Title
Utility-Scale Solar Data Update: 2020 Edition

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Utility-Scale Solar Data Update: 2020 Edition

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Photo source: sPower

Utility-Scale Solar Data Update: 2020 Edition

Purpose and Scope:

- Summarize publicly available data on key trends in U.S. utility-scale solar sector
- Focus on ground-mounted projects >5 MW_{AC}
  - There are separate DOE-funded data collection efforts on distributed PV
- Focus on historical data, emphasizing the most-recent full calendar year

Data and Methods:

- See summary at end of PowerPoint deck

Funding:

- U.S. Department of Energy's Solar Energy Technologies Office

Products and Availability:

- This briefing deck is complemented by a data file and visualizations
- All products available at: utilityscalesolar.lbl.gov

Presentation Contents

Deployment and Technology Trends

Installed Prices

Performance (Capacity Factors)

Power Purchase Agreement (PPA) Prices and LCOE

Concentrating Solar Thermal Power (CSP) Plants

Capacity in Interconnection Queues

Data and Methods

What's new this year in the online data set?

Consistent use of new regional boundaries

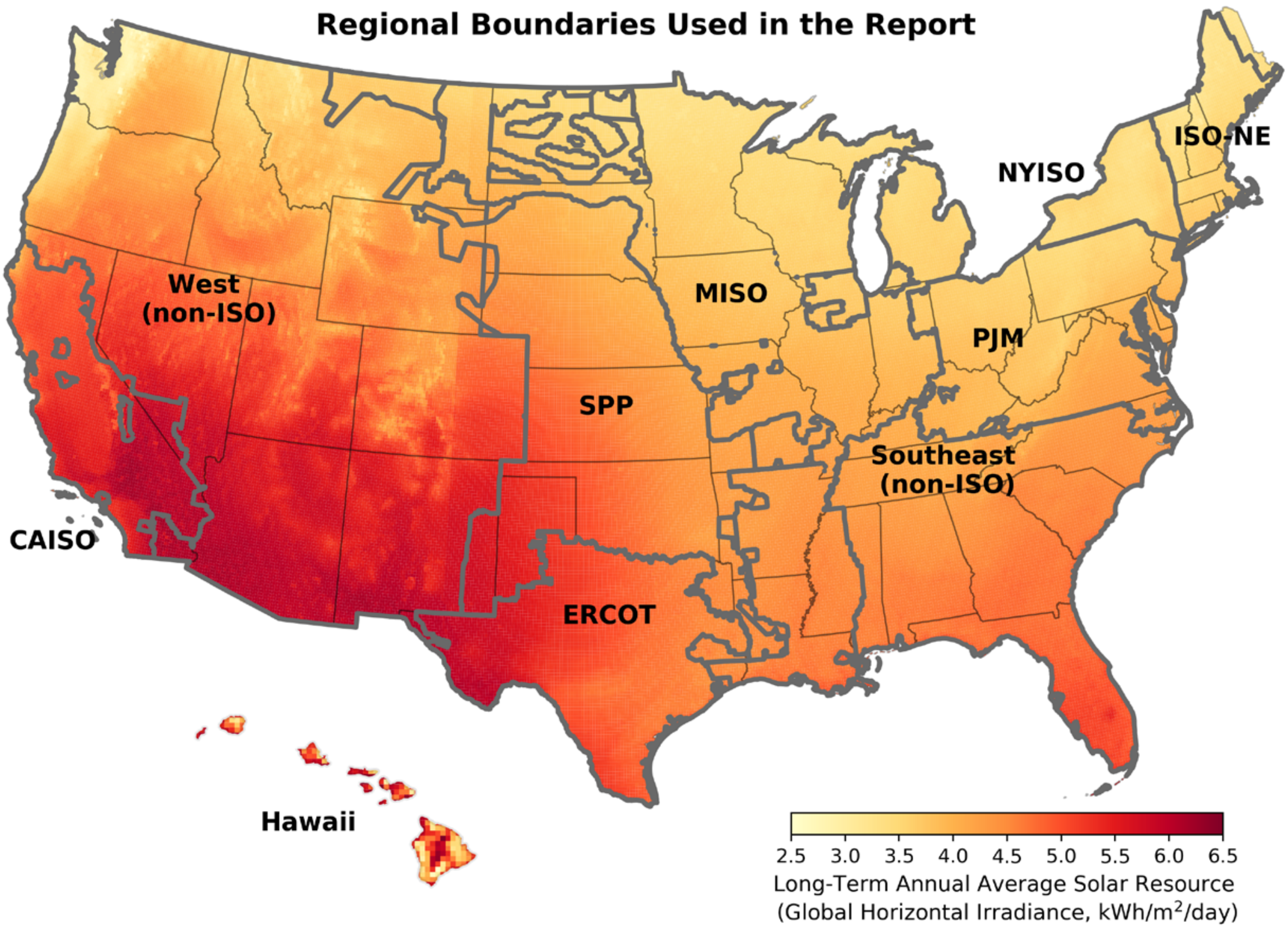
Additional data for online and planned hybrid projects

Inclusion of LevelTen Energy PV power sales price data

Further presentation of trends in levelized energy costs

Reorganization and refinement of content and figures

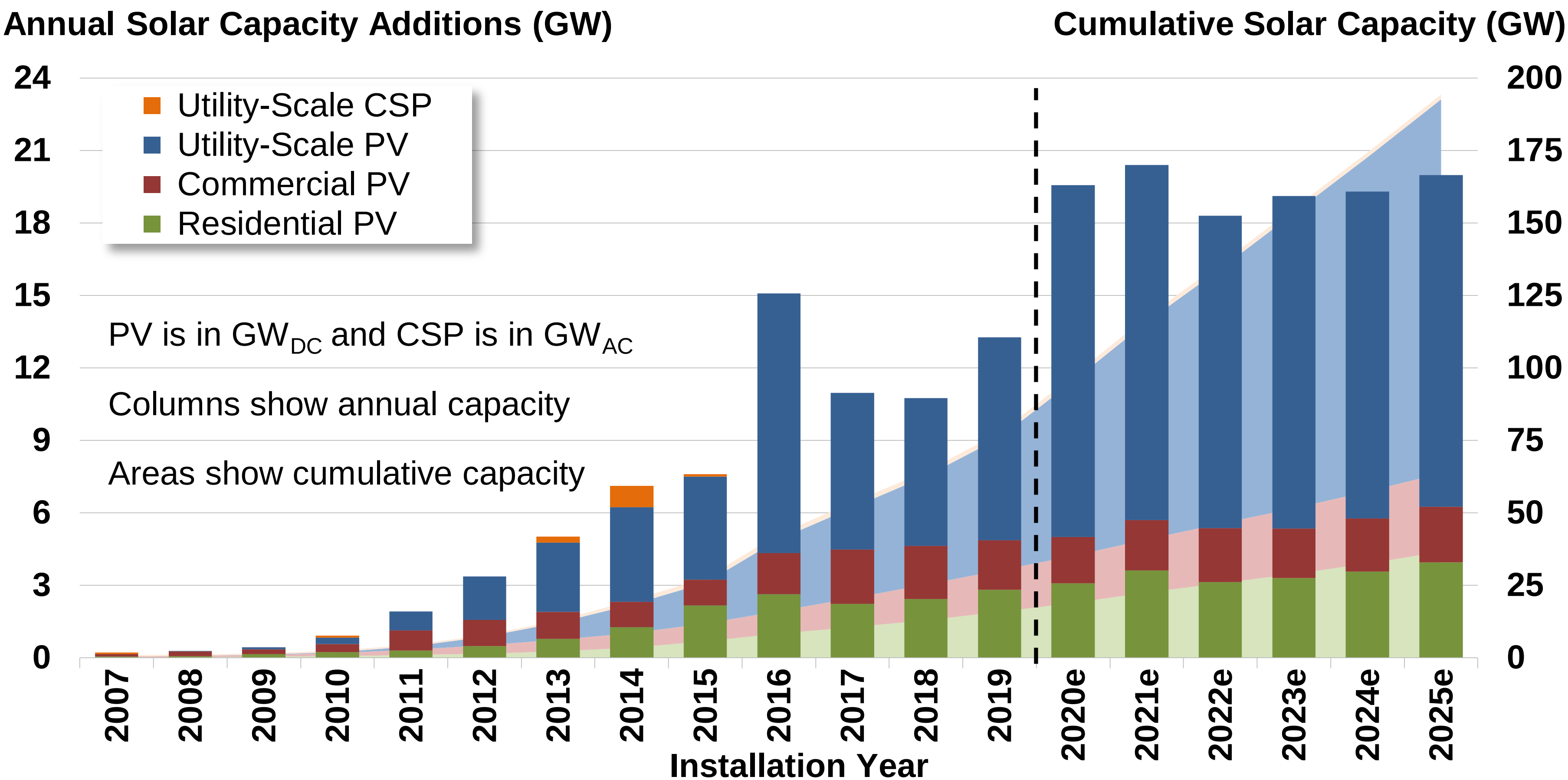
Regional boundaries applied in this analysis include the seven independent system operators (ISO) and two non-ISO regions



Source: NREL

Deployment and Technology Trends

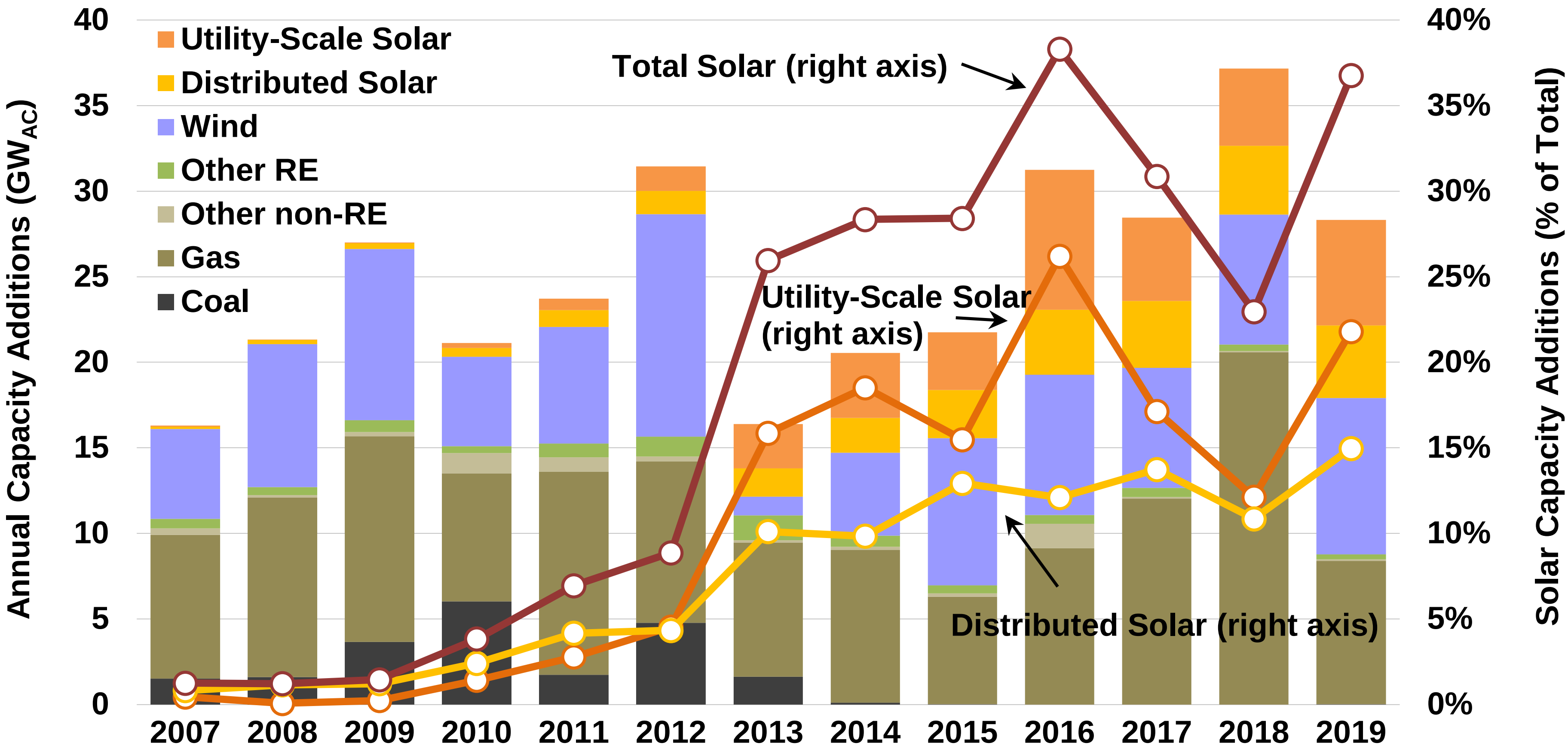
Annual and cumulative growth of U.S. solar power capacity



Sources: Wood Mackenzie and SEIA (2010-2019), IREC, Berkeley Lab.
Note: Wood Mackenzie and SEIA's definition of utility-scale PV capacity differs from LBNL both in size thresholds and treatment of project phase completion.

Interactive data visualizations: https://emp.lbl.gov/technology-trends and https://emp.lbl.gov/capacity-and-generation-state

Annual capacity additions of different generator types



Sources: ABB, AWEA WindIQ, Wood Mackenzie, Berkeley Lab

Note: This graph follows GTM/SEIA's split between distributed and utility-scale solar, rather than our 5 MW$_{AC}$ threshold

Over the past 5 years, solar (31%) and wind (28%) have accounted for 59% of all capacity additions to the U.S. grid (utility-scale solar was 18%)

Solar's market penetration by state

State	Solar generation as a % of in-state generation		Solar generation as a % of in-state load	
	All Solar	Utility-Scale Solar Only	All Solar	Utility-Scale Solar Only
California	19.9%	13.0%	17.7%	11.6%
Vermont	14.0%	7.5%	6.1%	3.2%
Nevada	13.7%	12.0%	14.8%	13.0%
Massachusetts	13.7%	4.9%	6.6%	2.4%
Hawaii	12.6%	2.4%	14.7%	2.9%
Arizona	6.6%	4.4%	9.9%	6.6%
Utah	6.6%	5.4%	8.5%	7.0%
North Carolina	5.7%	5.5%	5.6%	5.4%
New Mexico	4.7%	3.8%	6.6%	5.4%
New Jersey	4.7%	1.7%	4.7%	1.7%
Rest of U.S.	*0.9%*	*0.6%*	*1.0%*	*0.7%*
TOTAL U.S.	**2.6%**	**1.7%**	**2.9%**	**1.9%**

Source: EIA

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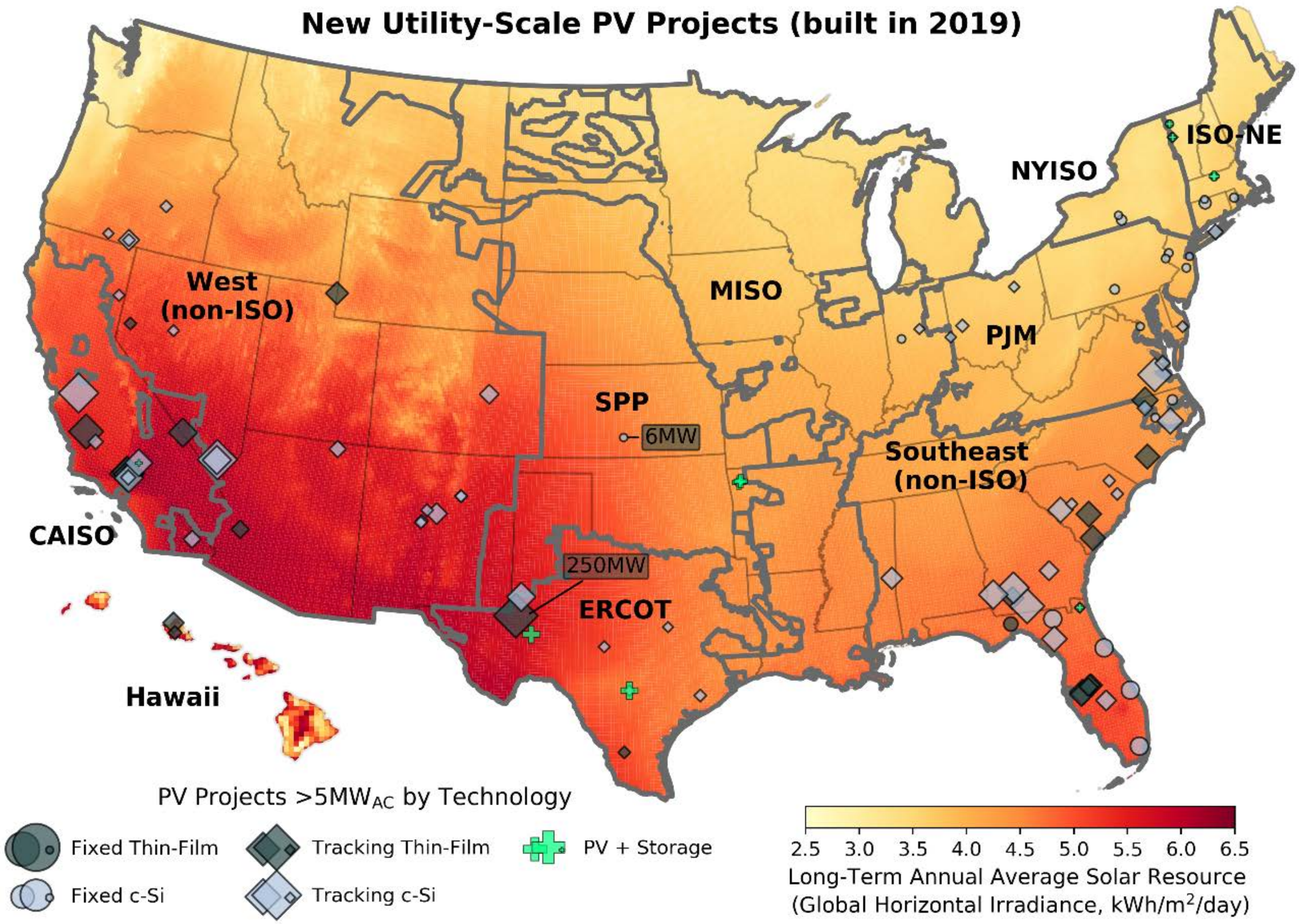
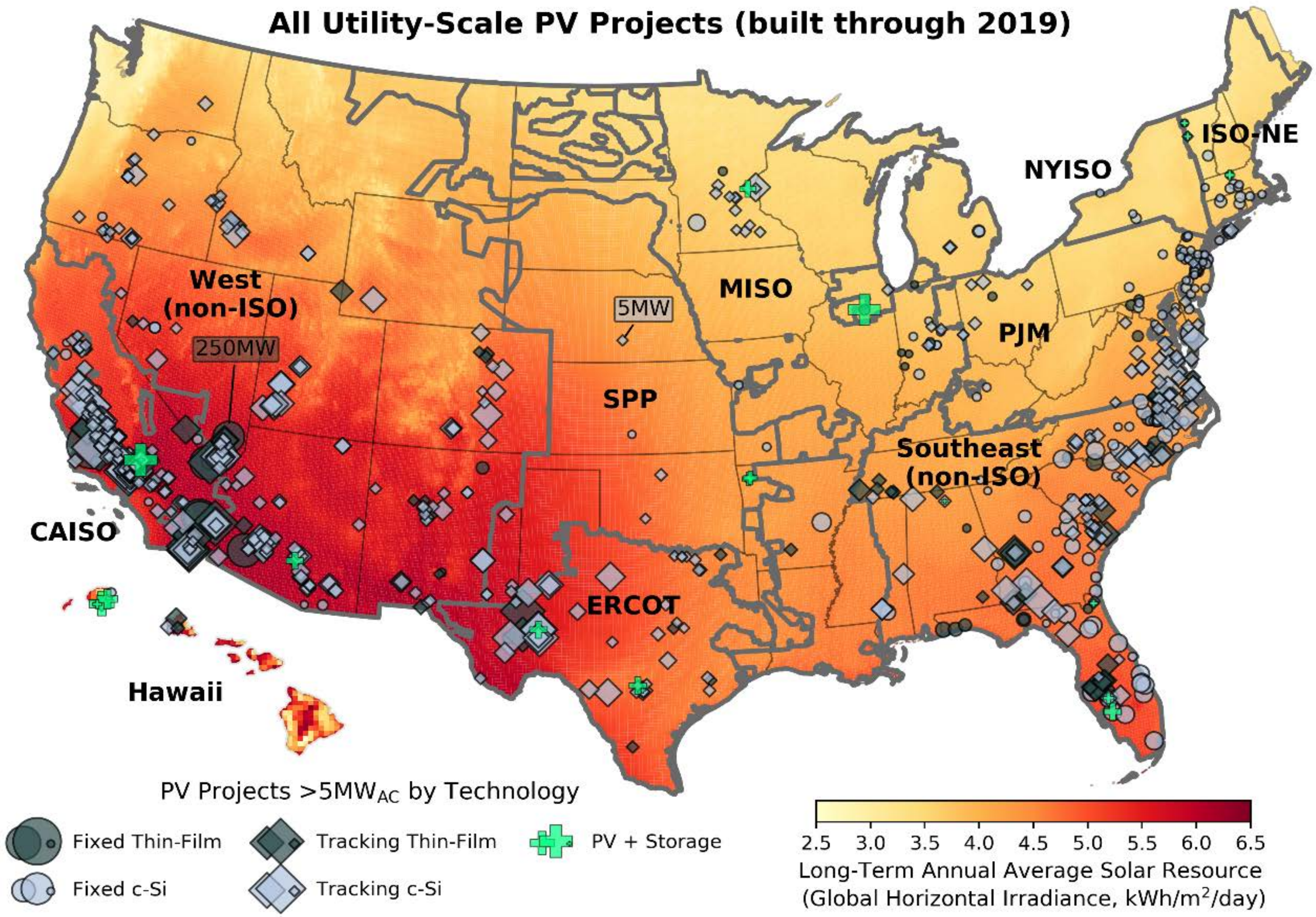
Utility-scale solar projects that were added in 2019



