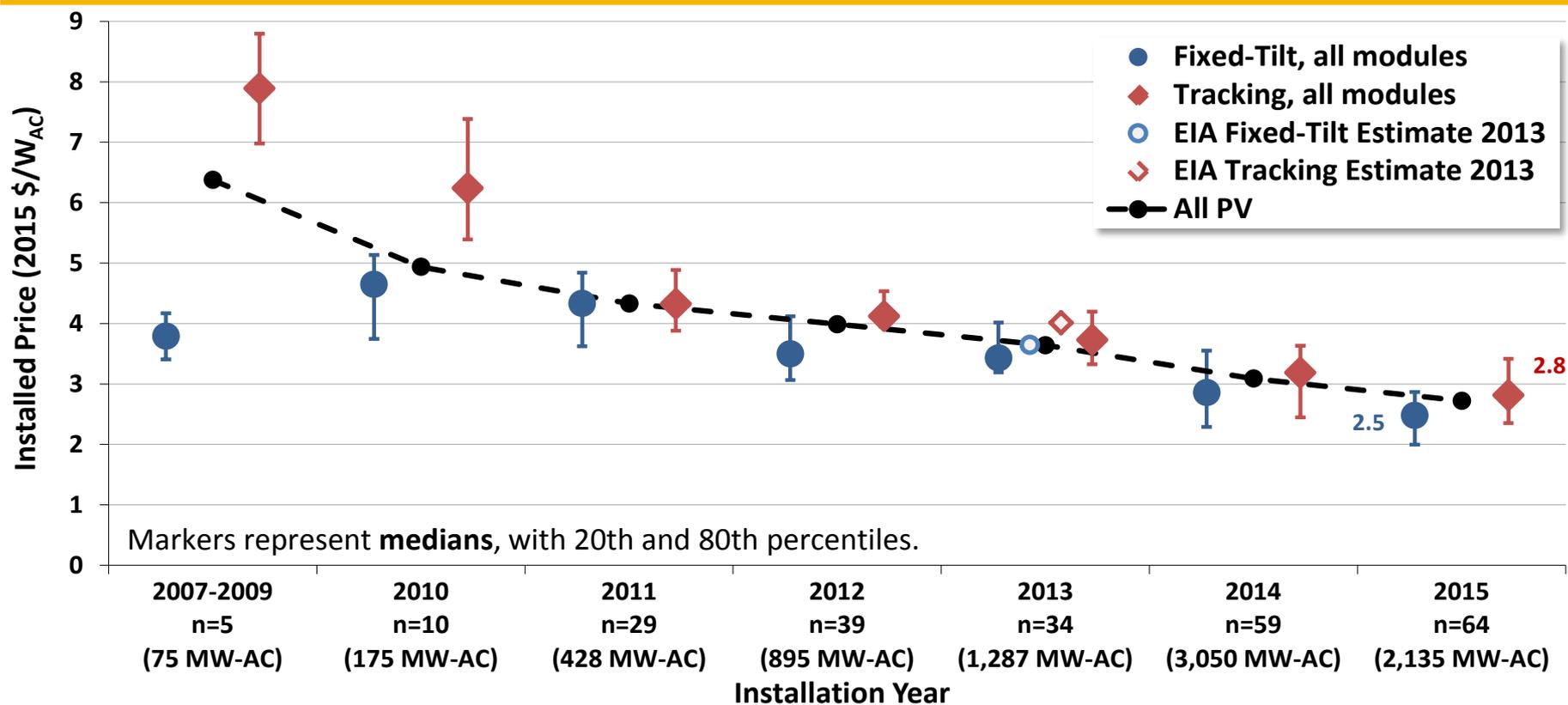
- ◆ Not only pricing medians but also pricing modes have continued to fall (moving towards the left) each year
- ◆ Share of relatively high-cost systems decreases steadily each year while share of low-cost systems increases
- ◆ Interquartile price spread is the smallest in 2015, pointing to a reduction in underlying heterogeneity of prices across all installed projects

Installed price decline led primarily by c-Si



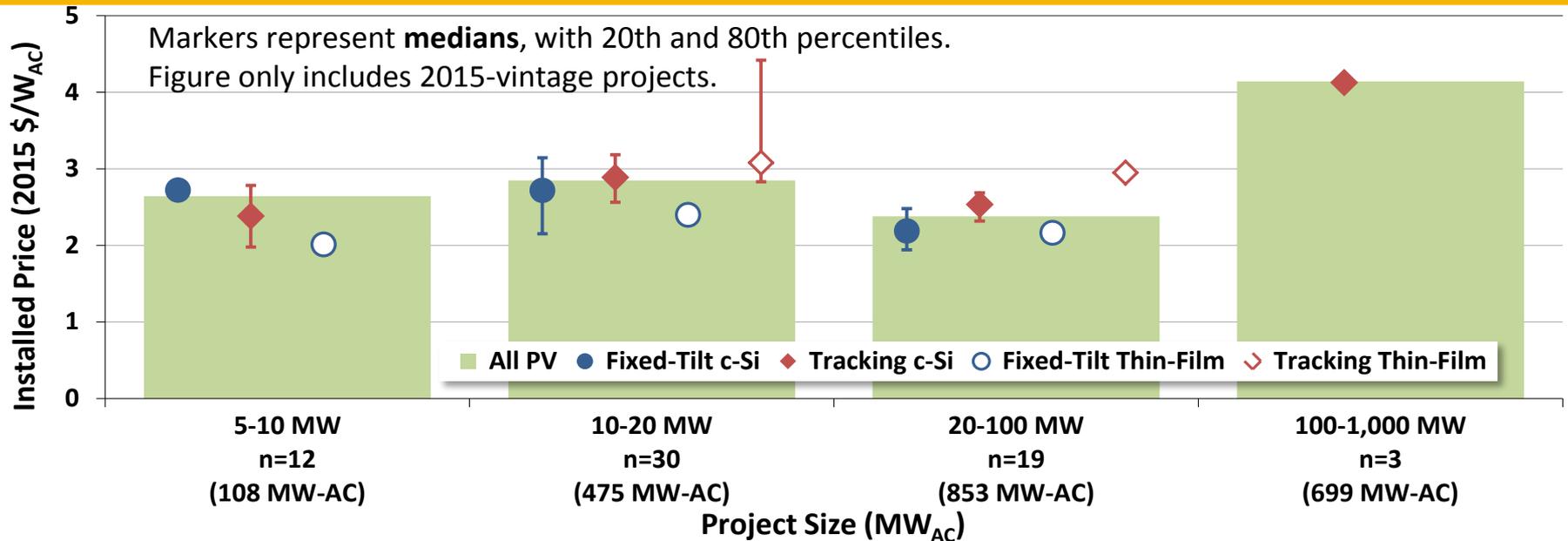
- ◆ Pricing has converged among the various mounting/module configurations over time
- ◆ The two CPV projects built in 2011 and 2012 were priced similar to PV at the time, while the 2014 CPV project was at the very low end of price distributions (unfortunately, no price data was available for the new 2015 C7 project)

Tracking projects command a premium of $\$0.3/W_{AC}$



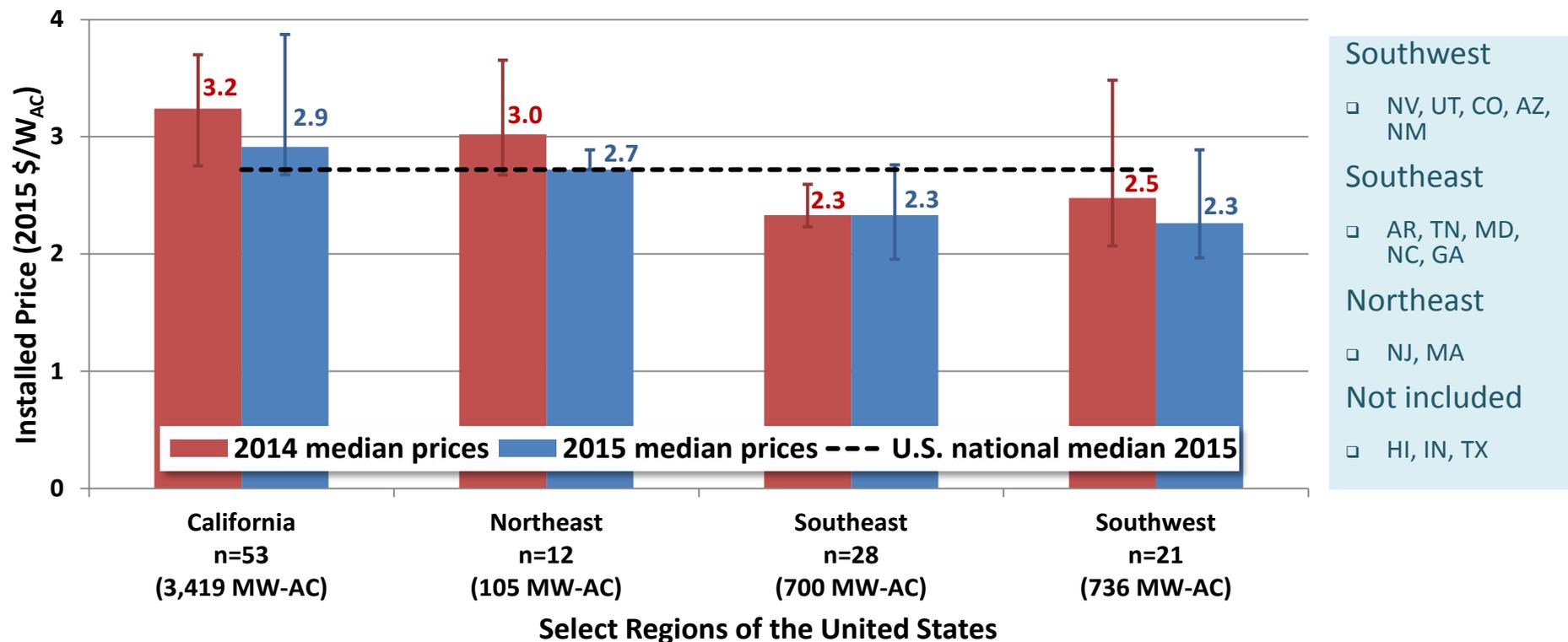
- ◆ Not surprisingly, tracking appears to be slightly more expensive than fixed-tilt
- ◆ New EIA summary statistics from project-level data for 2013 consistent with LBNL medians

2015 project sample does not reflect economies of scale



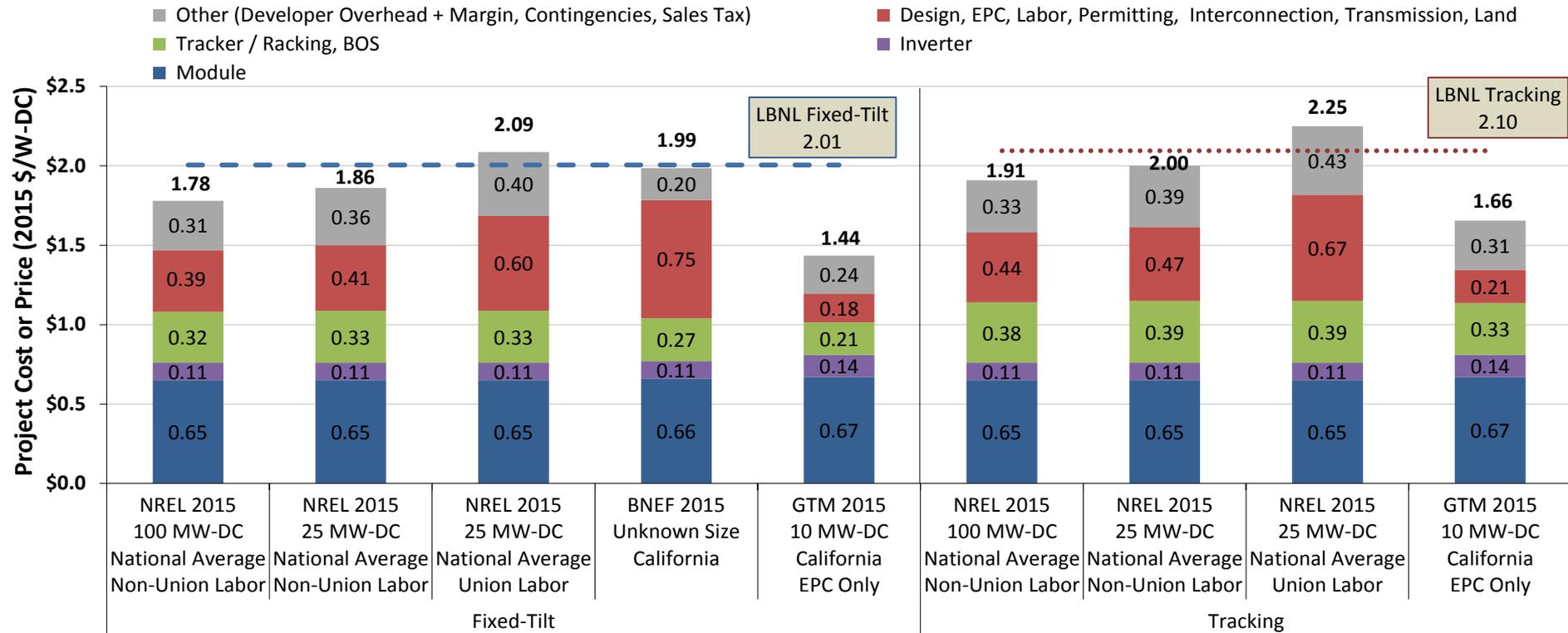
- ◆ Modular/scalable “power block” solutions from manufacturers like SunPower and First Solar may have already wrung out most of the cost savings otherwise available to larger projects.
- ◆ Potential savings may not fully be passed through from EPCs to developers, or procurement savings may occur at the portfolio rather than project level
- ◆ Several of the 100+ MW projects have been under construction for several years, possibly reflecting a higher-cost past. We find a correlation between increased COD-PPA lag and higher project prices (additional year of lag time results in premium of \$0.5/W_{AC}). Larger projects may face greater development, regulatory, interconnection costs that outweigh any economies of scale.

Project prices vary by region



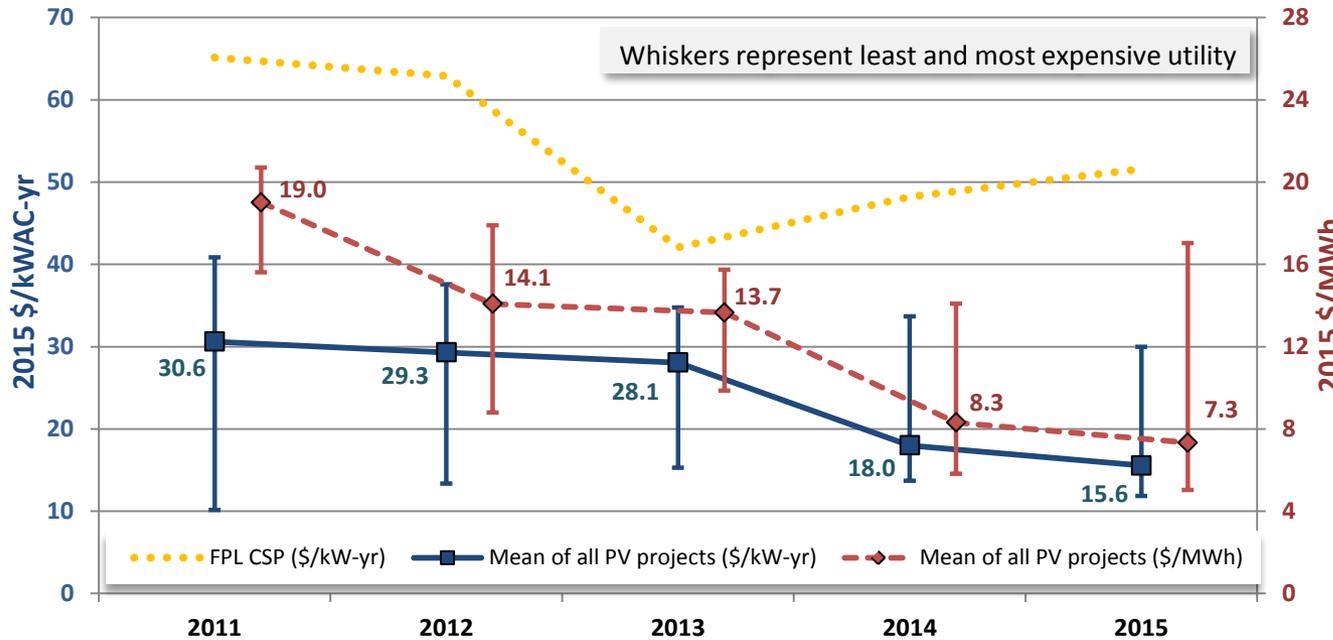
- ◆ Price differences driven in part by technology ubiquity (higher-priced tracking projects are more prevalent in the Southwest and California)
- ◆ Other factors may include labor costs and share of union labor, land costs, soil conditions or snow load, and balance of supply and demand

Bottom-up models roughly consistent with LBNL's top-down findings



- ◆ Prices presented here in DC terms, to be consistent with how presented by NREL, BNEF, GTM
- ◆ LBNL's top-down empirical prices are fairly close to modelled bottom-up prices
- ◆ GTM project represents only turn-key EPC costs and excludes permitting, interconnection, transmission, developer overhead, fees, and profit margins
- ◆ Difficult to ensure consistency of scope in cost categories and time horizon (under construction vs. operation date)