Source: Berkeley Lab

Interactive data visualizations: https://emp.lbl.gov/animated-map-pv-growth-gif and https://emp.lbl.gov/technology-trends

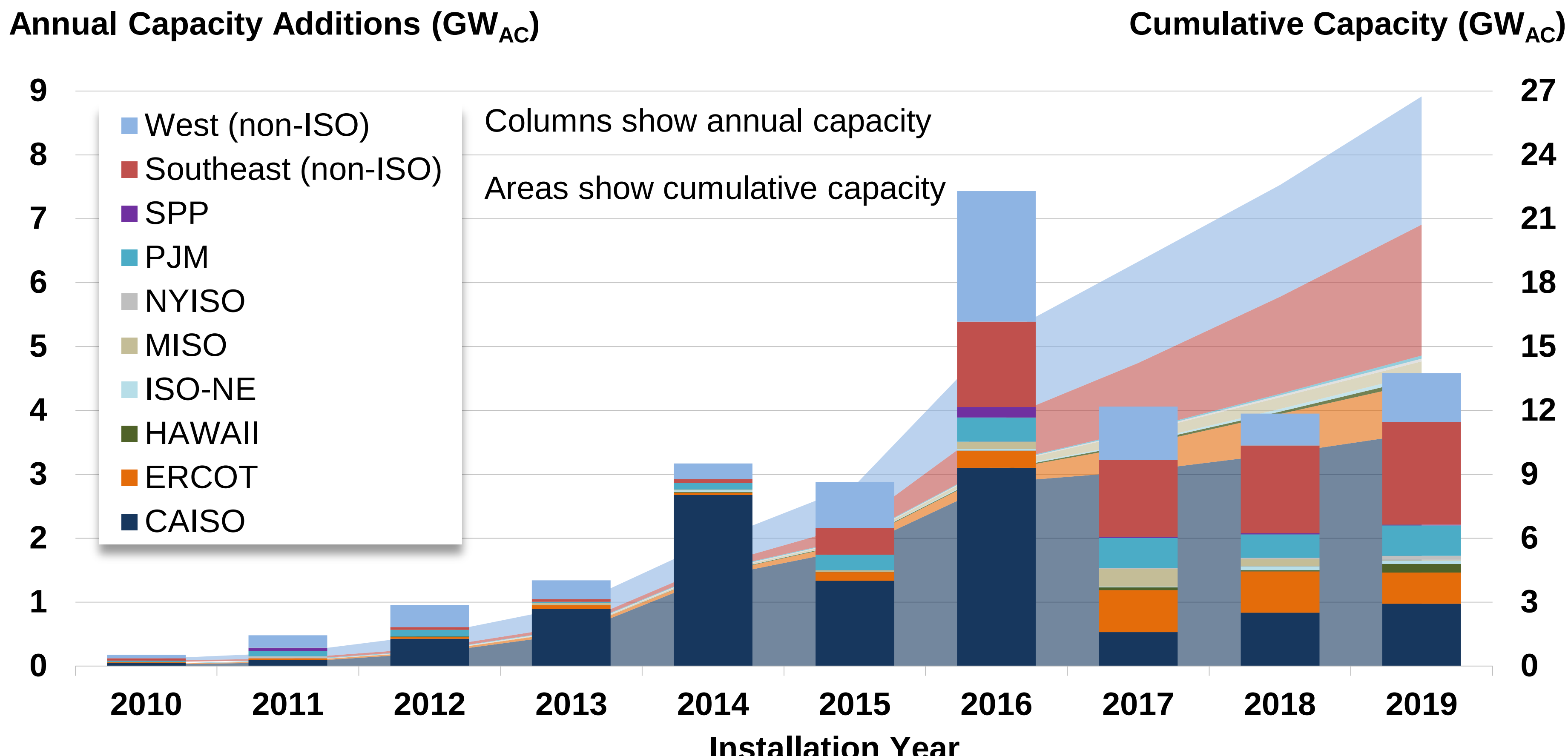
Utility-scale solar projects in operation at the end of 2019



Source: Berkeley Lab

Interactive data visualizations: https://emp.lbl.gov/animated-map-pv-growth-gif and https://emp.lbl.gov/technology-trends

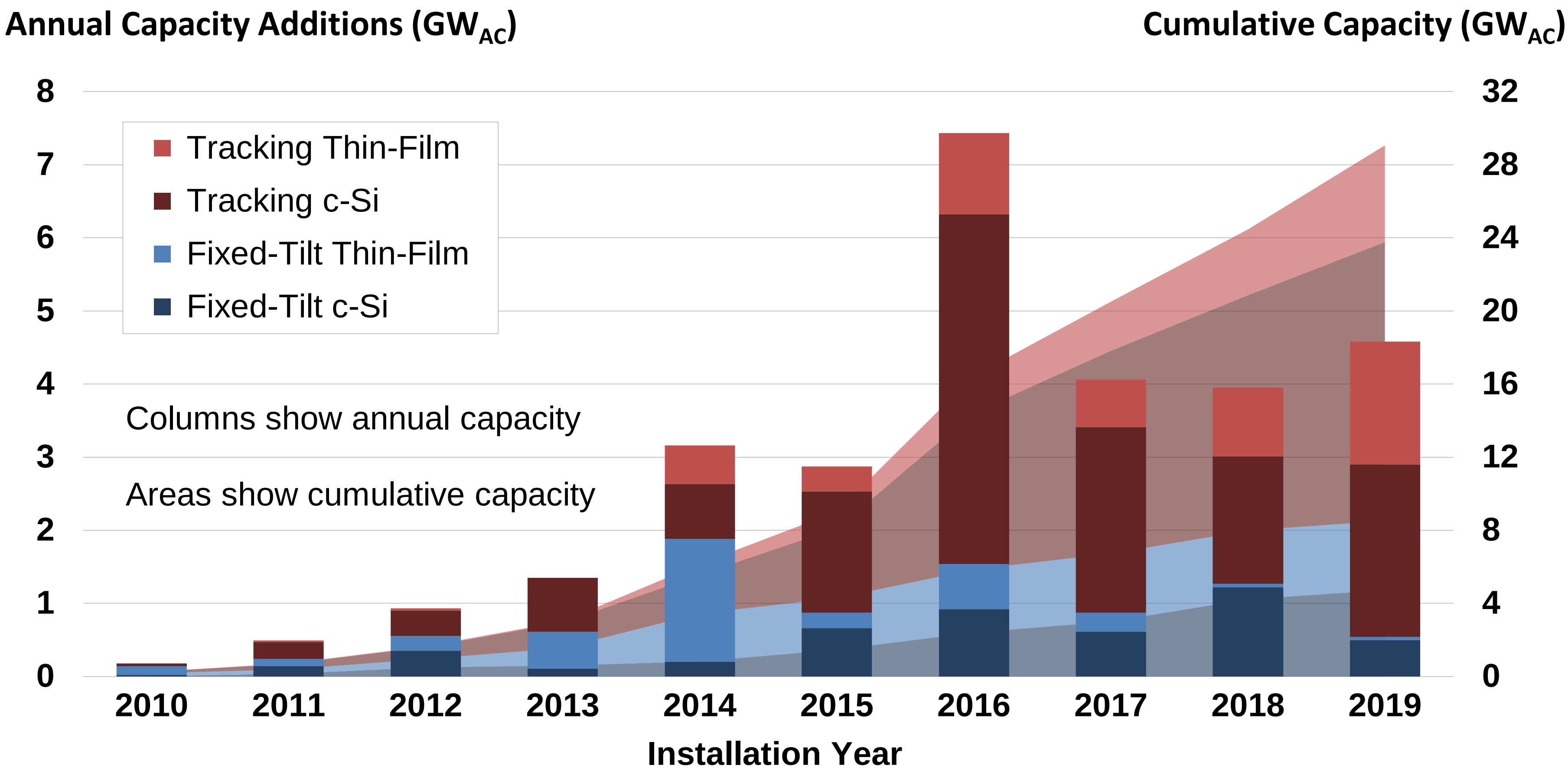
Annual and cumulative utility-scale PV capacity by region



Source: Berkeley Lab

For the third year in a row, the Southeast led all other regions in 2019 in terms of new utility-scale PV capacity additions.

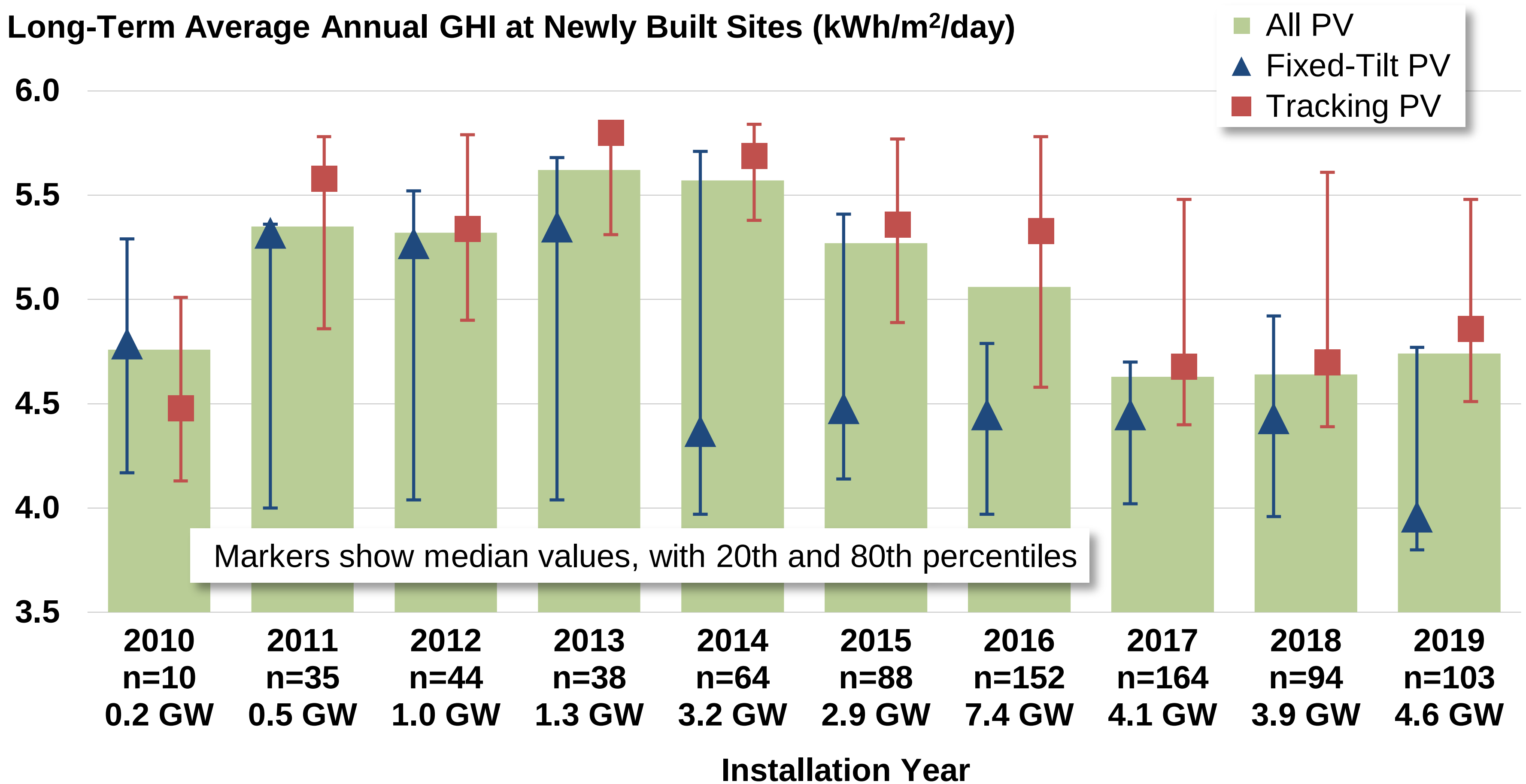
Annual and cumulative utility-scale PV capacity by module and mounting type



Source: Berkeley Lab

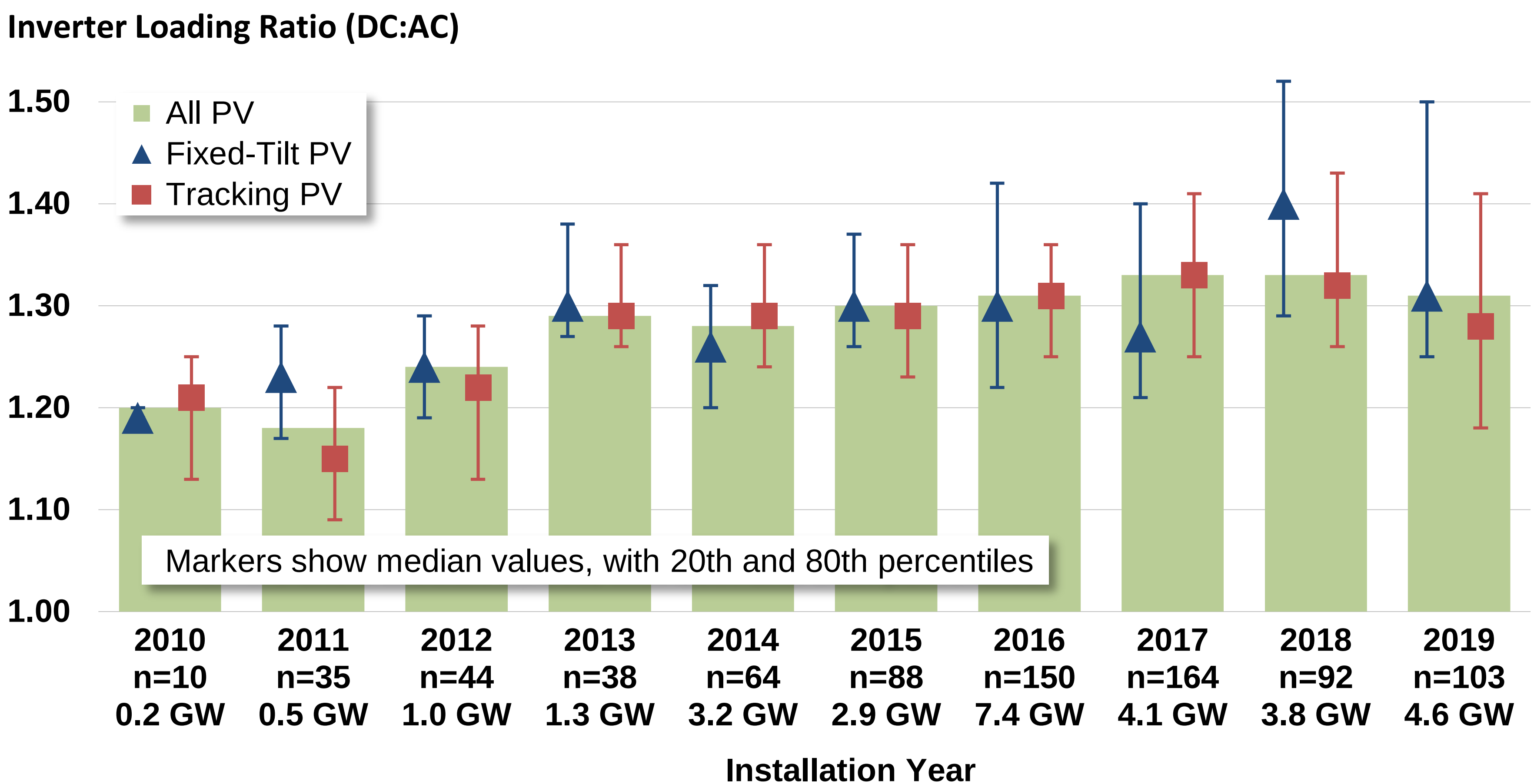
88% of all new utility-scale PV capacity added in the United States in 2019 employ tracking—the highest single-year share yet.