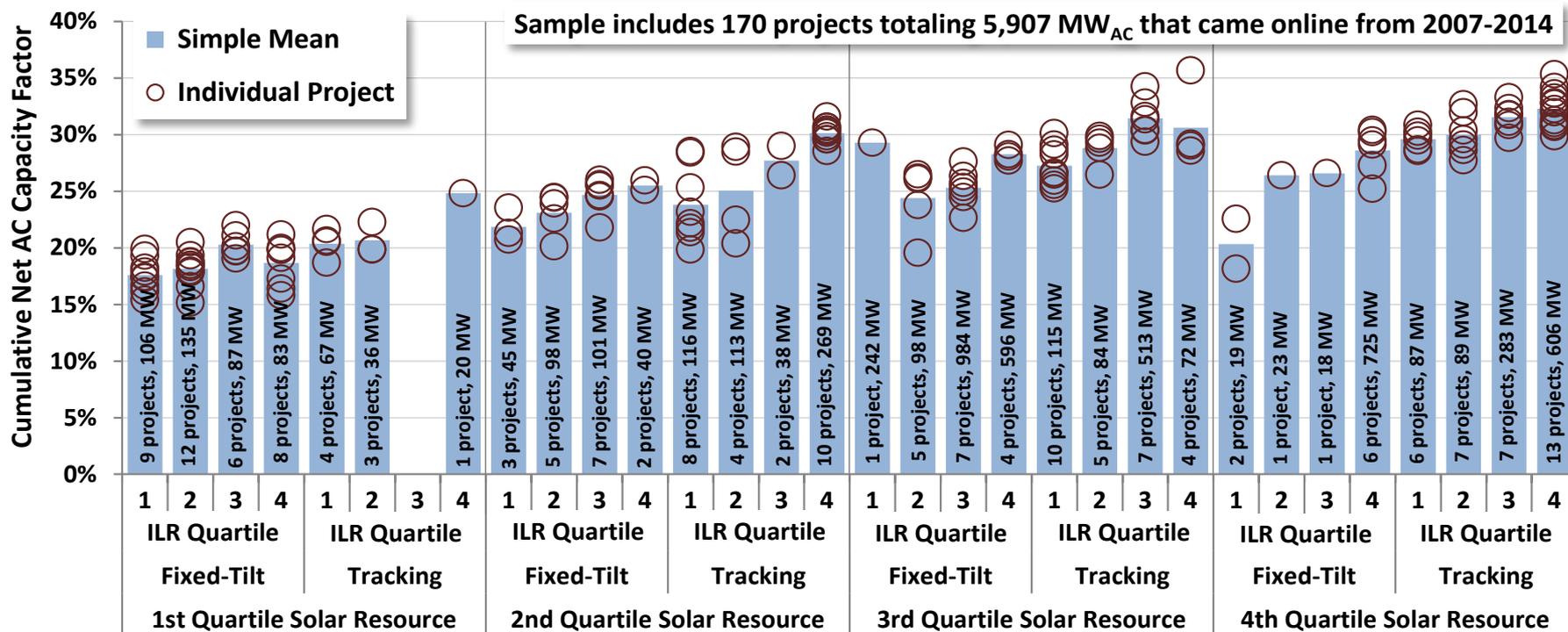
O&M cost data still very thin, but largely consistent with early years of cost projections



- ◆ Only a few utilities report solar O&M costs (see table), slow emergence of project-specific O&M costs
- ◆ O&M costs appear to be declining over time (as fleet size increases), to \$15.6/kW-yr and \$7.3/MWh
- ◆ Cost range among utilities continues to be large

Year	PG&E		PNM		APS *		FP&L	
	MW-AC	project #	MW-AC	project #	MW-AC	project #	MW-AC	project #
2011	#N/A	#N/A	#N/A	#N/A	51	3	110	3
2012	50	3	8	2	96	4	110	3
2013	100	6	30	4	136	6	110	3
2014	150	7	55	7	168	7	110	3
2015	150	7	95	11	191	9	110	3
predominant technology	Fixed-Tilt c-Si		4 fixed-tilt / 3 tracking thin-film, 4 tracking c-Si		primarily tracking c-Si		mix of c-Si and CSP	

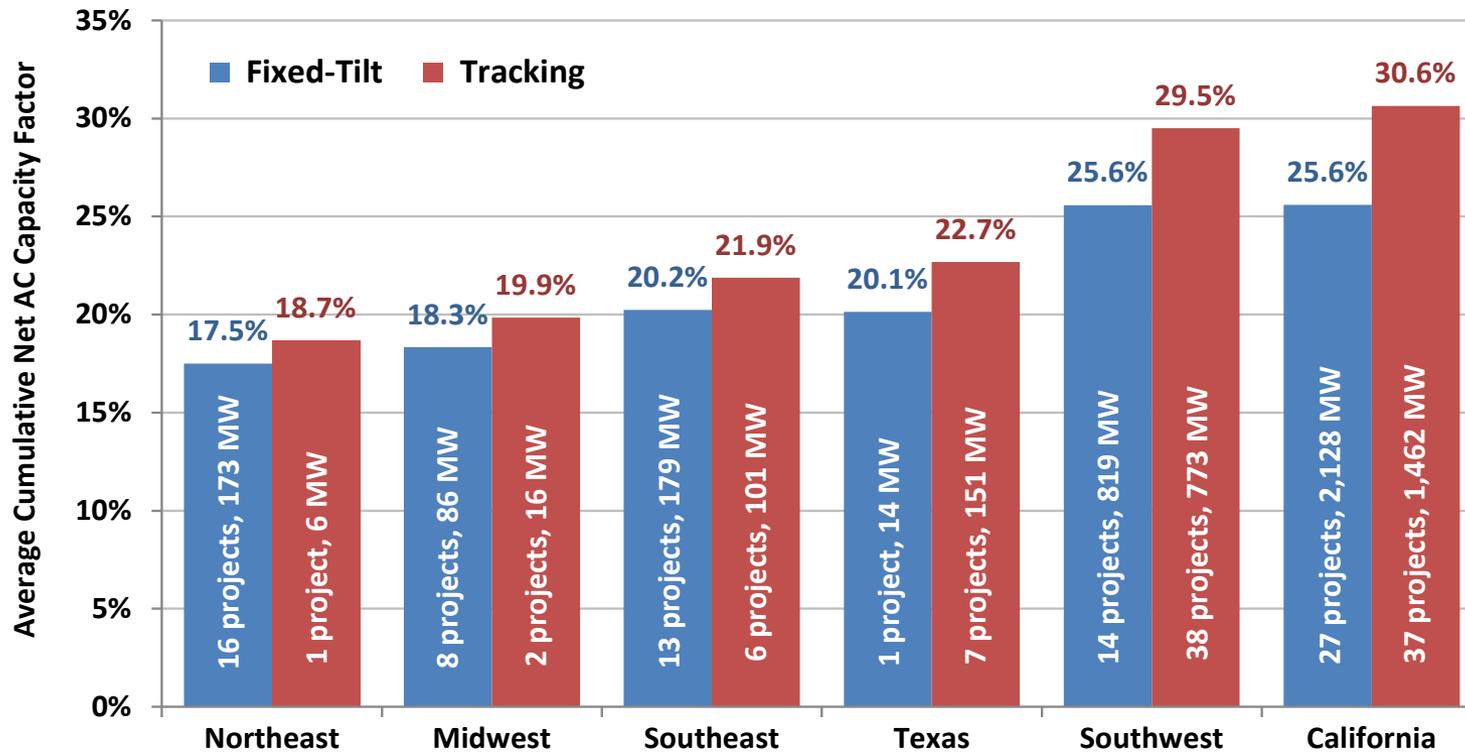
25.7% average sample-wide PV net capacity factor, but with large project-level range (from 15.1%-35.7%)



Project-level variation in PV capacity factor driven by:

- ◆ **Solar Resource (GHI):** Highest resource quartile has ~8 percentage point higher capacity factor than lowest
- ◆ **Tracking:** Adds ~4 percentage points to capacity factor on average across all four resource quartiles
- ◆ **Inverter Loading Ratio (ILR):** Highest ILR quartiles have ~4 percentage point higher capacity factor than lowest

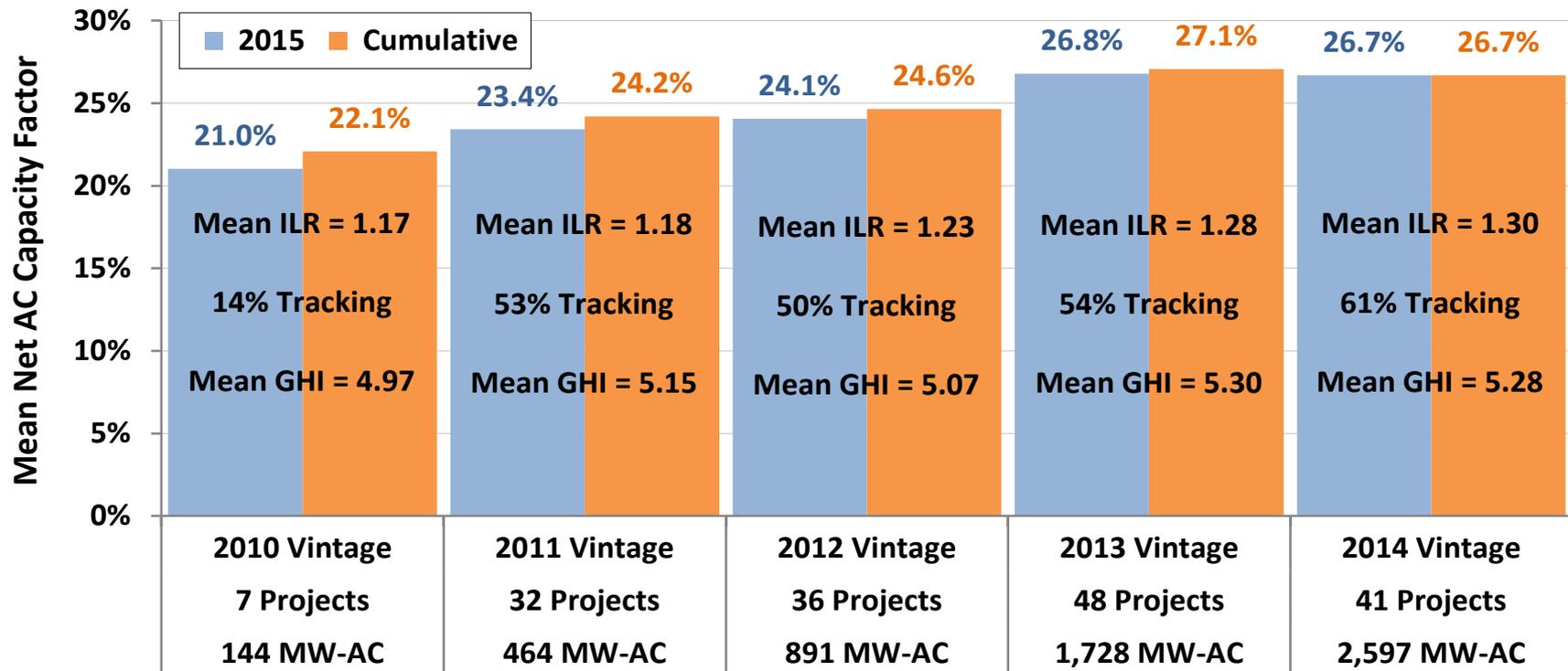
For those who prefer to think geographically rather than in terms of insolation quartiles...