Global horizontal irradiance (GHI) by mounting type and installation year



Source: Berkeley Lab (project information) and NREL (long-term annual average solar resource)

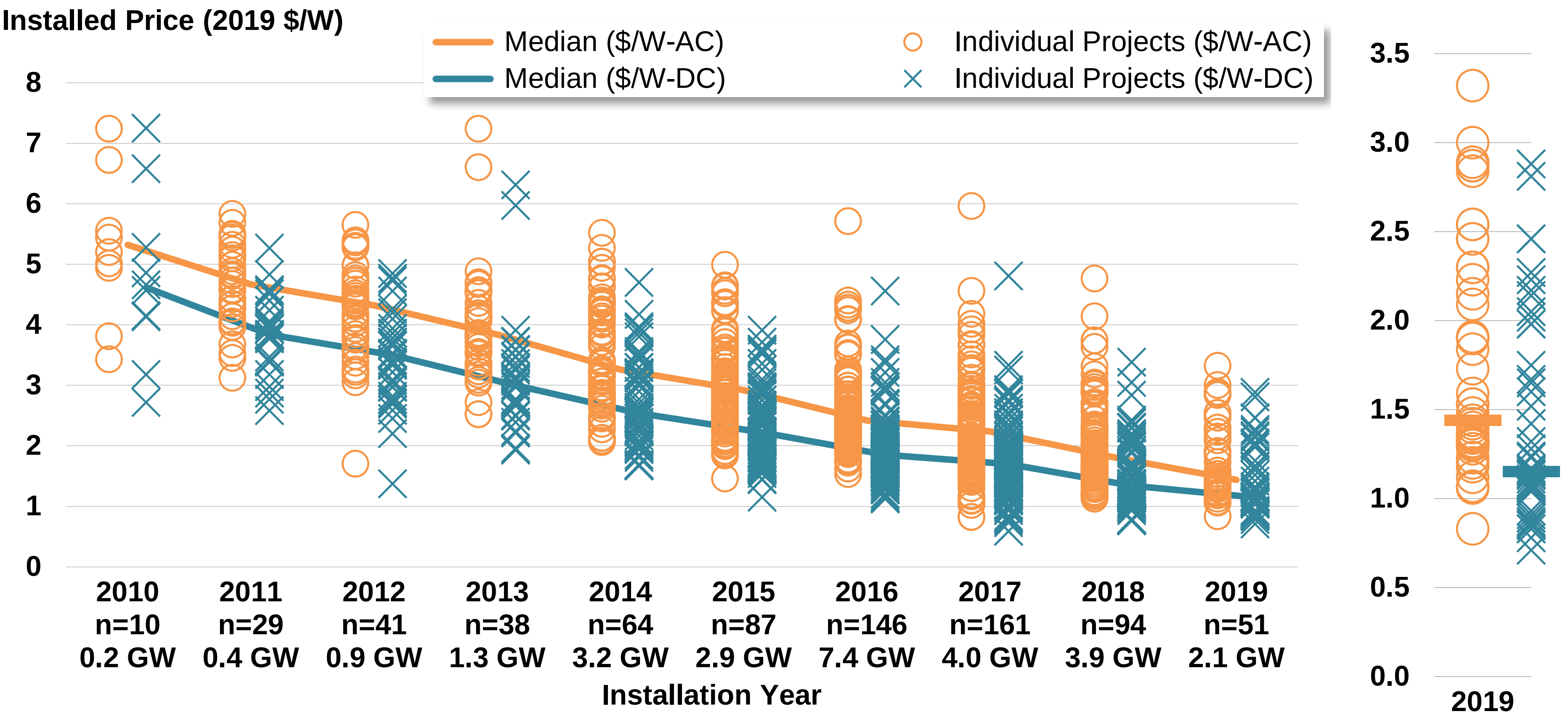
Inverter loading ratio by mounting type and installation year



Source: Berkeley Lab
Note: The Inverter Loading Ratio (ILR, or DC:AC ratio) describes the ratio of project capacity measured in MW_{DC} to the nominal inverter capacity measured in MW_{AC}

Installed Prices

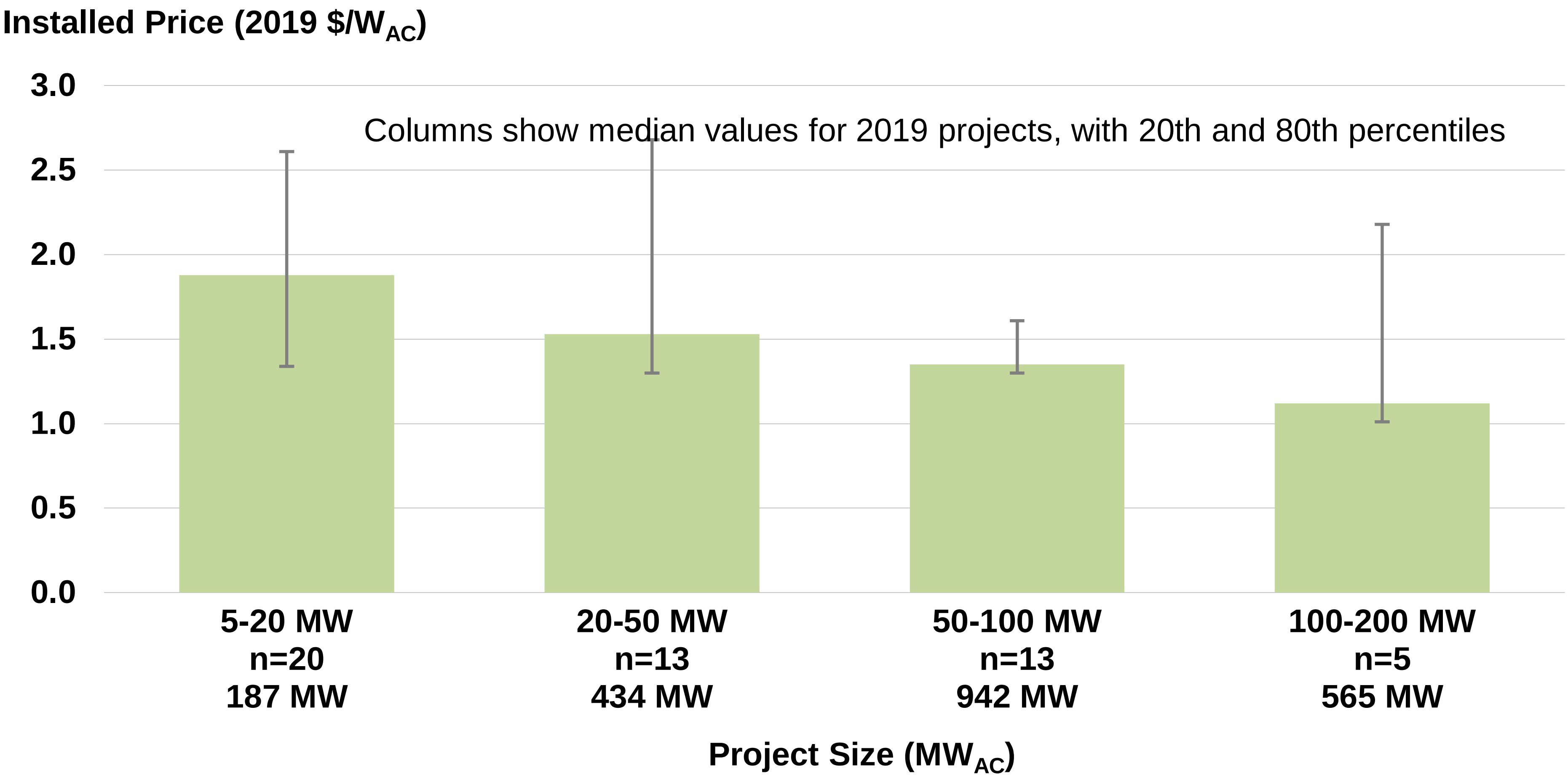
Installed price by year (in both DC and AC terms)



Sources: Berkeley Lab, Energy Information Administration

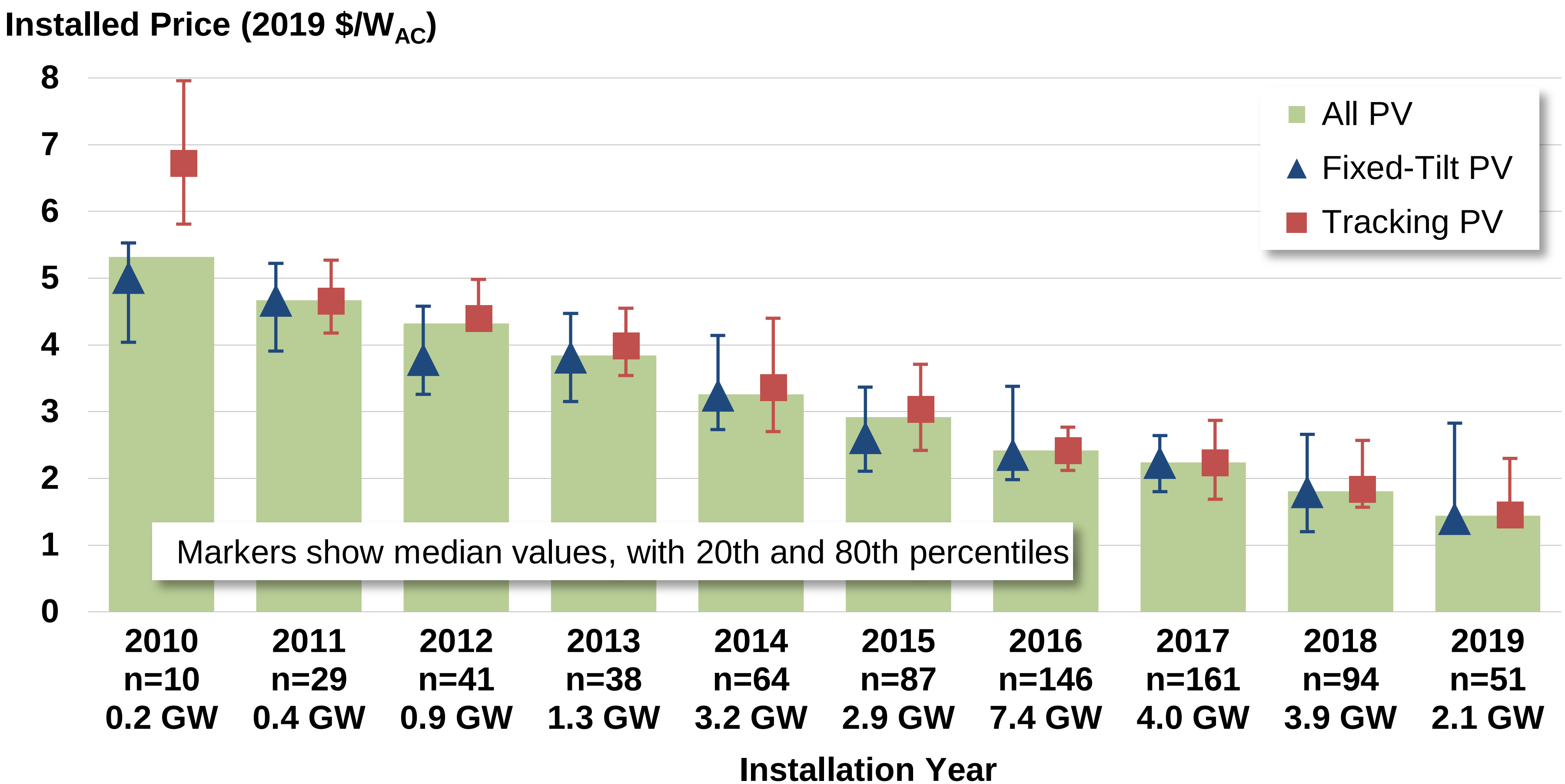
The median installed price of projects that came online in 2019 fell to $1.4/W$_{AC}$ ($1.2/W$_{DC}$), down 20% from 2018 and down by more than 70% from 2010.

Installed price by project size in 2019



Economies of scale are evident in the 2019 project cost data.

Installed price by mounting type and installation year



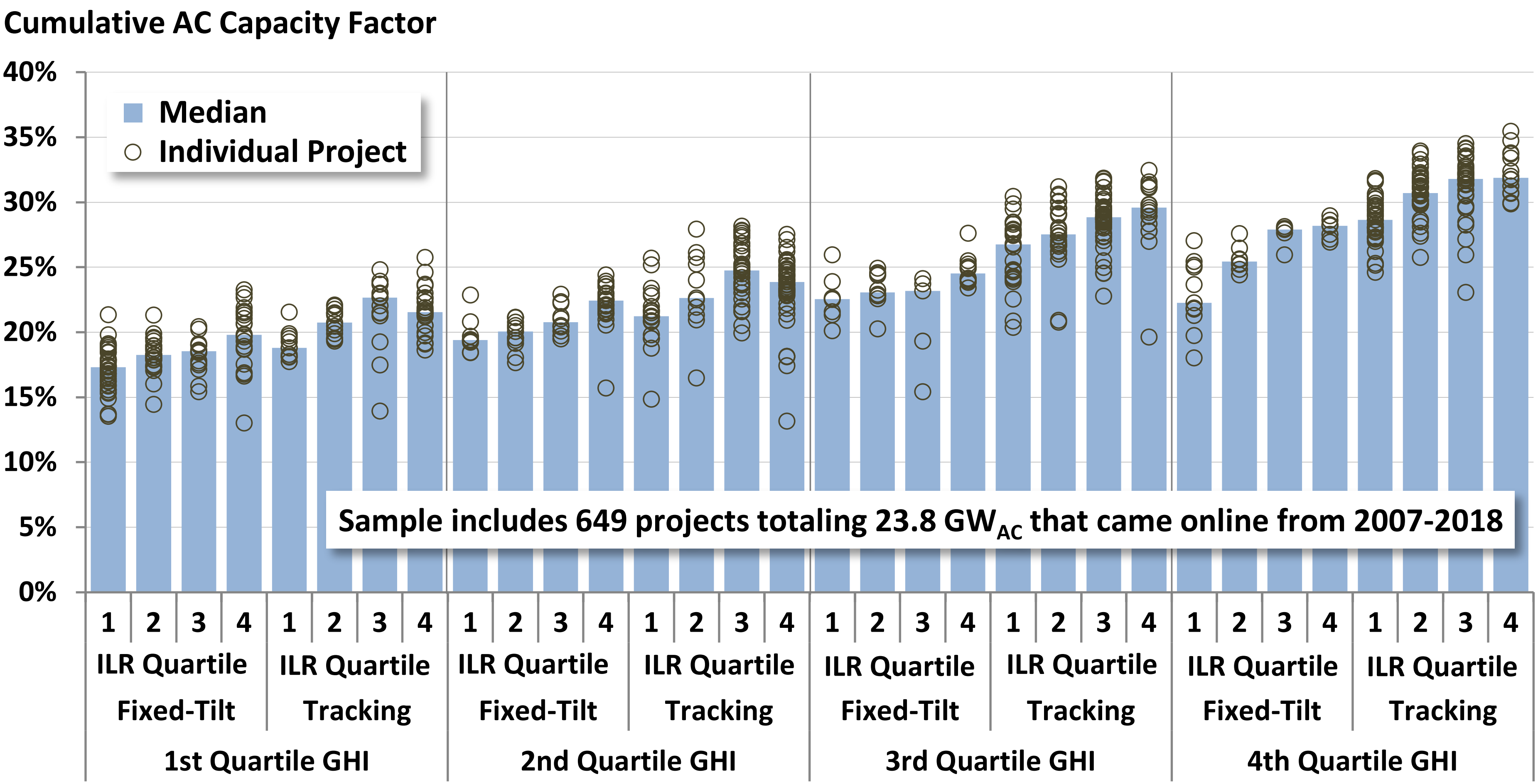
Sources: Berkeley Lab, EIA, FERC, SEC, trade press

The historical up-front cost premium for tracking has all but disappeared.

Performance (Capacity Factors)

Cumulative capacity factor by resource strength, fixed-tilt vs. tracking, and inverter loading ratio (ILR)

25% capacity factor sample-wide, but with large project-level range from 14%-35%

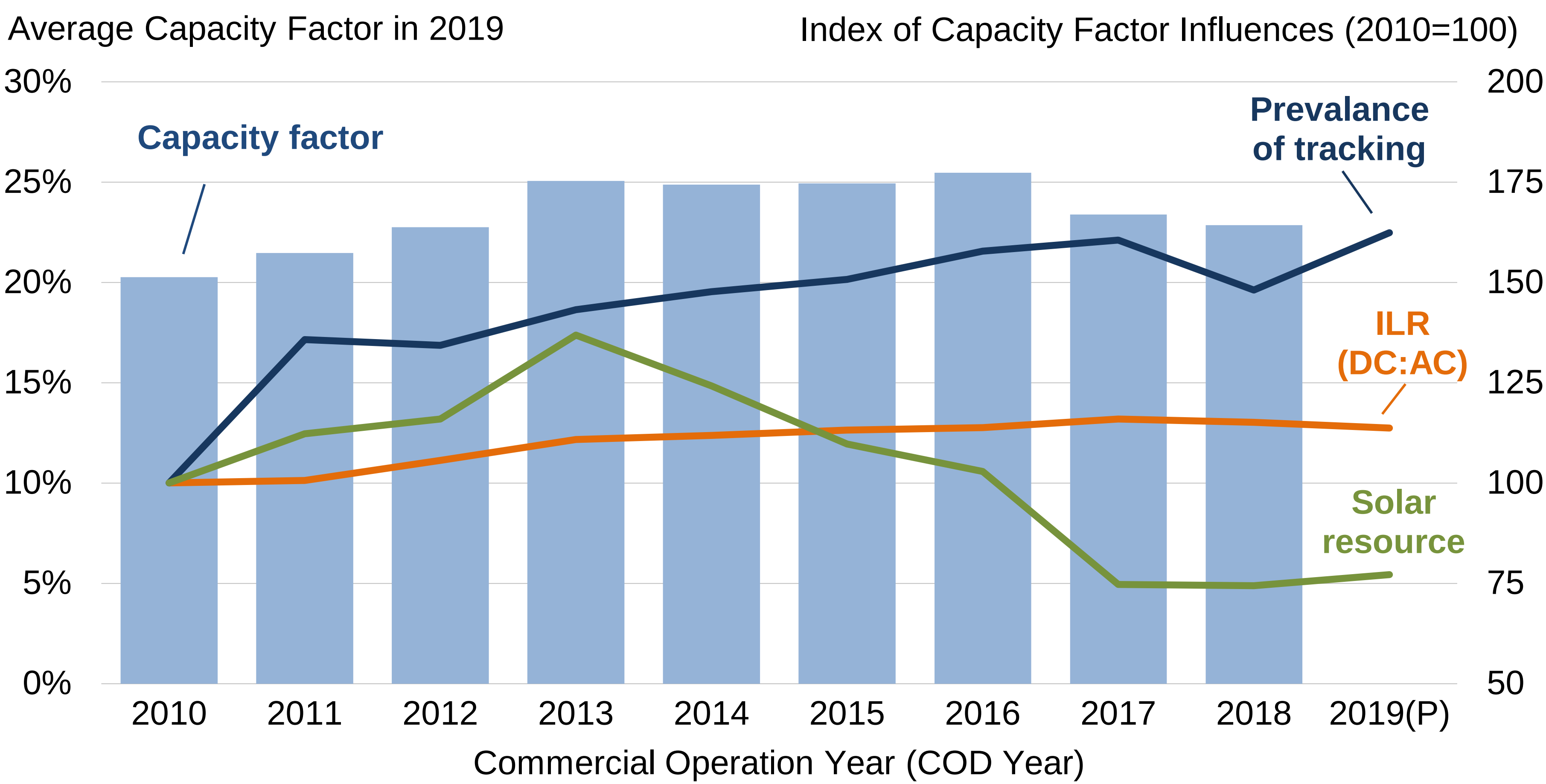


Source: EIA, FERC, Berkeley Lab

Interactive data visualization: https://emp.lbl.gov/pv-capacity-factors

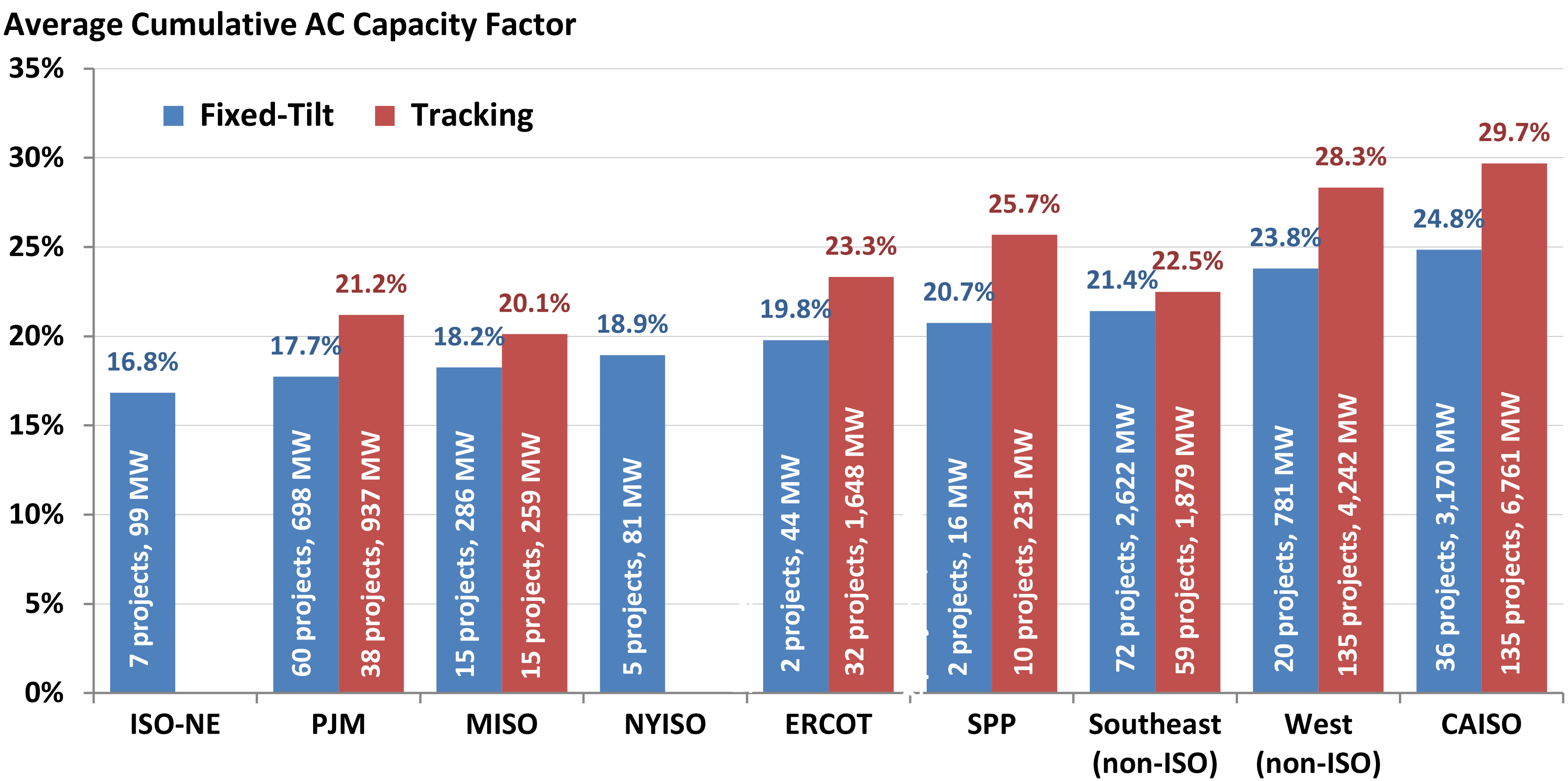
Utility-scale PV capacity factors and various drivers by commercial operation date

Flat-to-declining trend since 2013 reflects the expansion of the market into less-sunny regions of the United States (as depicted by the green “solar resource” line)



Source: EIA, FERC, Berkeley Lab

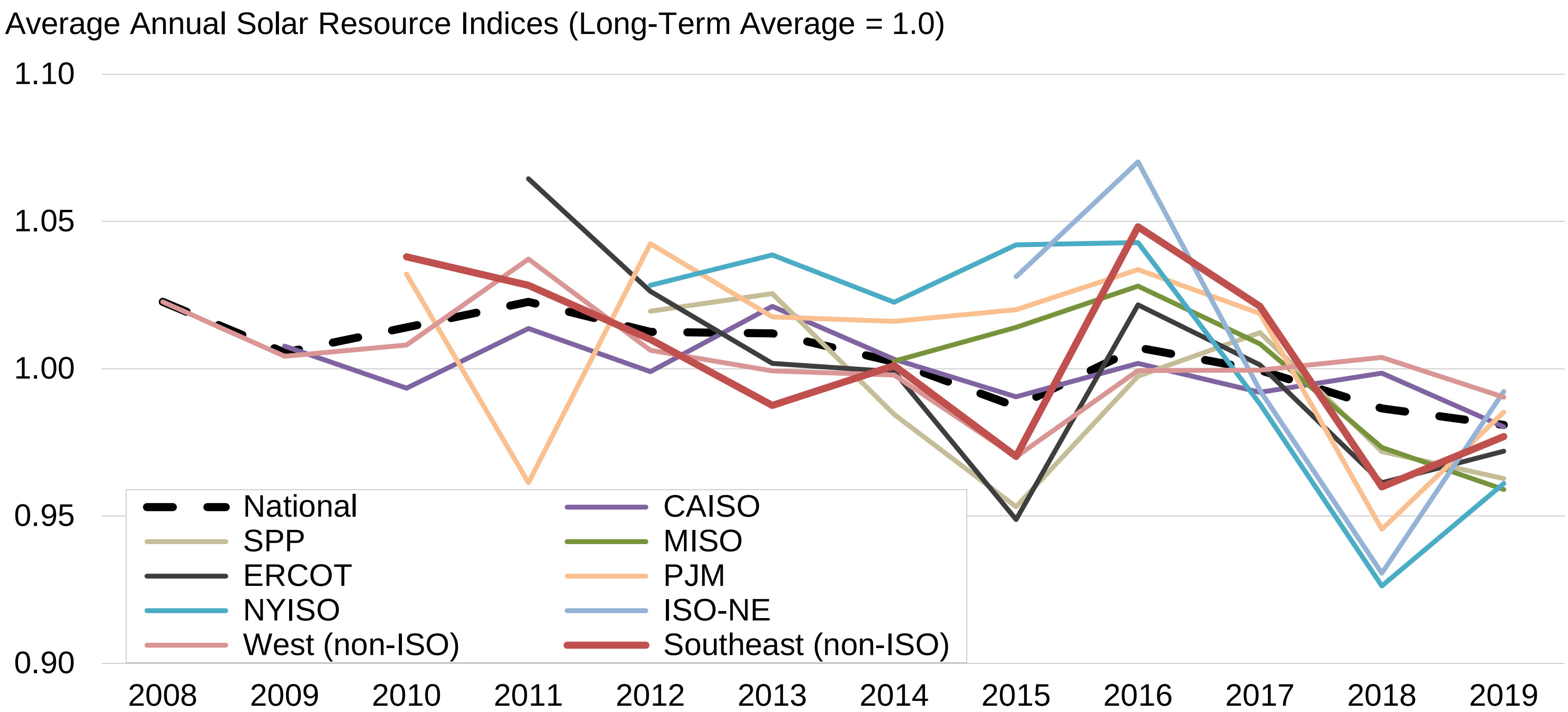
Cumulative capacity factor by region and fixed-tilt vs. tracking



Source: EIA, FERC, Berkeley Lab

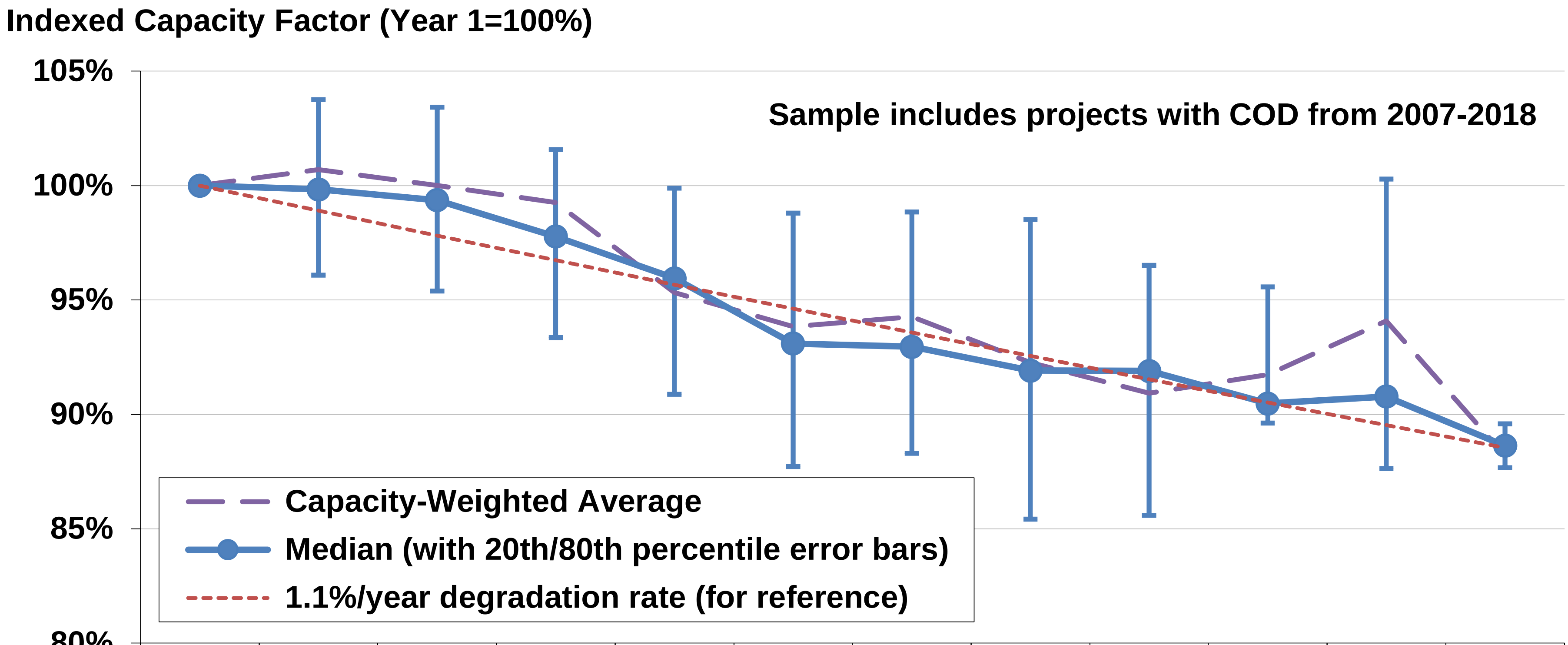
The high-insolation regions (West and CAISO) have the greatest number of projects using tracking, as well as the highest capacity factors.

Inter-annual variability in the solar resource among the sample, by region and nationally



Source: NSRDB, Berkeley Lab

Changes in fleet-wide capacity factors as projects age



Age:	1	2	3	4	5	6	7	8	9	10	11	12
Projects:	636	548	403	260	178	128	81	44	13	6	3	2
MW_{AC}:	23,626	19,942	16,188	8,739	6,048	3,313	1,567	675	227	83	29	19

Source: EIA, FERC, Berkeley Lab

For more analysis on utility-scale PV project performance as plants age, see:
https://emp.lbl.gov/publications/system-level-performance-and

Power Purchase Agreement (PPA) Prices and LCOE

Solar power sales price and LCOE analysis: data sets and methodology

- Berkeley Lab collects data on long-term power purchase agreement (PPA) prices for utility-scale solar and wind energy
- Solar sample includes 338 contracts totaling 23.1 GW_{AC} from projects built from 2007 to the present, or planned for future installation
- Prices reflect the bundled price of electricity and RECs as sold by the project owner under a PPA
  - Dataset excludes merchant plants, projects that sell renewable energy certificates (RECs) separately, and most direct retail sales
  - Prices reflect receipt of state and federal incentives (e.g., the ITC), and various market influences; as a result, prices do not reflect solar generation costs
- We also present LevelTen Energy data on PPA offers; these are often for shorter contract durations, and levelization details are unclear
- Levelized cost of energy is calculated based on following assumptions
  - Project-level CapEx and capacity factor data presented elsewhere in this deck
  - Levelized OpEx declines from \$35/kW_{DC}-yr in 2007 to \$17/kW_{DC}-yr in 2019 (2019\$); project life increases from 21.5 years in 2007 to 32.4 years in 2019 (from previous LBNL research)
  - Weighted average cost of capital (WACC) based on 10% equity return over time; debt interest rate varies with the market over time; constant 60%/40% debt/equity ratio
  - Combined income tax of 40% pre-2018 and 27% post-2017; 5-yr MACRS; 2% inflation

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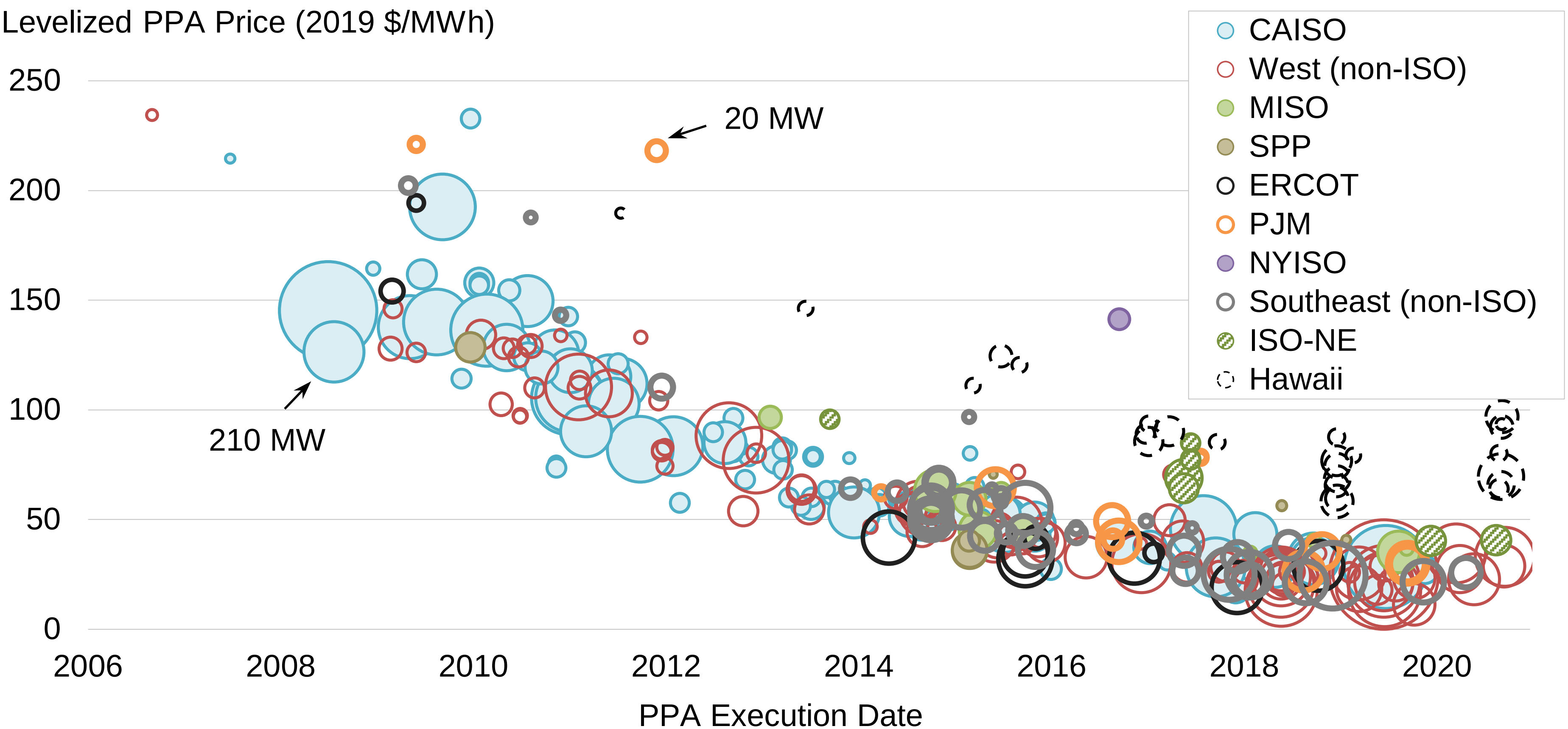
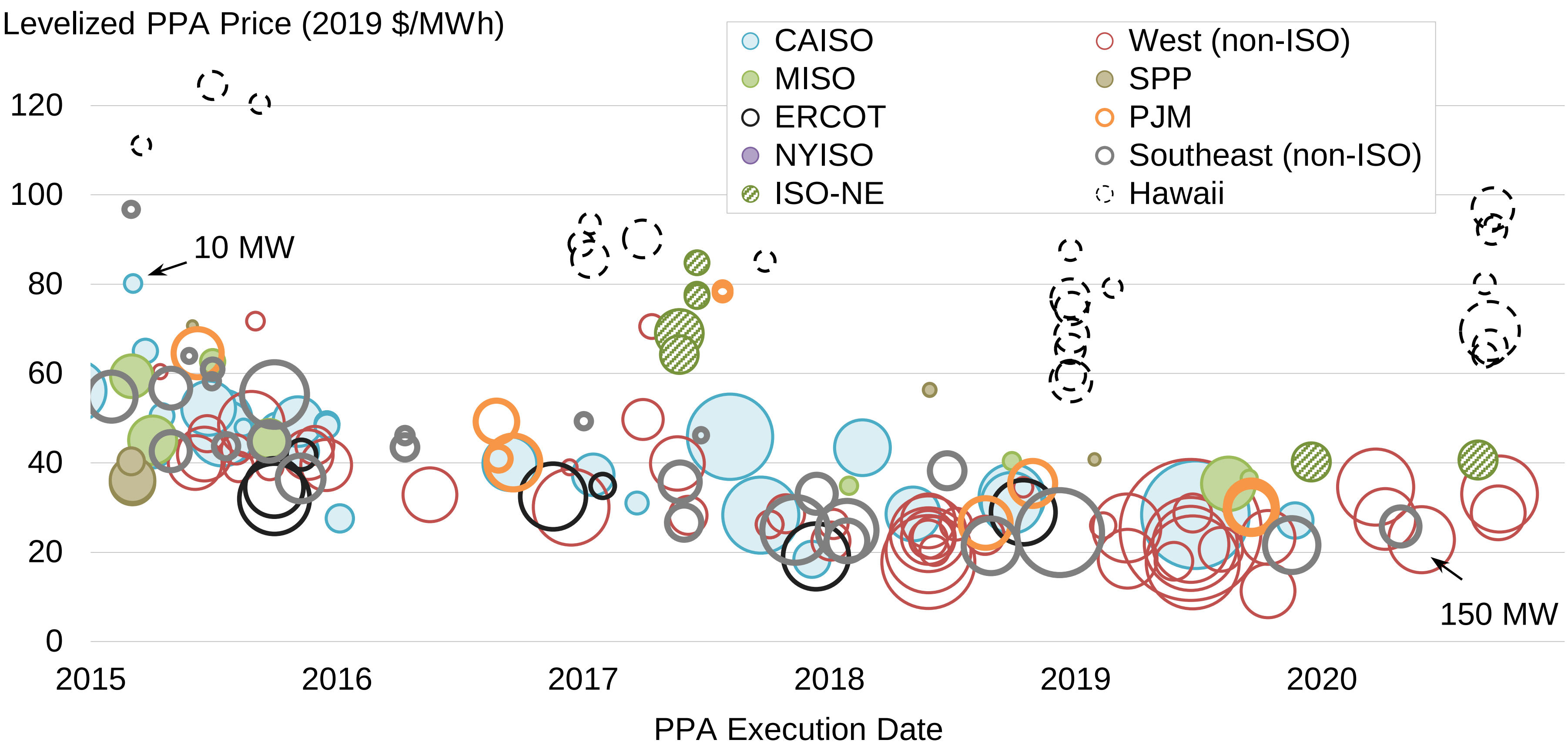
Levelized utility-scale PV PPA prices by PPA execution date and region (full sample)