Regions are defined in the map on slide 9

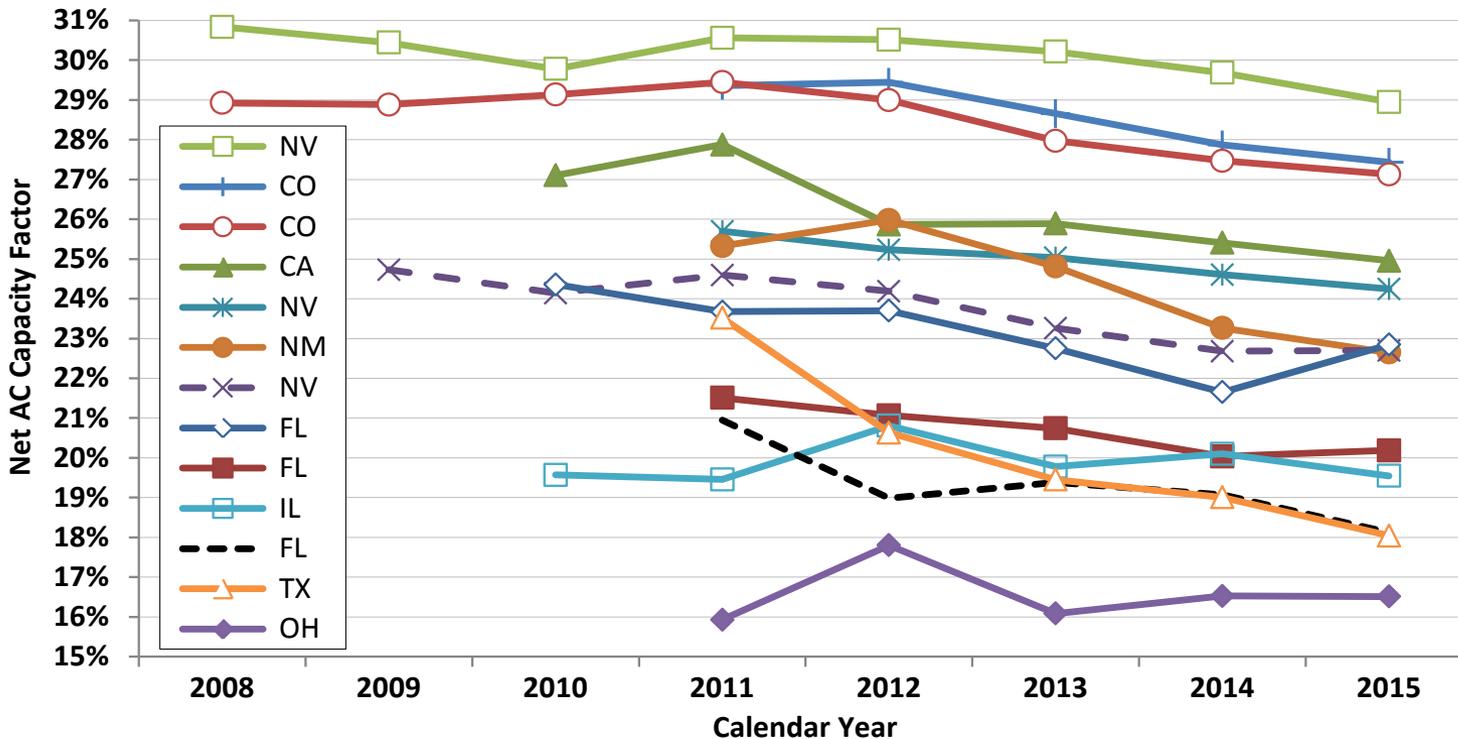
- ◆ Not surprisingly, capacity factors are highest in California and the Southwest, and lowest in the Northeast and Midwest (with the Southeast and Texas in between)
- ◆ Although sample size is small in some regions, the greater benefit of tracking in the high-insolation regions is evident, as are the greater number of tracking projects in those regions

More recent PV project vintages have higher capacity factors on average



- ◆ Higher capacity factors by vintage driven by an increase in tracking (most notably in 2011 and 2014), average inverter loading ratio (in every year), and long-term global horizontal irradiance at project sites (in 2011 and 2013)
- ◆ The fact that single-year 2015 capacity factors (blue columns) show same trend as cumulative capacity factors (orange columns) suggests that inter-year resource variation is not much of a driver

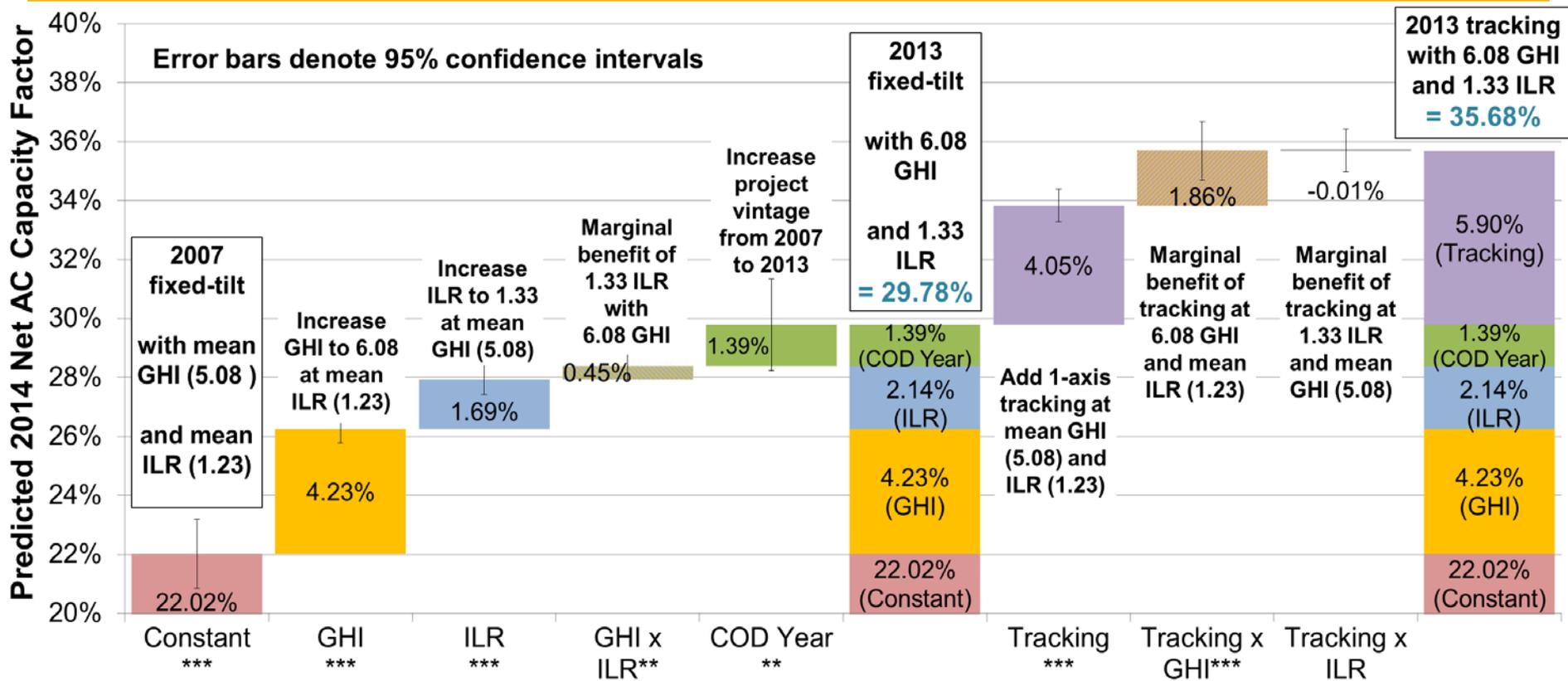
Performance degradation is difficult to assess at the project-level, due to modest impact



Graph shows a time series of capacity factors by calendar year for the 13 projects in our sample that have been operating for at least 5 (and for as many as 8) years

- ◆ Over the 8-year period shown in the graph, a degradation rate of 0.5%/year would reduce a 30% capacity factor to 29%—a modest decline that could easily be swamped by inter-year variation in the strength of the solar resource
- ◆ Though degradation is no doubt present in the graph above, the 2013-2015 decline (evident among Western projects in particular) is more likely attributable to below-normal summer insolation

Earlier regression analysis offers additional insights into sources of net capacity factor gains