Source: Berkeley Lab, FERC

Interactive data visualizations: https://emp.lbl.gov/pv-ppa-prices and https://emp.lbl.gov/capex-lcoe-and-ppa-prices-region

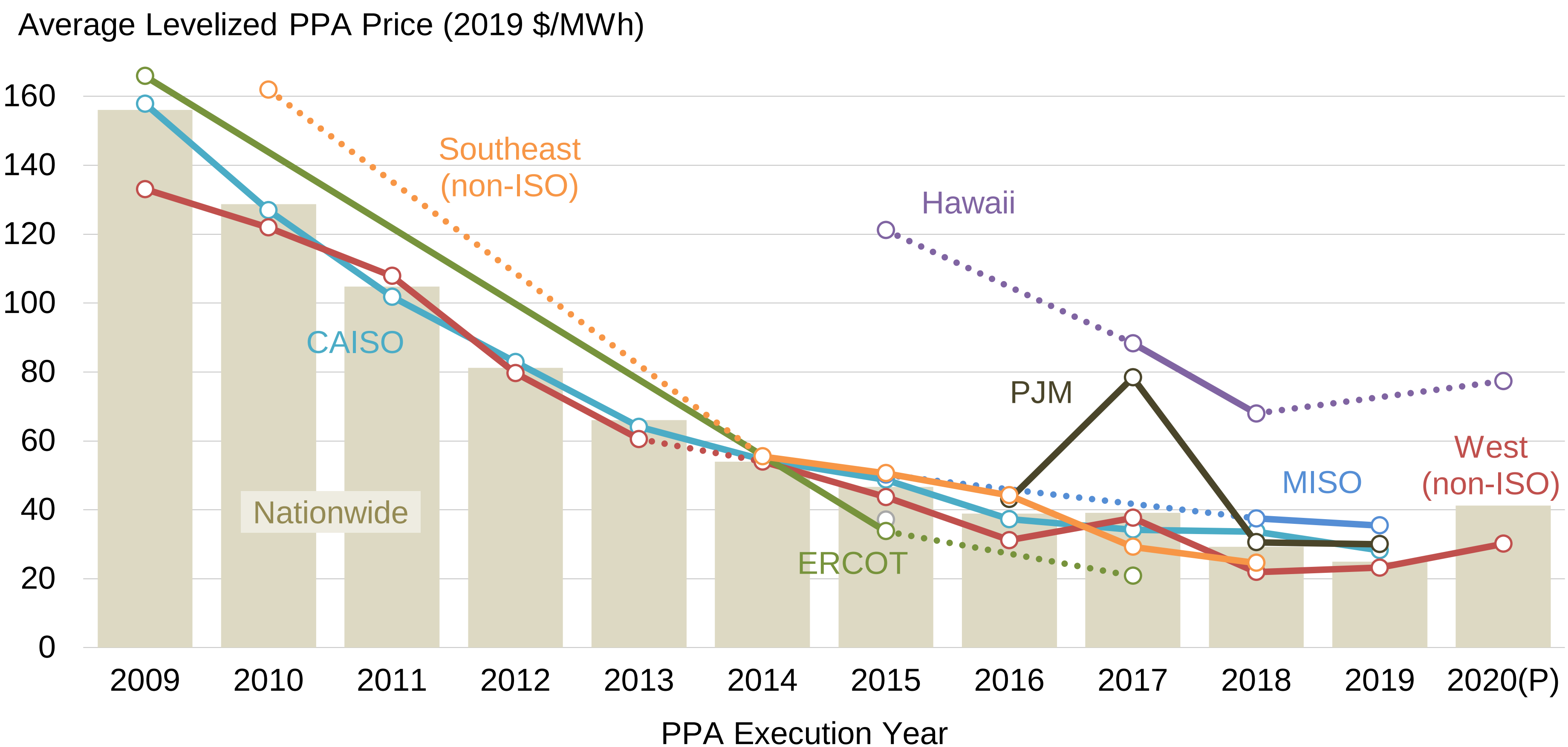
Levelized utility-scale PV PPA prices by PPA execution date and region (recent sub-sample of the data shown on prior slide)



Source: Berkeley Lab, FERC

Interactive data visualizations: https://emp.lbl.gov/pv-ppa-prices and https://emp.lbl.gov/capex-lcoe-and-ppa-prices-region

Generation-weighted average levelized PPA prices by PPA execution date: national and regional averages

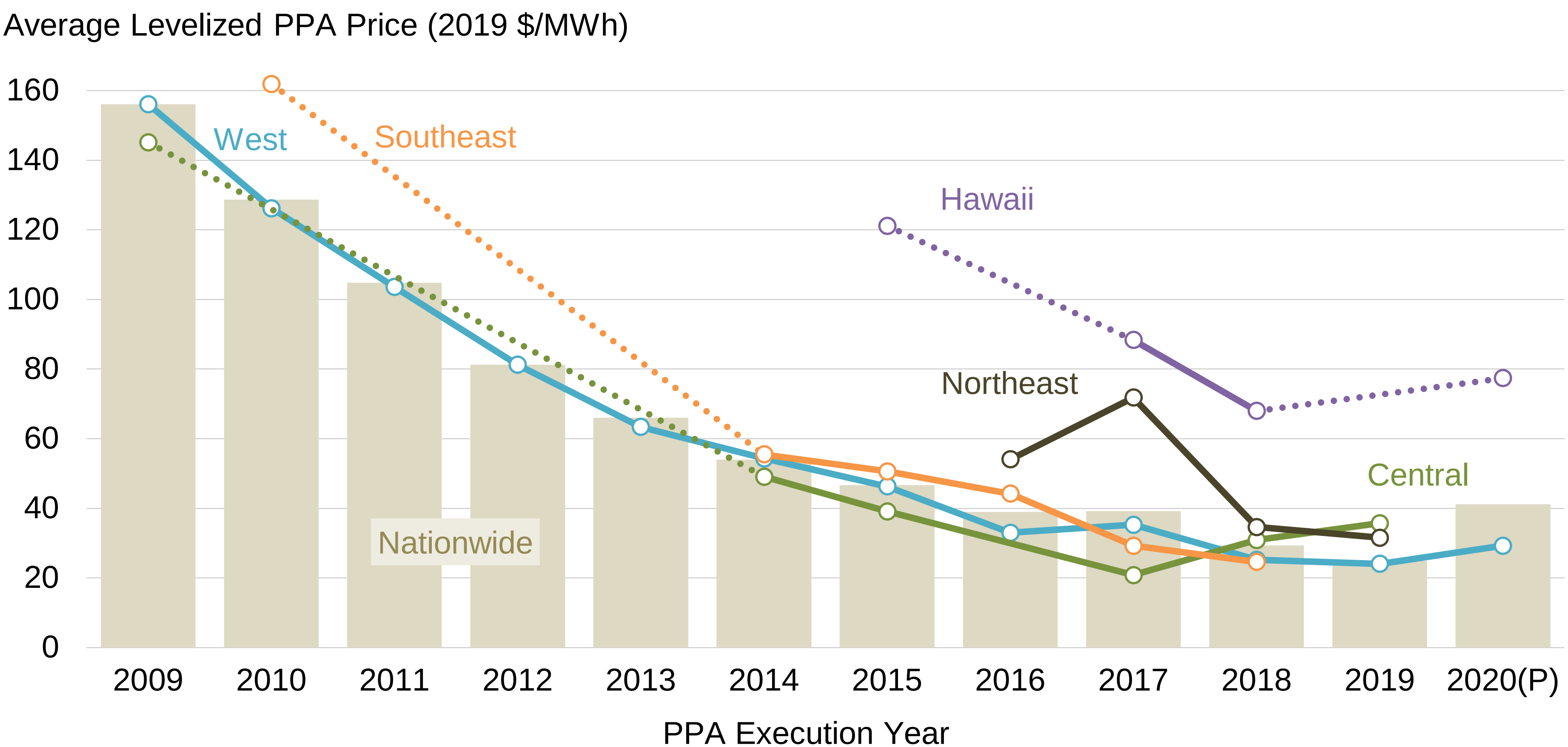


Source: Berkeley Lab, FERC

Note: Region-years with <2 projects are excluded from the graph. The dashed portions of lines span intermediate years that have no data (e.g., 2016 in Hawaii, or 2011-2013 in the Southeast). 2020 data are preliminary (P).

Interactive data visualizations: https://emp.lbl.gov/pv-ppa-prices and https://emp.lbl.gov/capex-lcoe-and-ppa-prices-region

Generation-weighted average levelized PPA prices by PPA execution date: national and consolidated regional averages



Source: Berkeley Lab, FERC

Note: West = CAISO and West (non-ISO); Central = MISO, SPP and ERCOT; Northeast = PJM, NYISO and ISO-NE; Southeast = Southeast (non-ISO). Region-years with <2 projects are excluded from the graph. The dashed portions of lines span intermediate years that have no data (e.g., 2016 in Hawaii, or 2011-2013 in the Southeast). 2020 data are preliminary (P).

Interactive data visualizations: https://emp.lbl.gov/pv-ppa-prices
and https://emp.lbl.gov/capex-lcoe-and-ppa-prices-region

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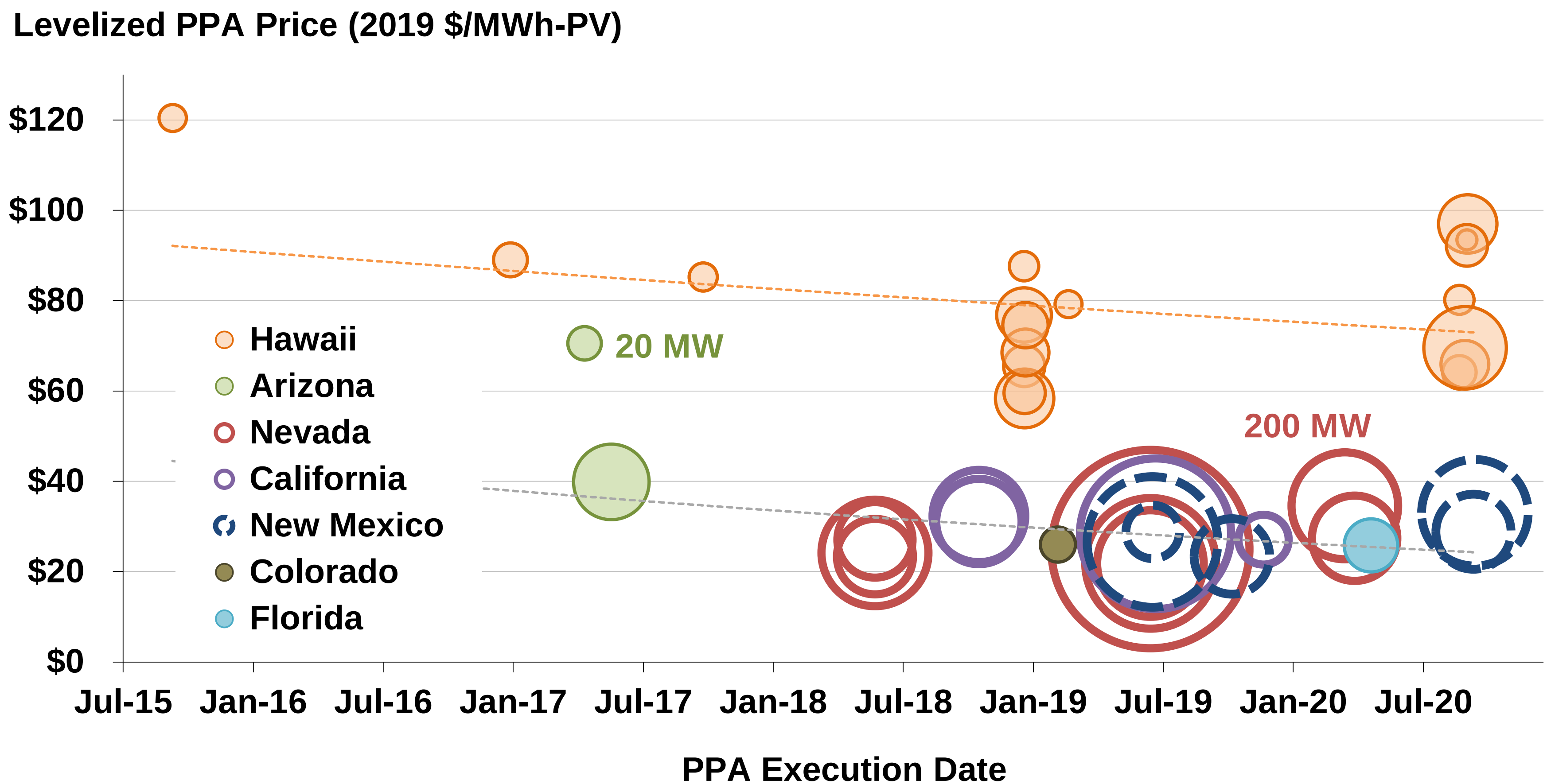
Levelized PPA price of PV+battery hybrid projects in the sample



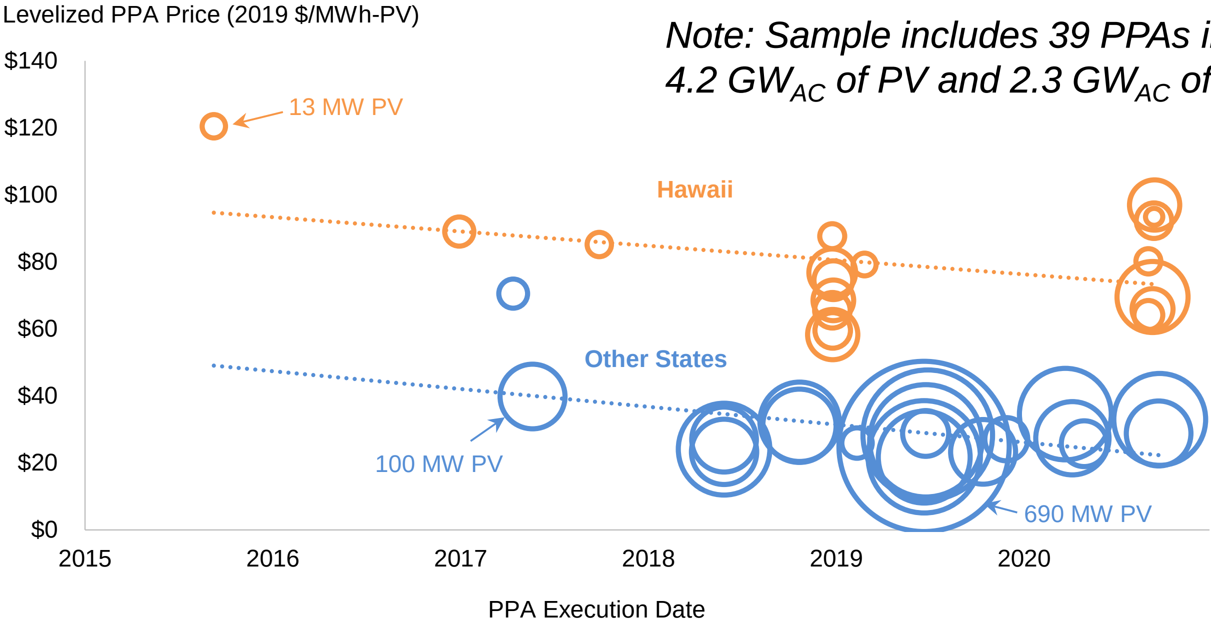
Source: Berkeley Lab, FERC

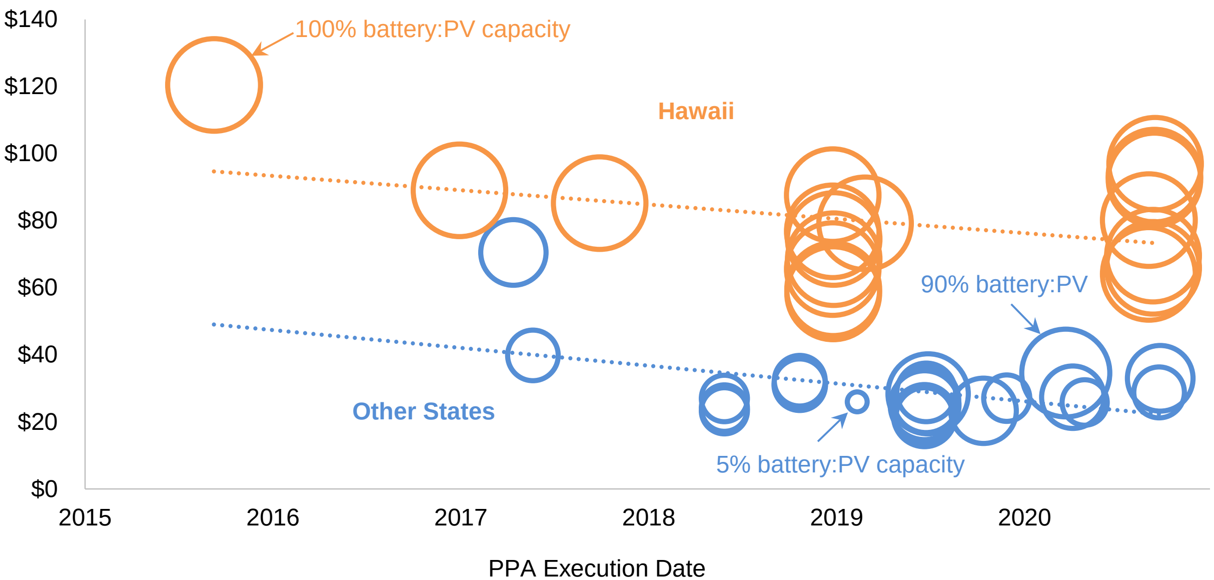
Note: Sample includes 39 PPAs in 7 states totaling 4.2 GW_{AC} of PV and 2.3 GW_{AC} of batteries

See public data file (at utilityscalesolar.lbl.gov) for details on >110 operating and planned PV+battery hybrid projects in 20 states

Levelized PPA price of PV+battery hybrid projects in the sample

Note: Sample includes 39 PPAs in 7 states totaling 4.2 GW_{AC} of PV and 2.3 GW_{AC} of batteries

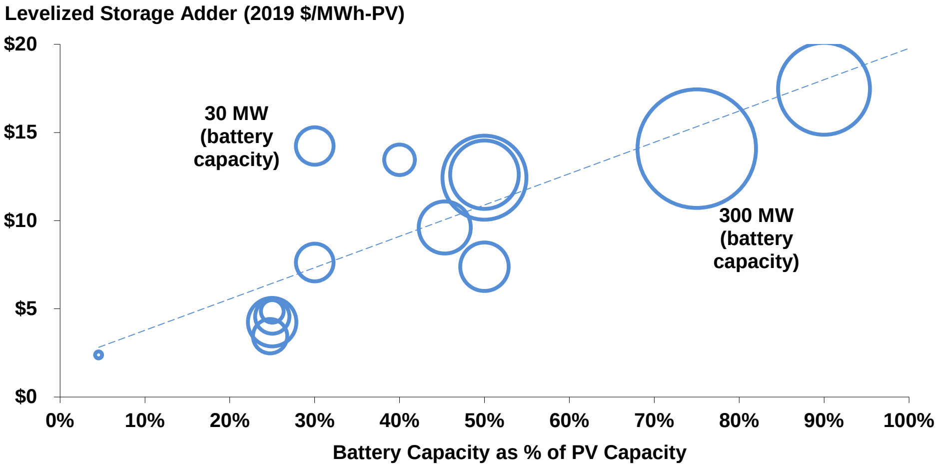


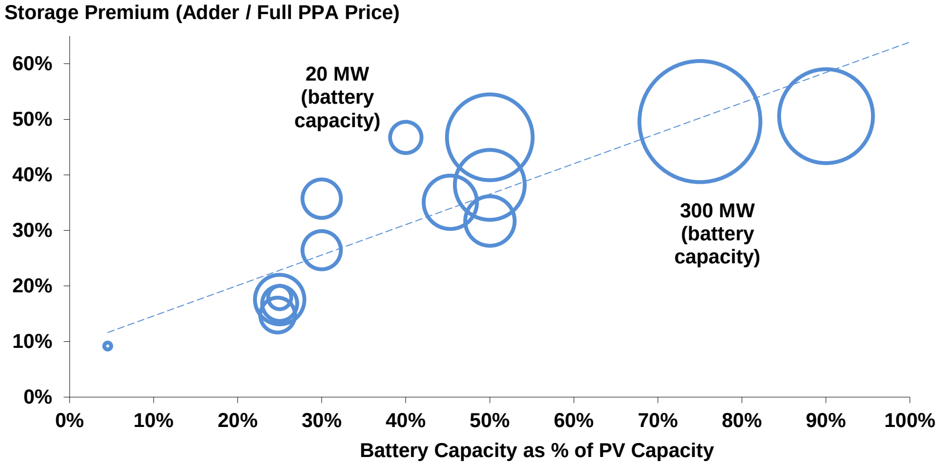


Hawaii generally has smaller PV projects than the mainland (top graph), but with larger relative battery sizing (100% battery:PV capacity, bottom graph)

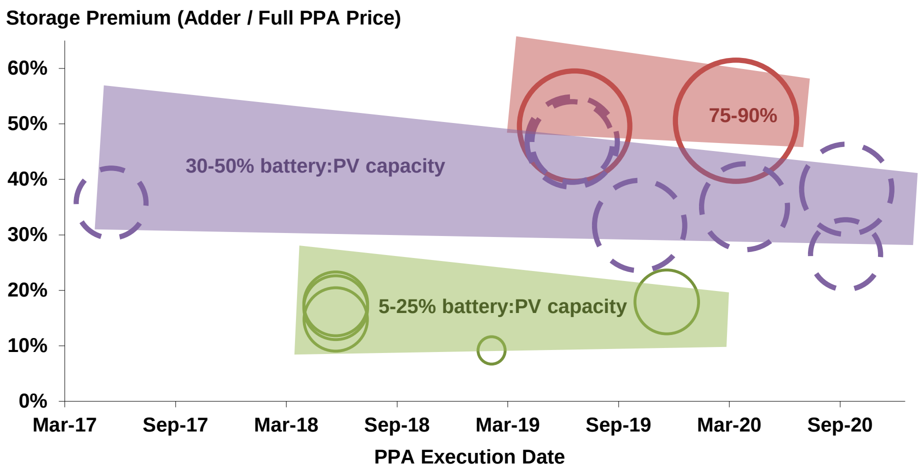
See public data file (at utilityscalesolar.lbl.gov) for details on >110 operating and planned PV+battery hybrid projects in 20 states

Levelized storage adder ($/MWh-PV) and premium (%) by battery:PV capacity ratio and PPA execution date





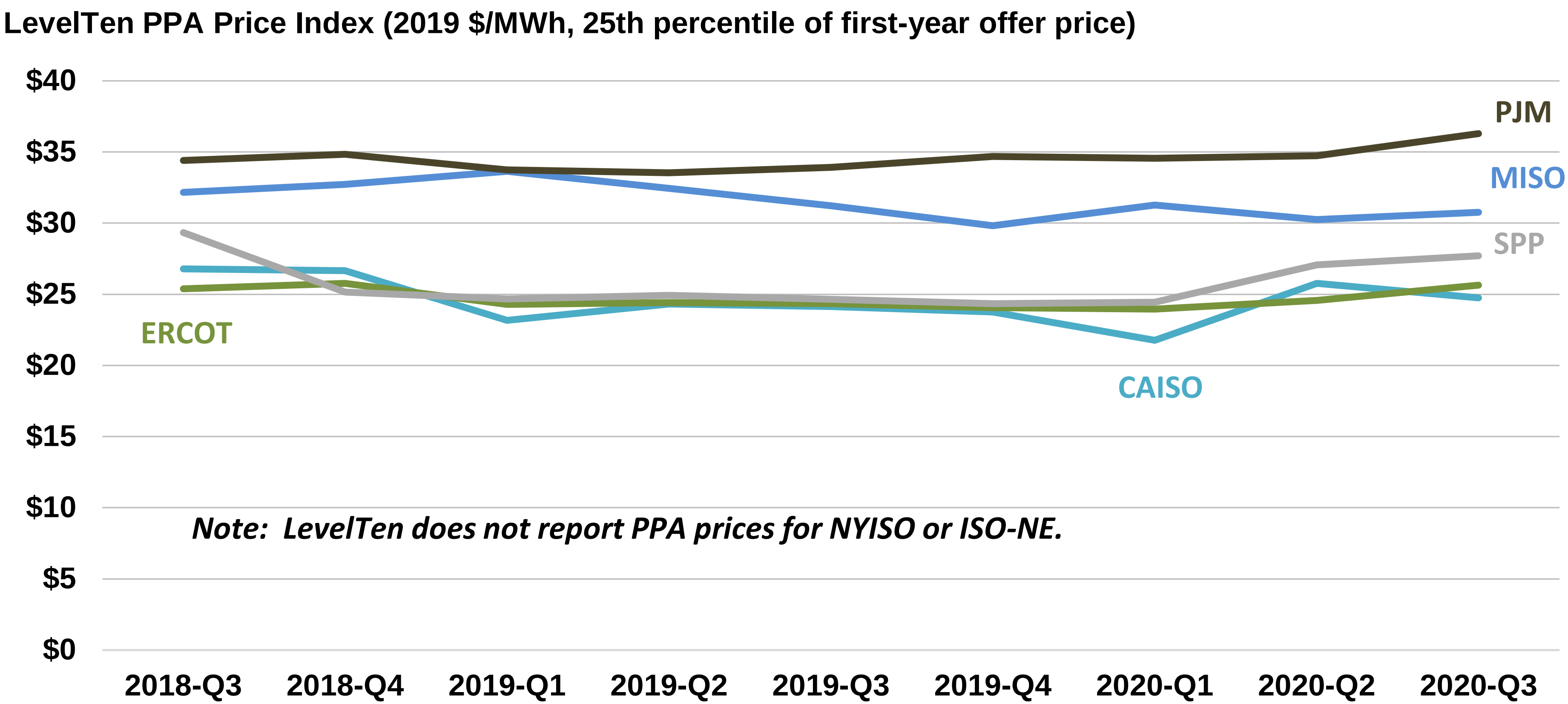
See public data file (at utilityscalesolar.lbl.gov) for details on >110 operating and planned PV+battery hybrid projects in 20 states



Source: Berkeley Lab, FERC

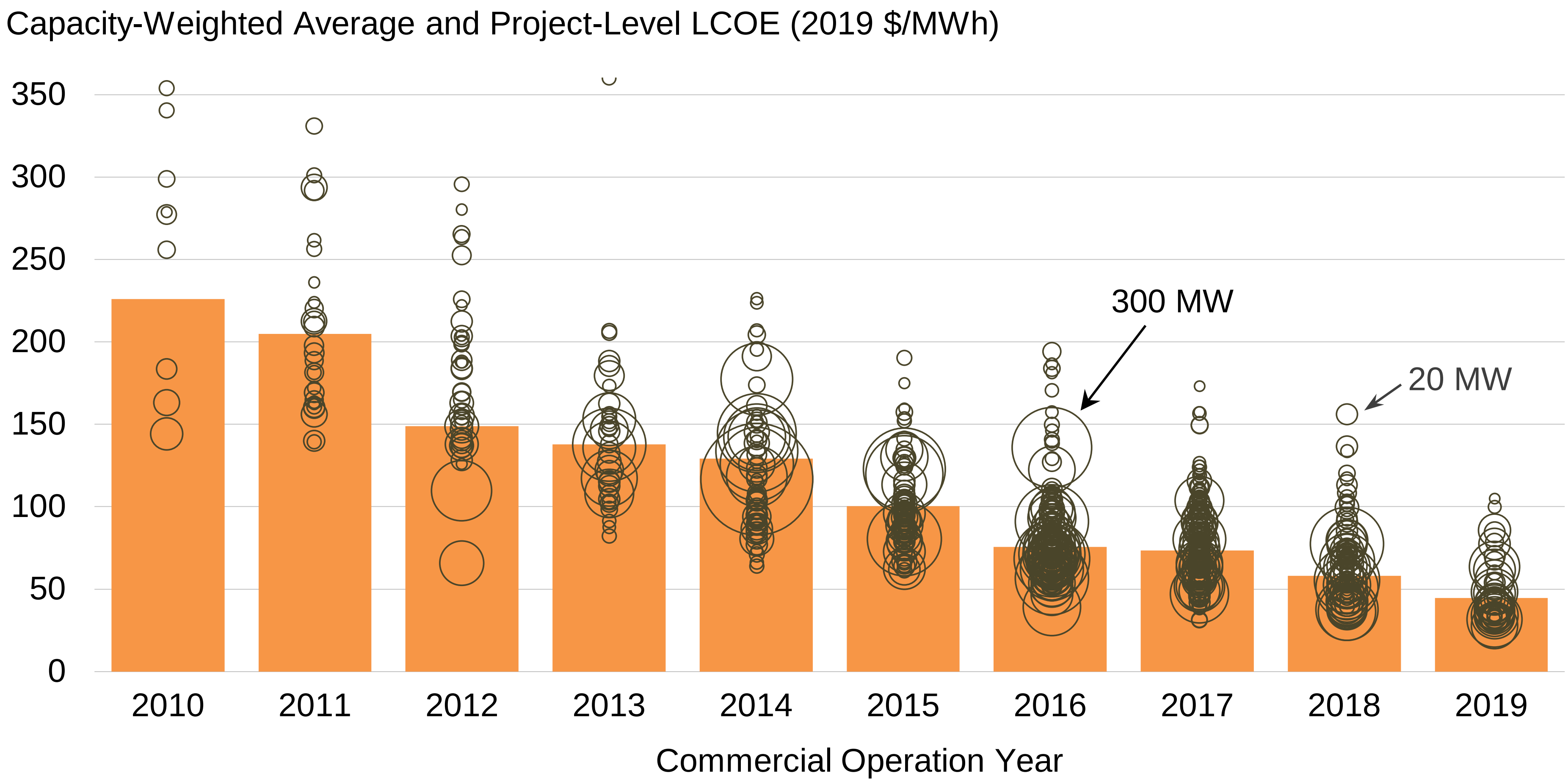
Note: Sample includes 14 PPAs in 5 states totaling 2.0 GW_{AC} of PV and 1.0 GW_{AC} of batteries

LevelTen Energy utility-scale PV PPA price indices



Source: LevelTen Energy

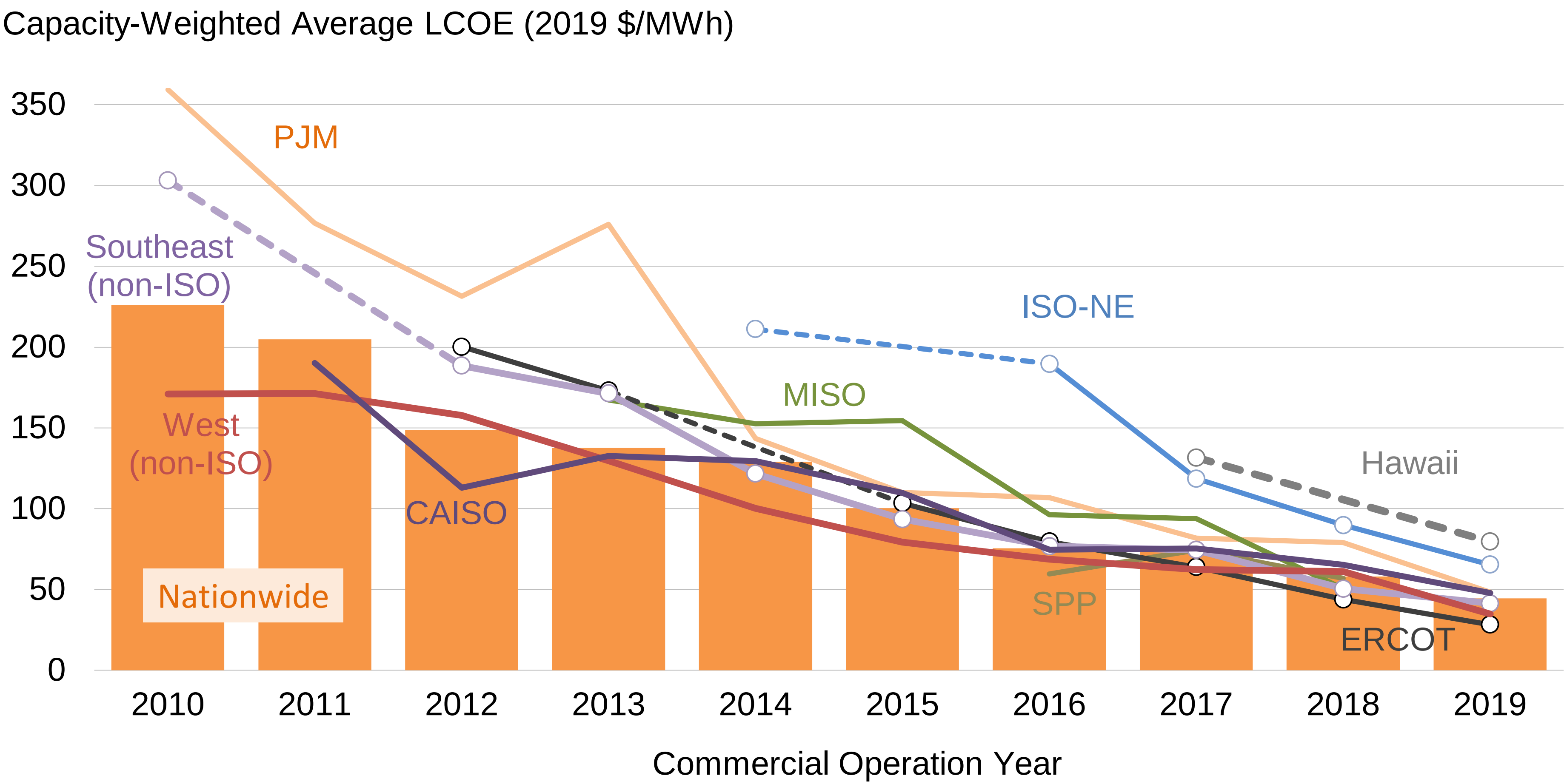
LCOE of utility-scale PV by commercial operation date



Source: Berkeley Lab

Note: Yearly estimates reflect variations in installed cost, capacity factors, operational costs, cost of financing, and project life; includes accelerated depreciation but excludes the ITC.