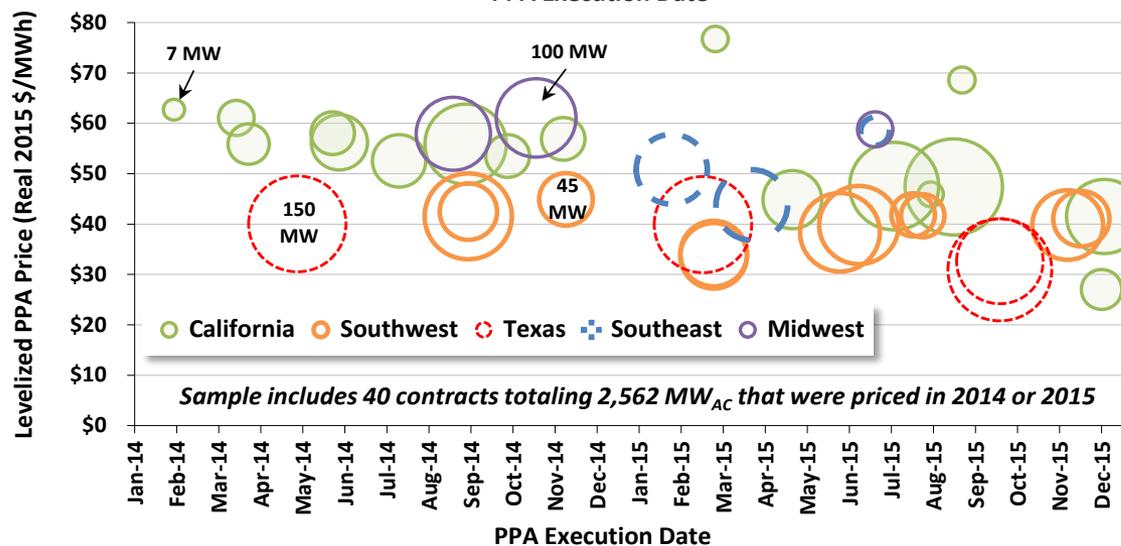
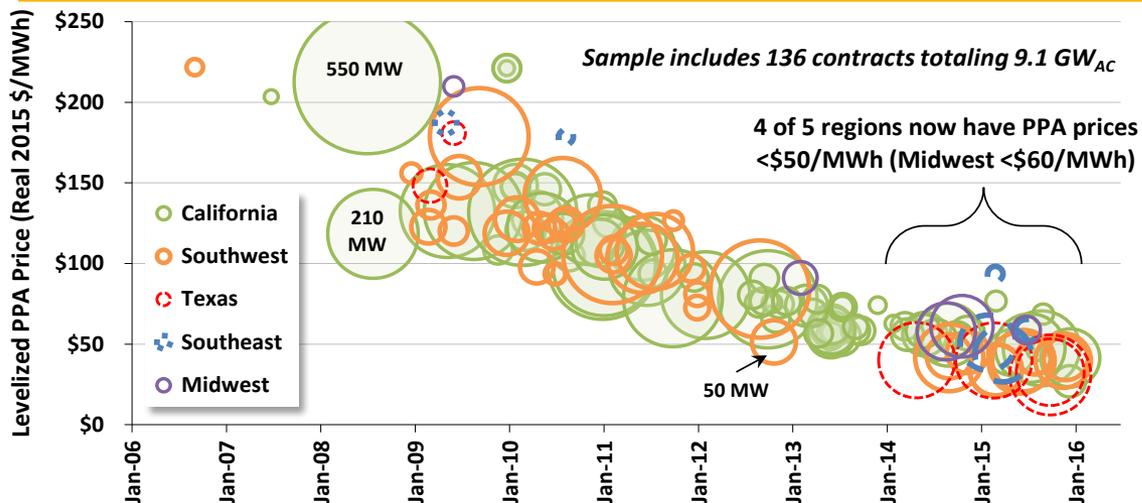


Regression Terms and Significance Levels (***p<0.01, **p<0.05)

Graph progresses from a 2007 fixed-tilt project with average GHI and ILR (on the far left) to a 2013 fixed-tilt project with a higher GHI and ILR (in the middle) to a 2013 tracking project with the same higher GHI and ILR (on the far right).

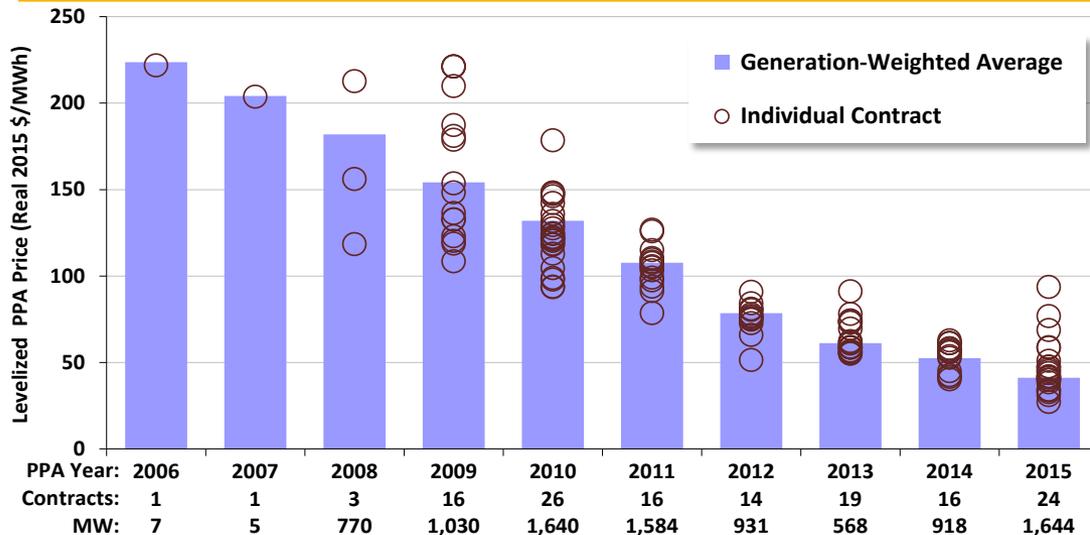
More information at: <https://emp.lbl.gov/publications/maximizing-mwh-statistical-analysis>

Combination of falling installed prices and better project performance enables lower PPA prices

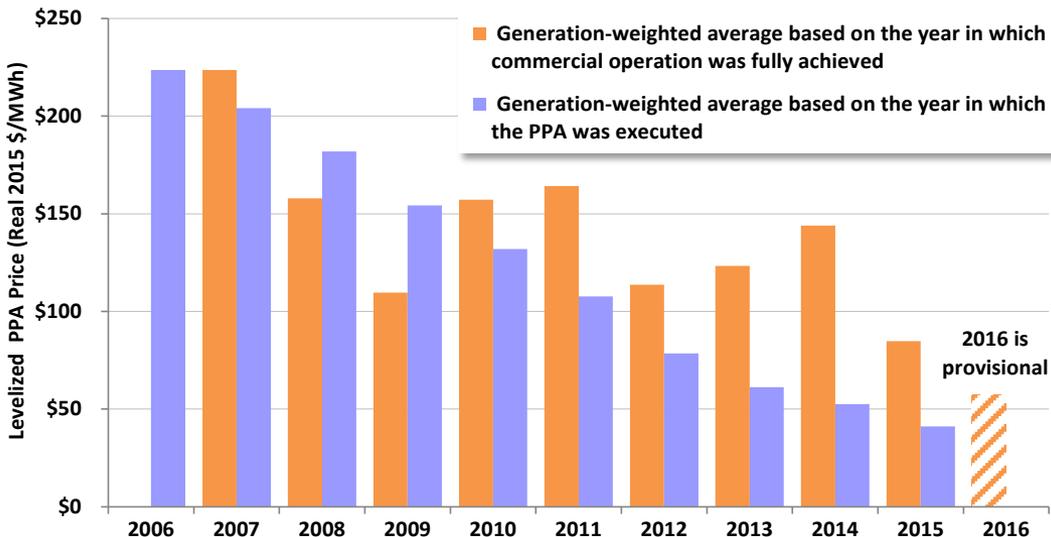


- ◆ PPA prices are levelized over the full term of each contract, after accounting for any escalation rates and/or time-of-delivery factors, and are shown in real 2015 dollars
- ◆ Top graph shows the full sample; bottom graph shows a sub-sample of PPAs signed in 2014 or 2015
- ◆ CA and the Southwest dominate the sample, but 2014 and 2015 saw a broadening of the market to TX, AR, AL, FL—and even MN and MI
- ◆ Strong/steady downward price trend since 2006 to <50\$/MWh in 2015
- ◆ Smaller projects (e.g., 20-50 MW) seemingly no less competitive
- ◆ >75% of the sample is currently operational

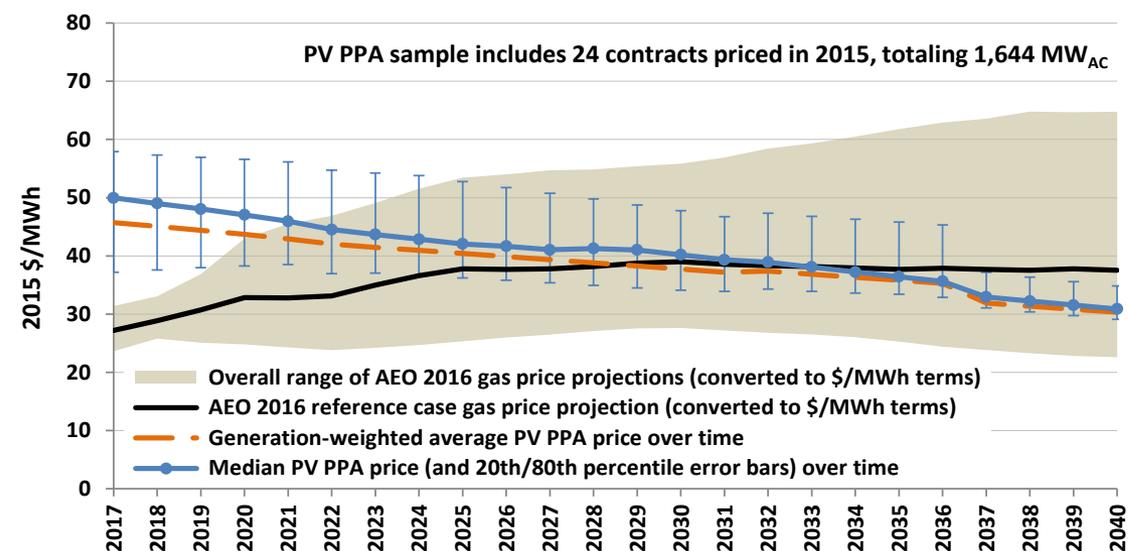
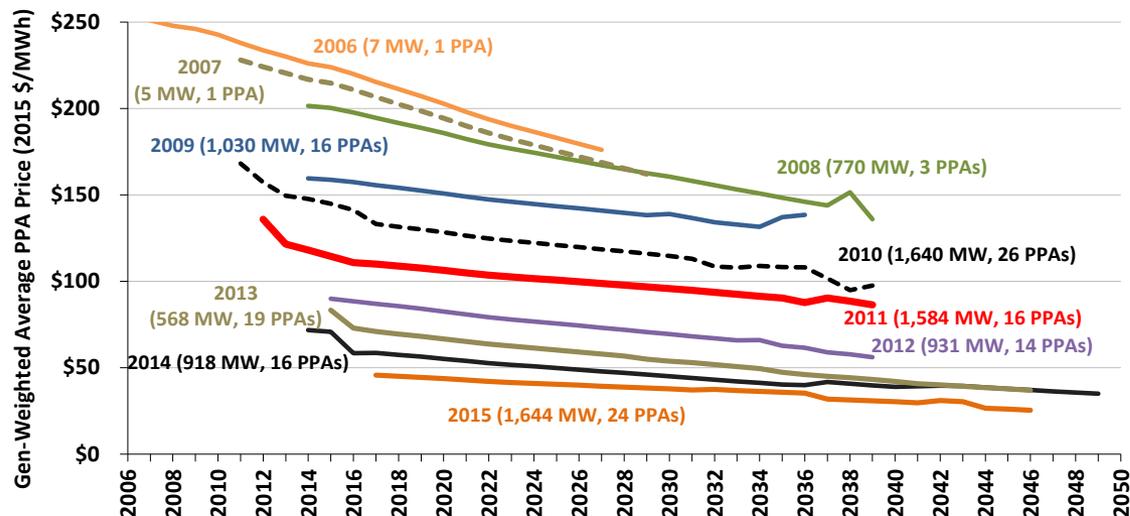
On average, levelized PPA prices have fallen by nearly 75% since 2009



- ◆ Top figure presents the same data as previous slide, but in a different way: each circle is an individual contract, and the blue columns show the average levelized PPA price each year
- ◆ Remarkably steady downward trend in the average PPA price over time has slowed in recent years as average prices approached and then fell below \$50/MWh
- ◆ Price decline over time is more erratic when viewed by commercial operation date (orange columns in bottom graph) rather than PPA execution date (blue columns)
- ◆ Though the average levelized price of PPAs signed in 2015 is ~\$40/MWh, the average levelized PPA price among projects that came online in 2015 is significantly higher, at ~\$85/MWh



PV PPA prices generally decline over time in real dollar terms, in contrast to fuel cost projections



- ◆ ~70% of PV sample has flat annual PPA pricing (in nominal dollars), while the rest escalate at low rates
- ◆ Thus, average PPA prices *decline* over time in real dollar terms (top graph)
- ◆ Bottom graph compares 2015-vintage PPA prices to range of gas price projections from *AEO 2016*, showing that...
- ◆ ...although PV is currently priced higher than the cost of burning fuel in a combined-cycle unit, over longer terms PV is likely to be more competitive, and can help protect against fuel price risk

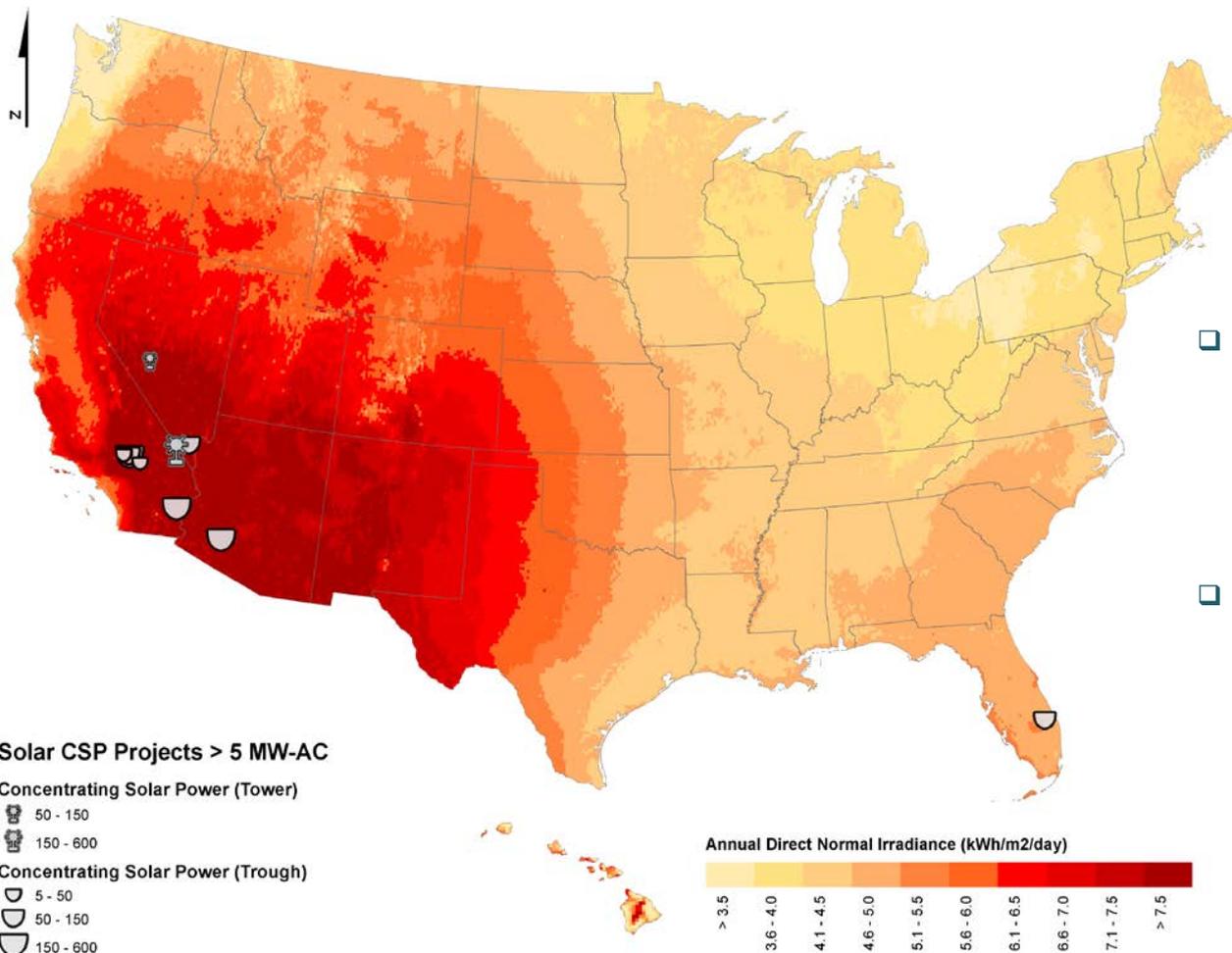
Concentrating Solar Power (CSP) Projects