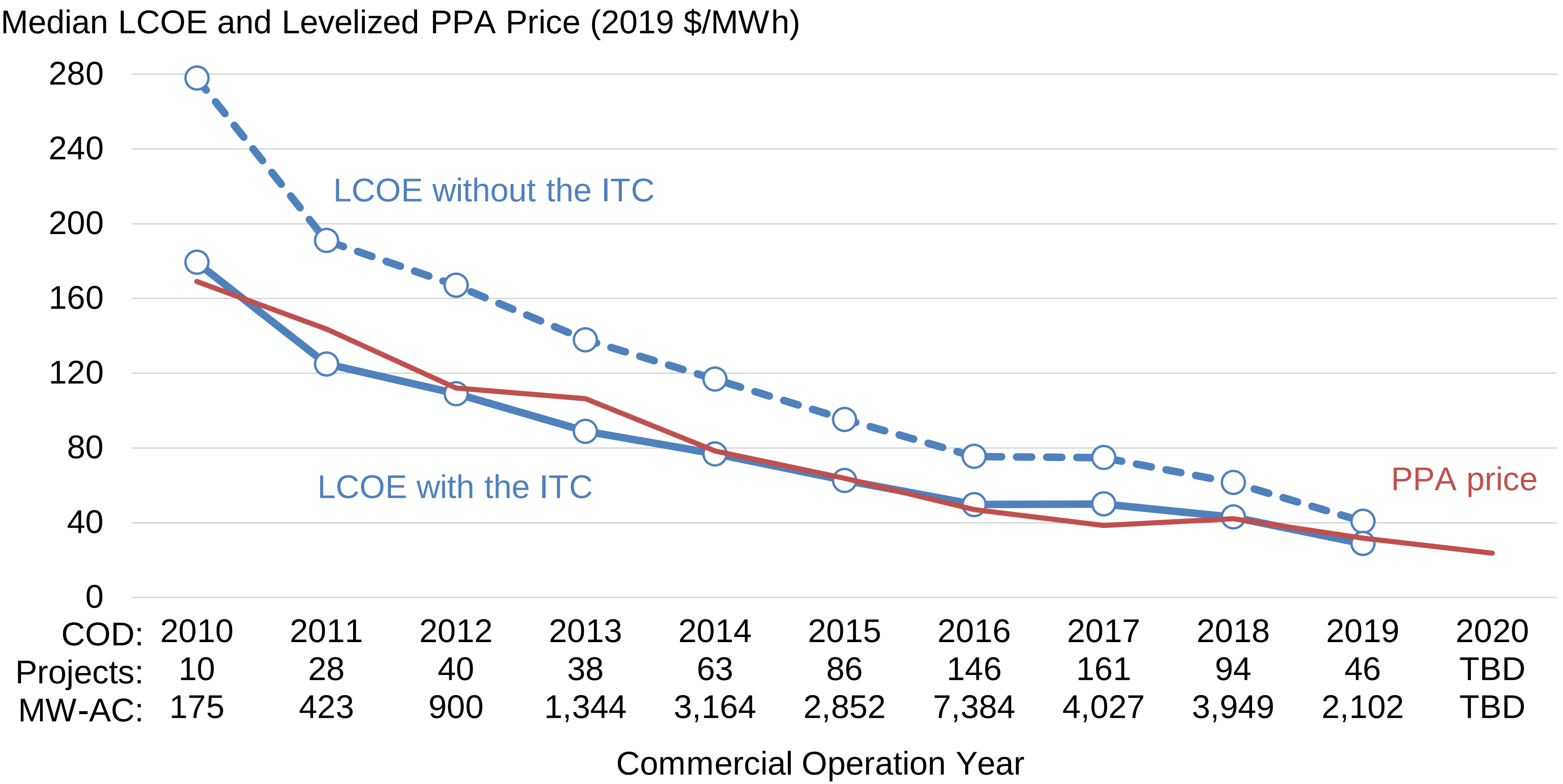
LCOE of utility-scale PV by commercial operation date



Source: Berkeley Lab

Note: Yearly estimates reflect variations in installed cost, capacity factors, operational costs, cost of financing, and project life; includes accelerated depreciation but excludes the ITC. The dashed portions of lines span intermediate years that have no data (e.g., 2018 in Hawaii, 2015 in ISO-NE).

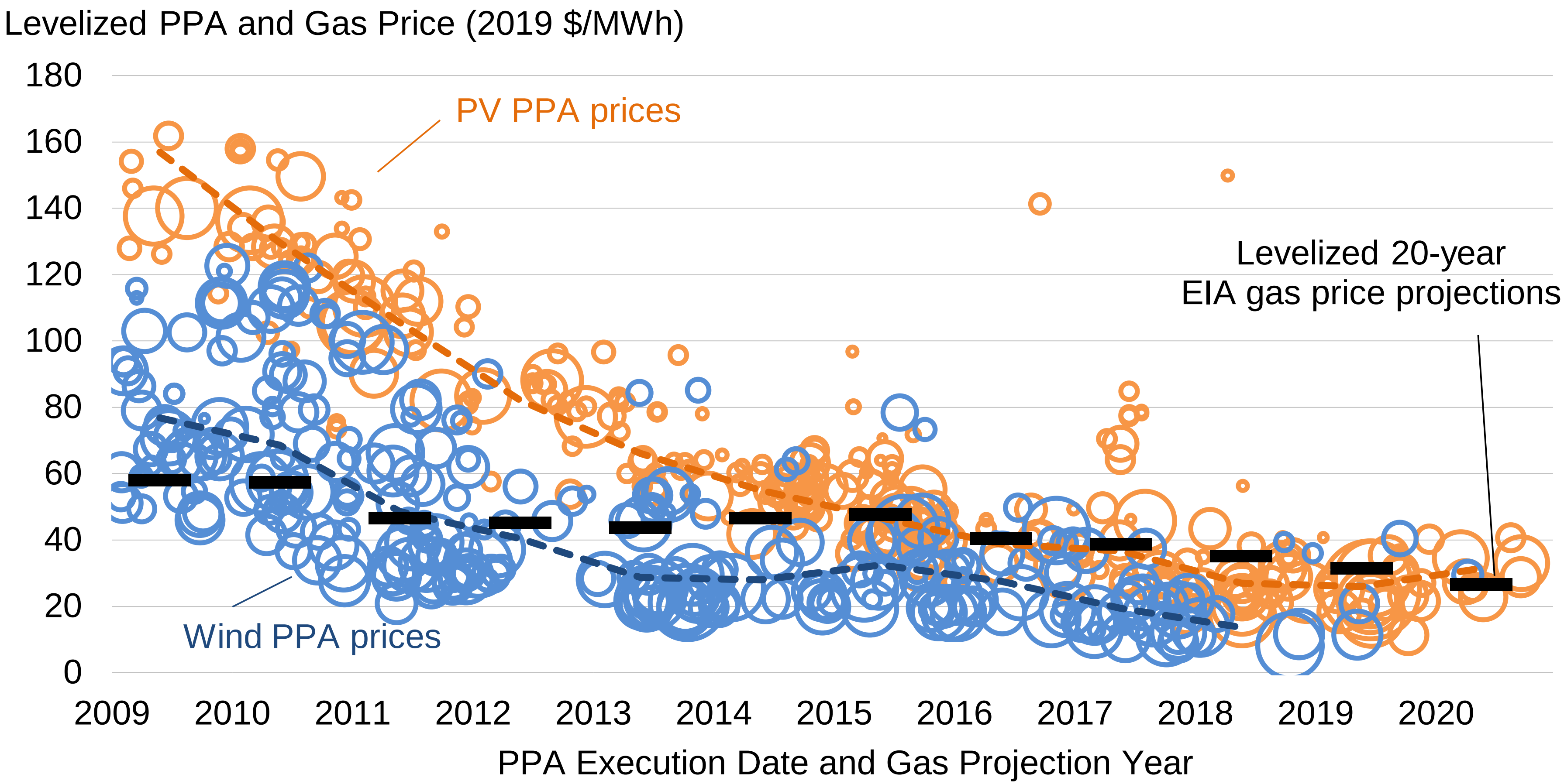
Comparison of LCOE and PPA prices for utility-scale PV



Source: Berkeley Lab

Close agreement between median PPA price and LCOE (with the ITC) suggests an efficient cost-based PPA market and pass-through of the ITC

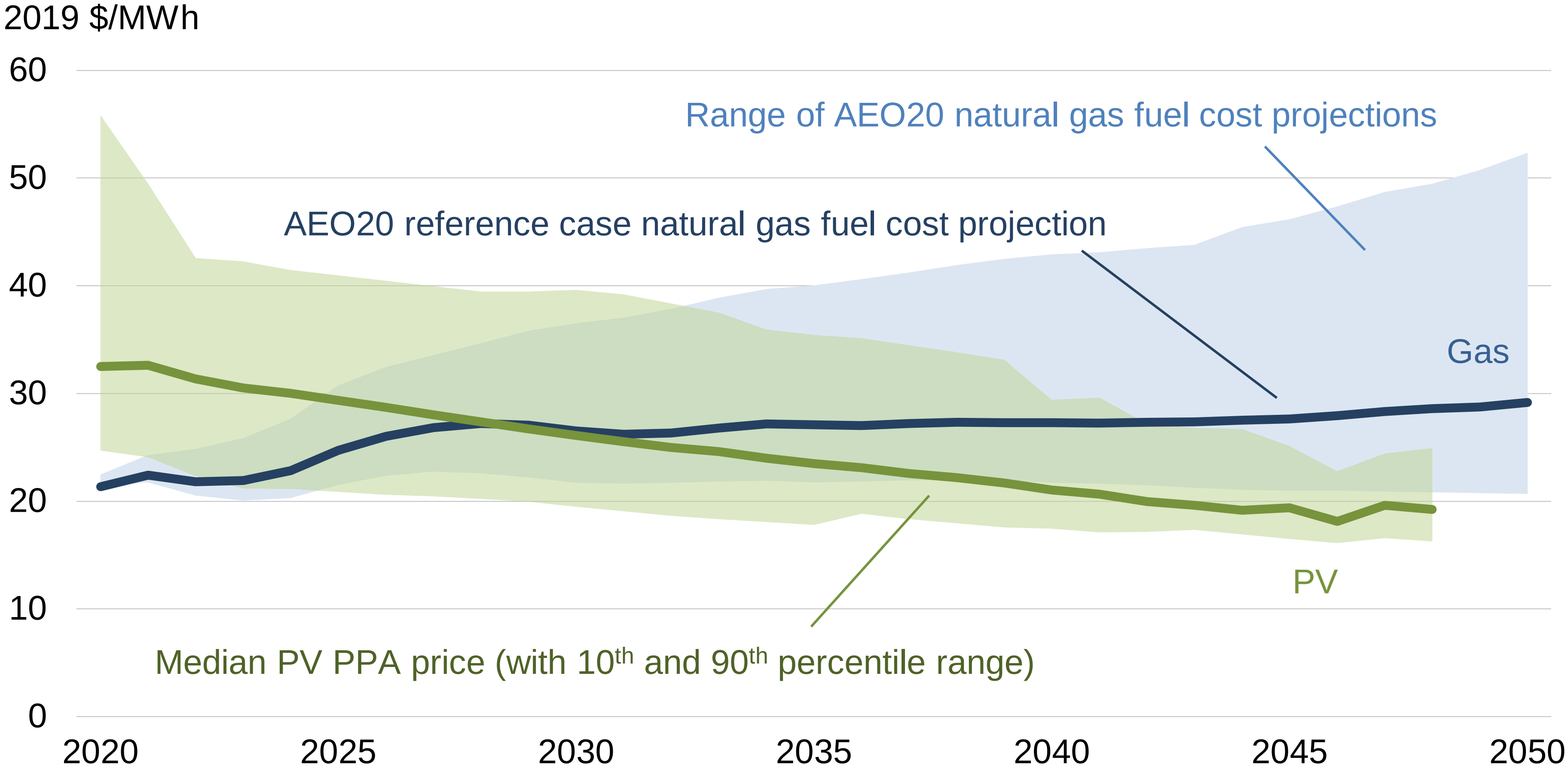
Levelized PV and wind PPA prices and levelized gas prices



Source: Berkeley Lab, FERC, Energy Information Administration

Note: Excludes projects in Hawaii. Smallest bubble sizes reflect smallest-volume PPAs (<5 MW), whereas largest reflect largest-volume PPAs (>500 MW).

Utility-scale PV PPA prices and natural gas fuel costs by calendar year over time

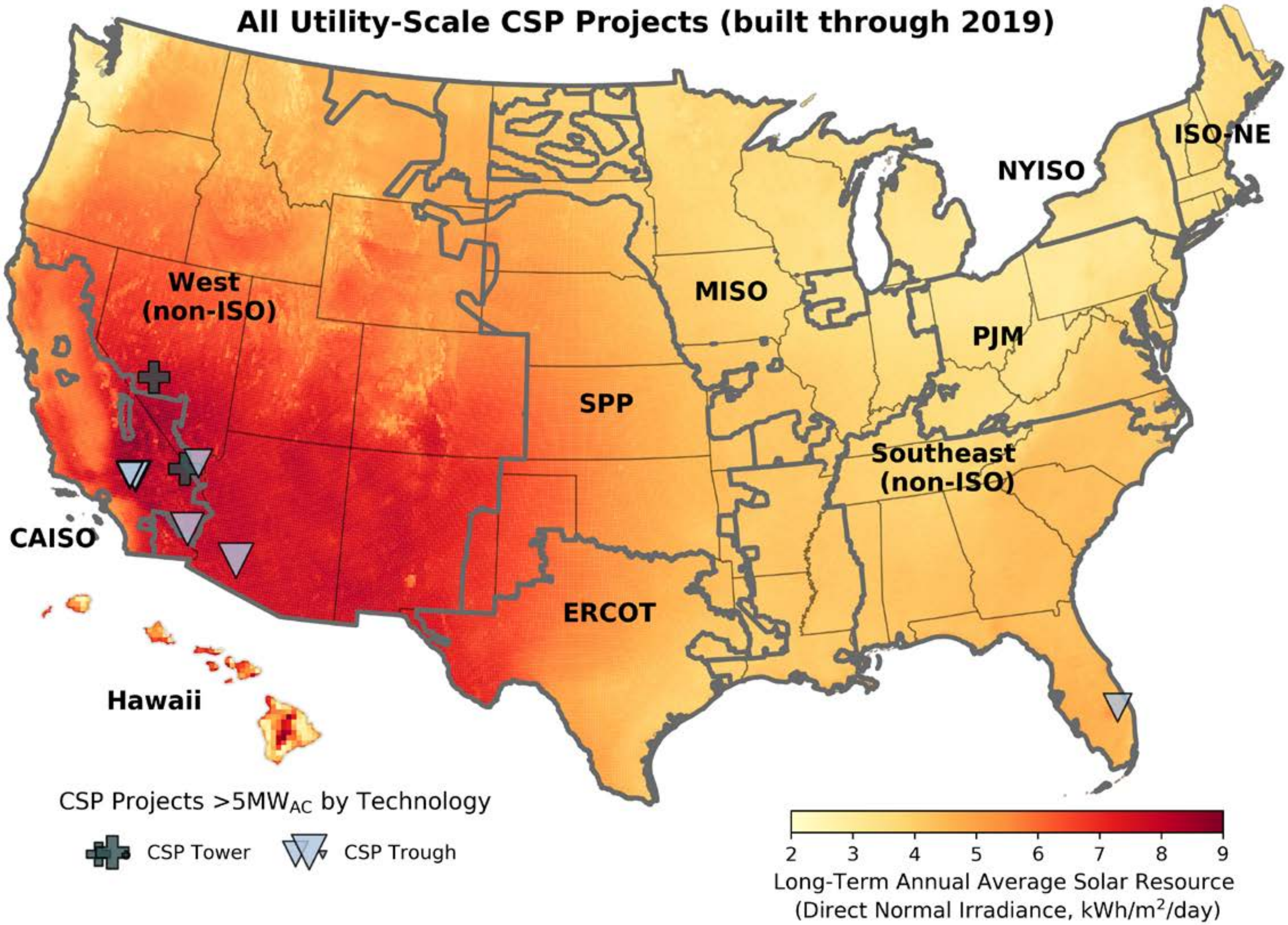


Source: Berkeley Lab, FERC, Energy Information Administration

Notes: PV PPA price median and range reflect 56 PPAs executed 2018-2020. AEO 2020 delivered gas price projections are converted from $/MMBtu to 2019 $/MWh using the heat rates implied by the modeling output. Price comparisons shown are far from perfect—see earlier 2019 report for details.