Photo Credit: Solar Reserve: Crescent Dunes

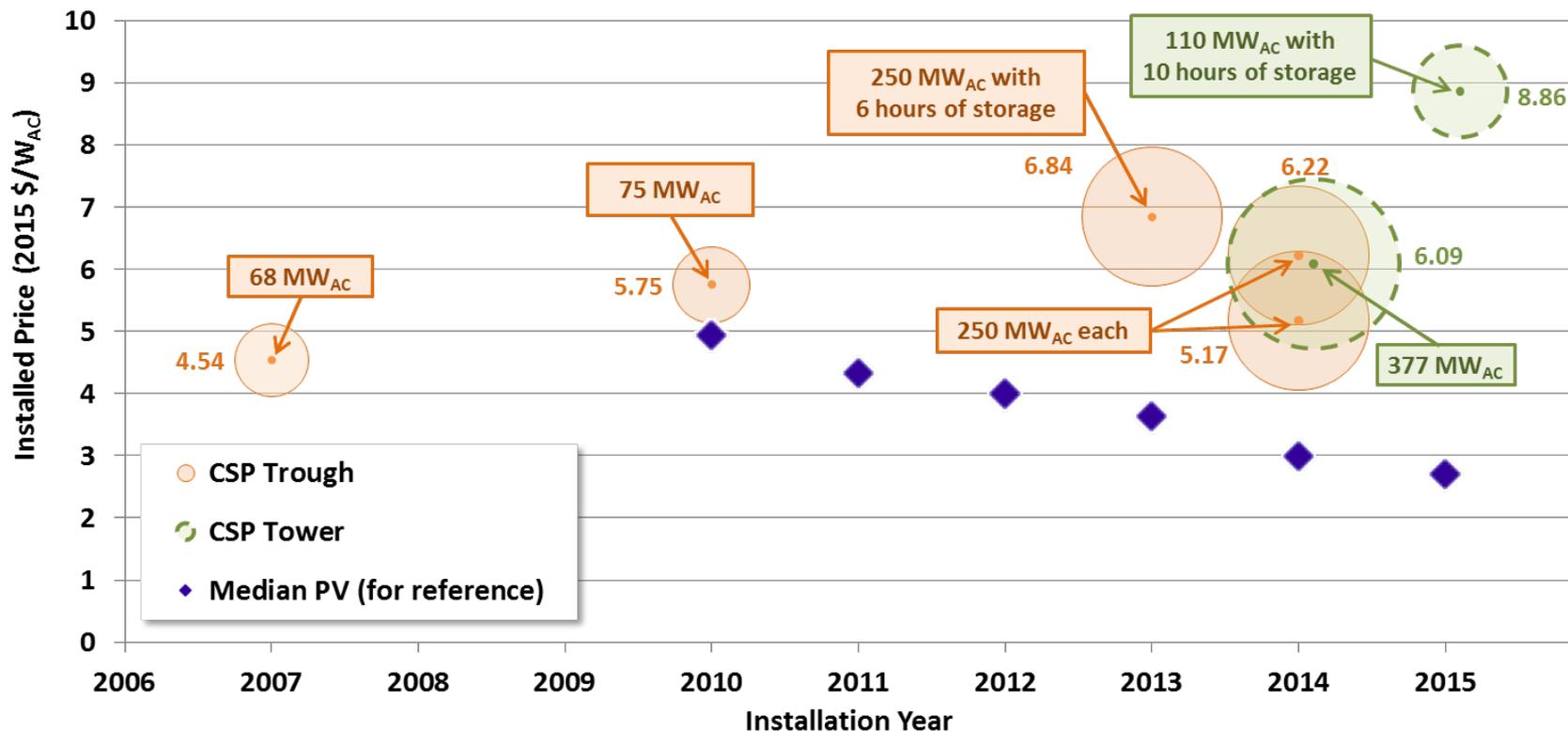
Sample description of CSP projects

CSP project population: 16 projects totaling 1,781 MW_{AC}



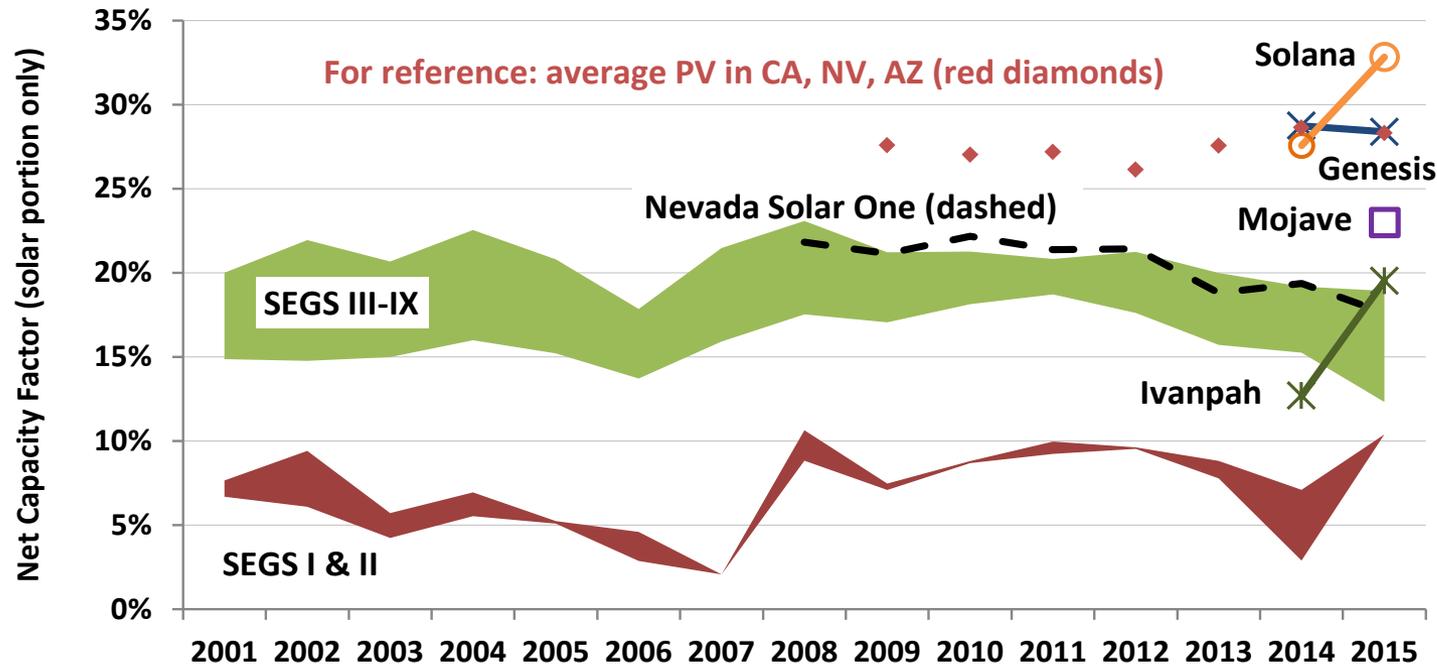
- After nearly 400 MW_{AC} built in the late-1980s (and early-1990s), no new CSP was built in the U.S. until 2007 (68 MW_{AC}), 2010 (75 MW_{AC}), and 2013-2015 (1,237 MW_{AC})
- Prior to the large 2013-15 build-out, all utility-scale CSP projects in the U.S. used parabolic trough collectors
- The five 2013-2015 projects include 3 parabolic troughs (one with 6 hours of storage) totaling 750 MW_{AC} (net) and two “power tower” projects (one with 10 hours of storage) totaling 487 MW_{AC} (net)

Not much movement in the installed price of CSP



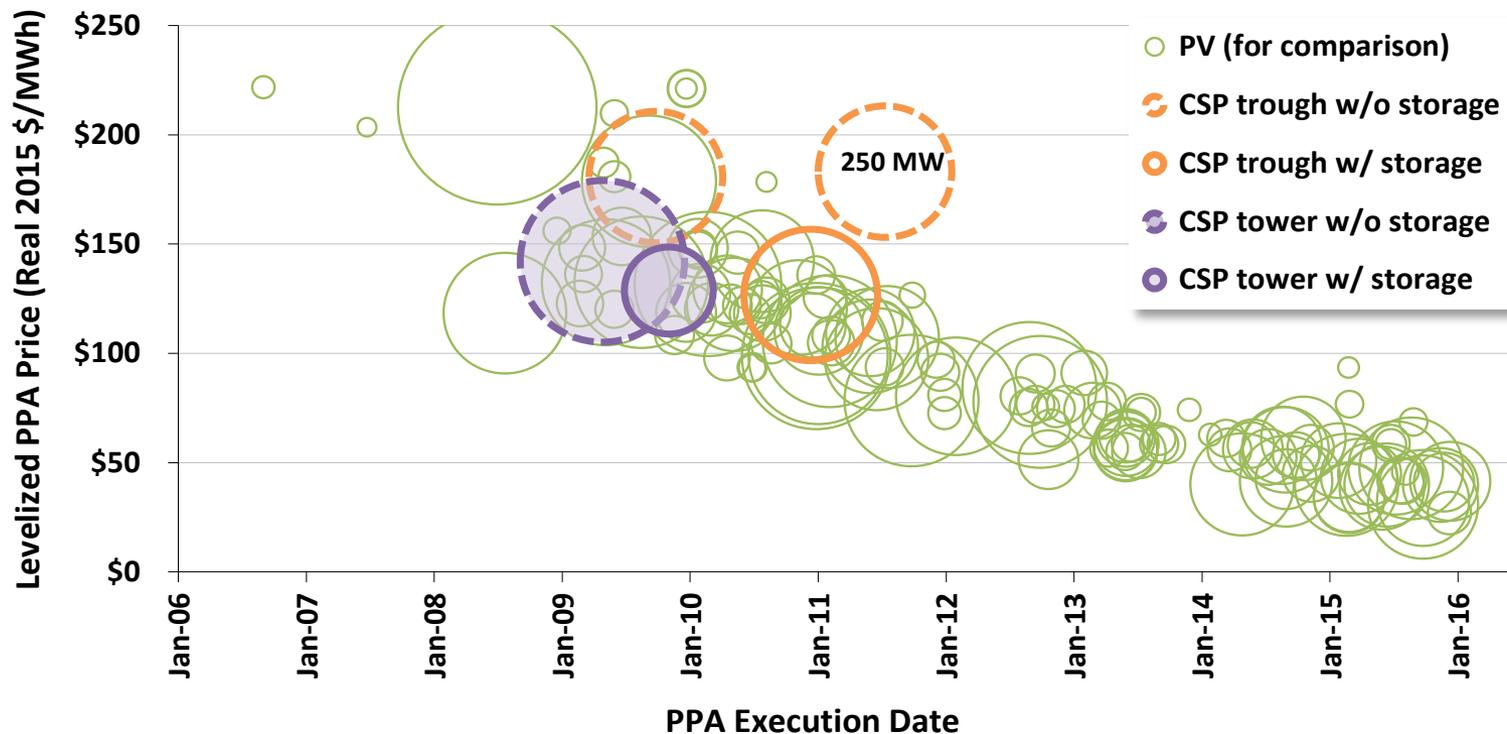
- ◆ Small sample of 7 projects (5 built in 2013-15) using different technologies makes it hard to identify trends
- ◆ That said, there does not appear to be much of a trend (in contrast to PV's steady downward trend)
- ◆ To be fair, newest projects are much larger, and include storage and/or new technology (power tower) in some cases, making comparisons difficult

Newer CSP projects have struggled with teething issues, but performance improved in 2015



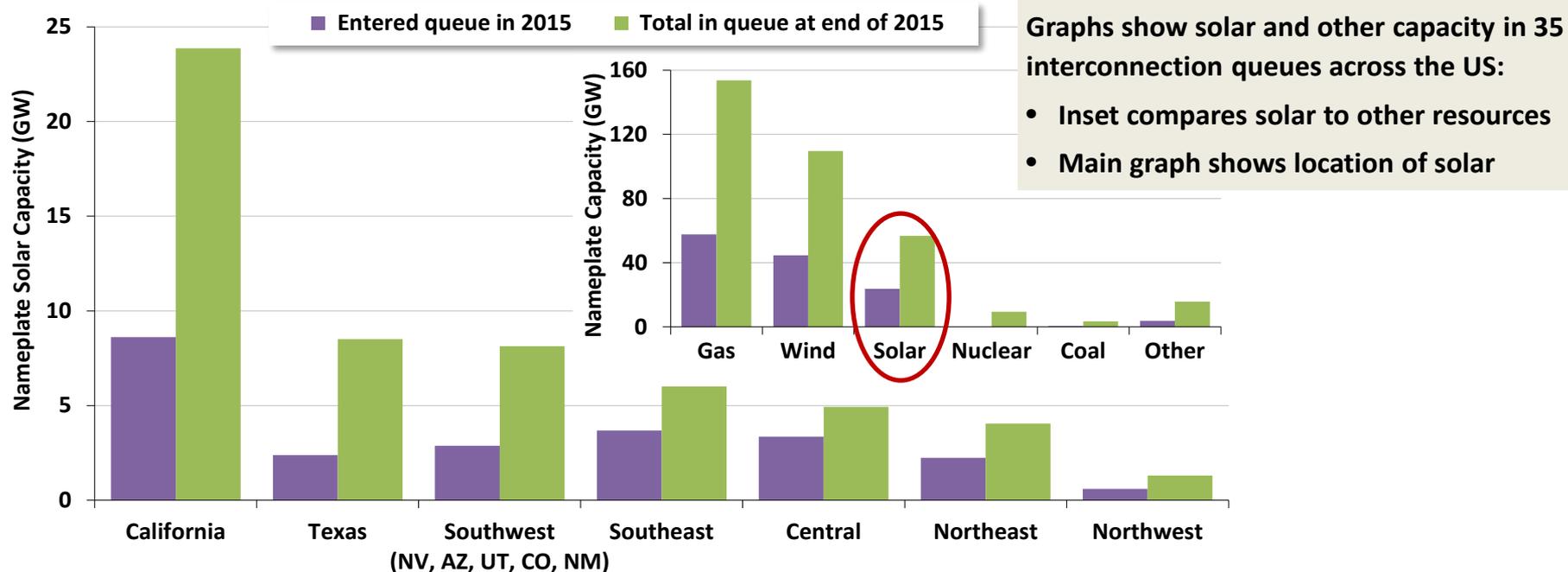
- ◆ Capacity factors at Solana and Ivanpah improved in 2015, but were still below long-term, steady-state expectations (the ramp-up is still in progress)
- ◆ Genesis maintained its 2014 capacity factor (at expectations), but similar Mojave trough project fell a little short
- ◆ Newer CSP projects generally performing better than older CSP projects, but not necessarily any better than PV projects
- ◆ SEGS I & II have been decommissioned (and may be replaced with PV)

Though once competitive, CSP PPA prices have failed to keep pace with PV's price decline



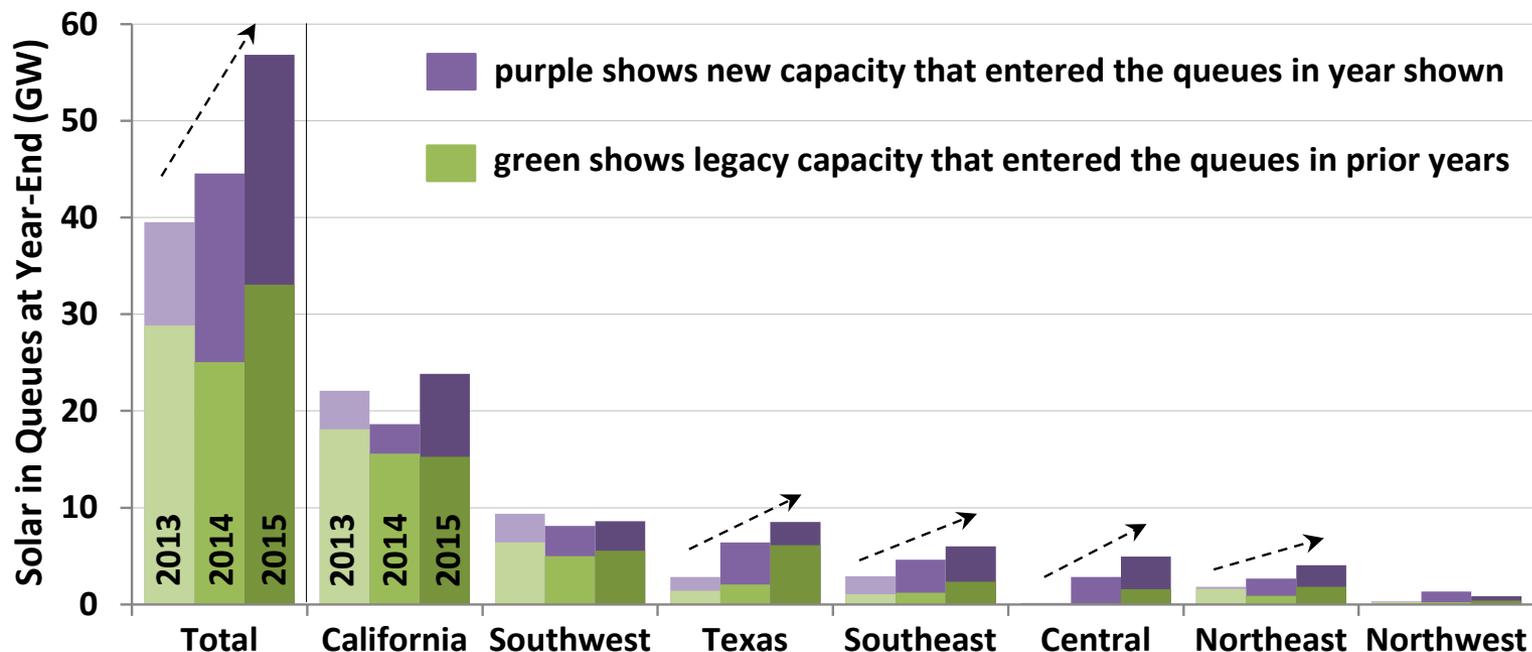
- ◆ When PPAs for the most recent batch of CSP projects (with CODs of 2013-15) were signed back in 2009-2011, they were still mostly competitive with PV
- ◆ But CSP has not been able to keep pace with PV's price decline
- ◆ Partly as a result, no new PPAs for CSP projects have been signed since 2011

Looking ahead: long-term ITC extension should support continued growth in the utility-scale solar pipeline



- ◆ December 2015's extension of the 30% ITC through 2019 (along with the switch to a "start construction" rather than "placed in service" deadline), with a gradual phase down to 10% thereafter, should ensure continued momentum for the foreseeable future
- ◆ 56.8 GW of solar was in the queues at the end of 2015 (up from 44.6 GW at end of 2014): *more than 5 times the installed solar capacity in our project population at the end of 2015*
- ◆ Solar was in third place in the queues, behind natural gas and wind

Relative growth of solar pipeline in various regions suggests a broadening market



- ◆ The utility-scale solar pipeline has been replenished and has even grown in recent years, despite the record buildout in 2014 and 2015
- ◆ Although California and (to a lesser extent) the Southwest still dominate the interconnection queues, recent **growth** in the queues has come largely from outside of those two traditional markets—e.g., Texas and the Southeast, Central, and Northeastern regions
- ◆ *Not all of these projects will ultimately be built (some will undoubtedly fall by the wayside)*

Questions?

Download the full report, a data file, and this slide deck at:

<http://utilityscopesolar.lbl.gov>

Download all of our other solar and wind work at:

<http://emp.lbl.gov/reports/re>

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