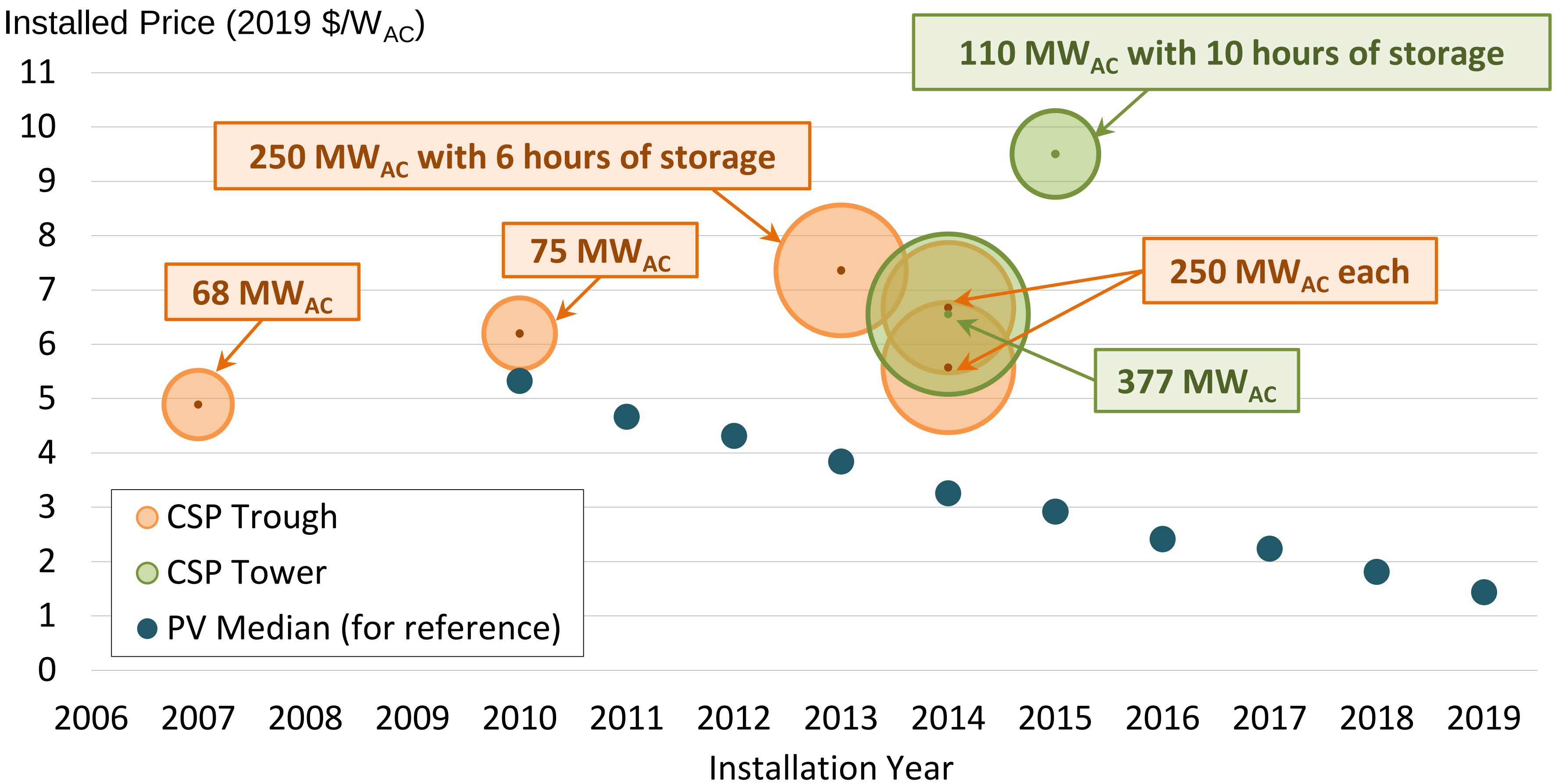
Concentrating Solar Thermal Power (CSP) Plants

Location of CSP projects versus Direct Normal Irradiance (DNI)



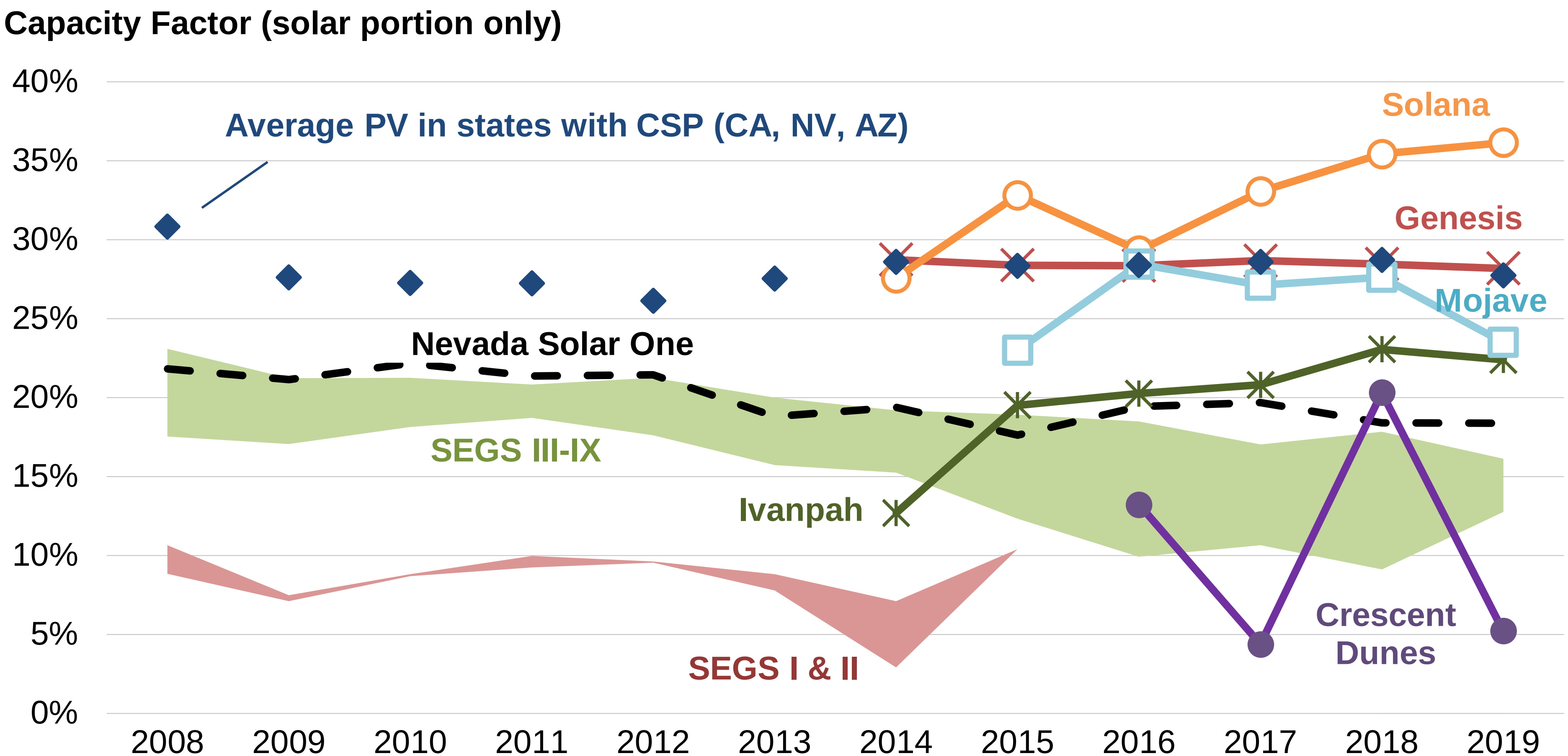
Sources: Berkeley Lab, EIA

Installed price of CSP projects over time



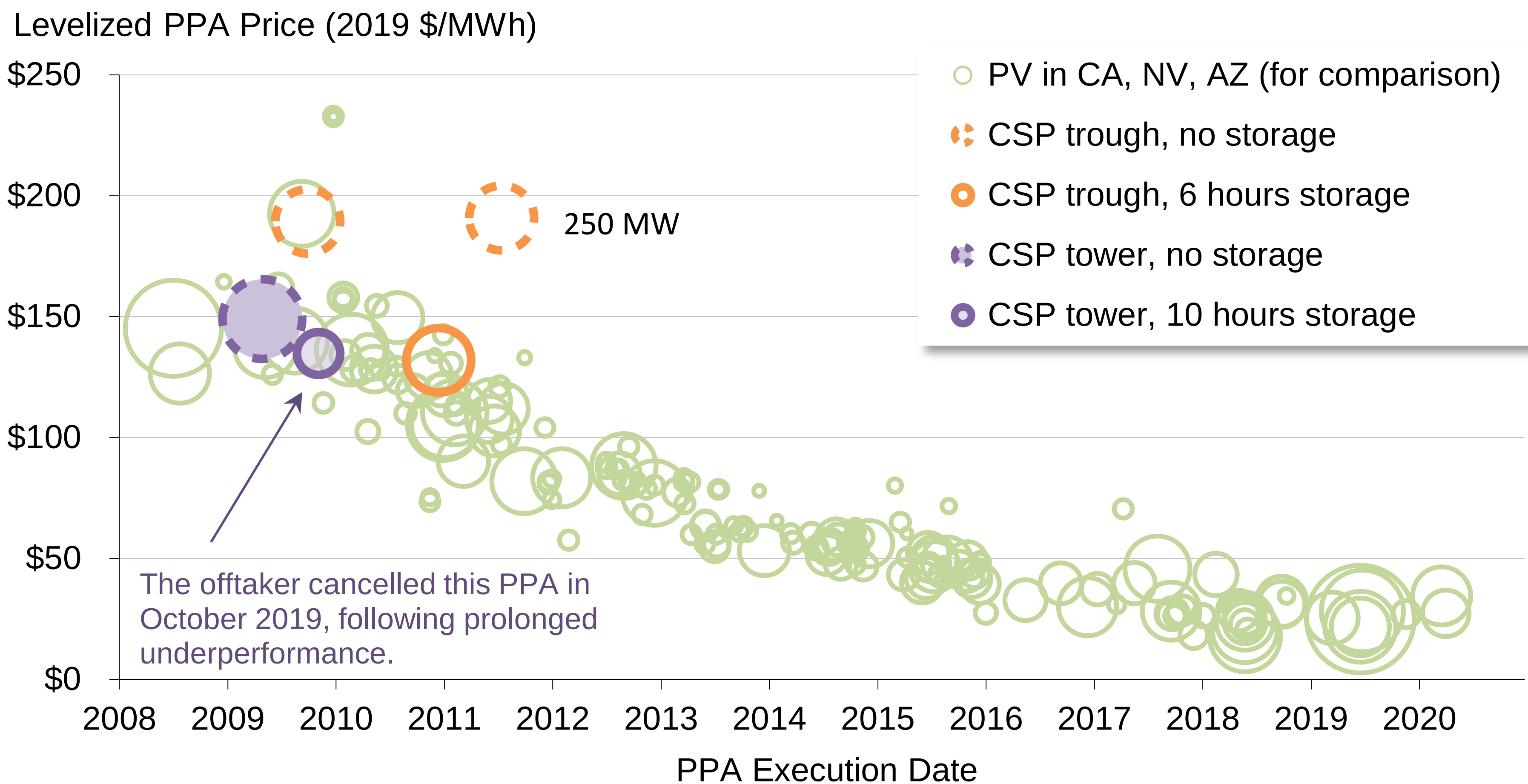
Sources: Berkeley Lab

Capacity factor of CSP projects (solar portion only) over time



Sources: Berkeley Lab, EIA, FERC

Levelized CSP and utility-scale PV PPA prices (in CA, NV, and AZ) by PPA execution date



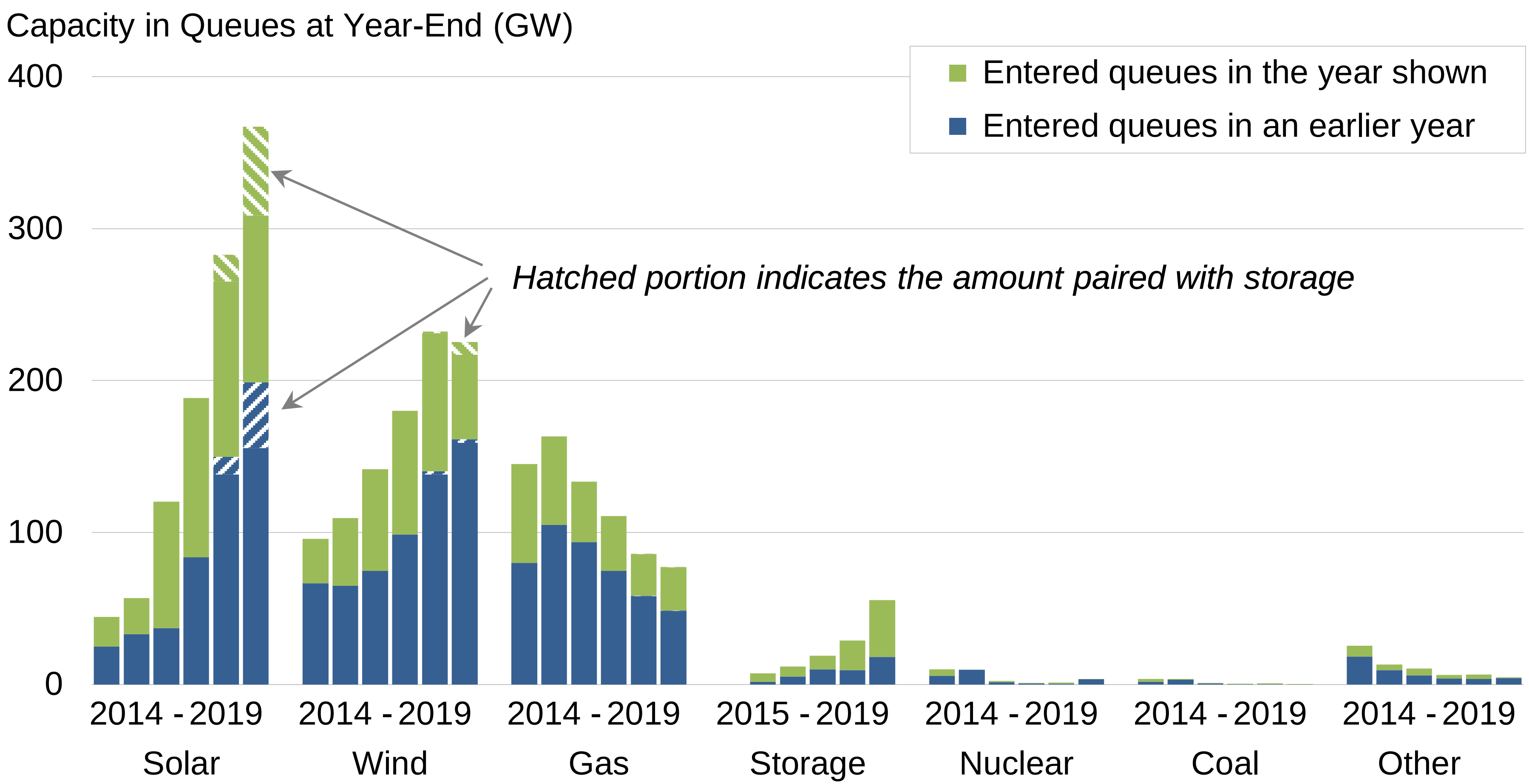
Sources: Berkeley Lab, FERC

Capacity in Interconnection Queues

Scope of generator interconnection queue data

- Data compiled from **interconnection queues** for 7 ISOs and 30 utilities, representing ~80% of all U.S. electricity load
  - Projects that connect to the bulk power system
  - Includes all projects in queues through the end of 2019
  - Filtered to include only “active” projects: removed those listed as “online,” “withdrawn,” or “suspended”
- Hybrid / co-located projects identified via either of these two methods:
  - “Generator Type” field includes **multiple types for a single queue entry** (row)
  - Two or more queue entries (of different generator types) that share the **same point of interconnection** and sponsor, queue date, ID number, and/or COD
    - Emphasis was placed on identification of PV+storage and wind+storage
    - Other hybrid configurations are likely undercounted
- **Note that being in an interconnection queue does not guarantee ultimate construction: majority of plants are not subsequently built**

Generation capacity in 37 selected interconnection queues from 2014 to 2019, by resource type

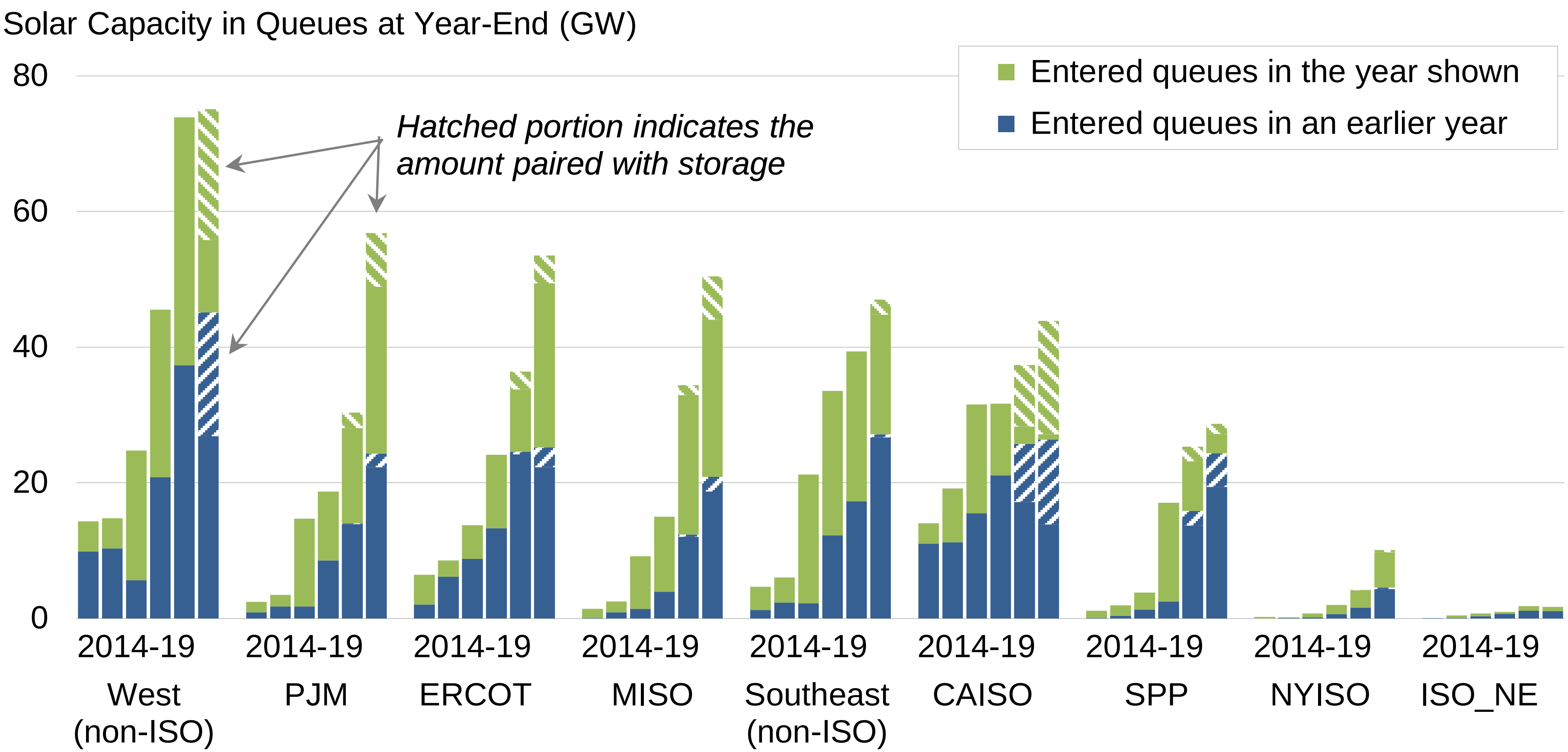


Source: Berkeley Lab review of interconnection queues

Note: Not all of this capacity will be built

Interactive data visualization: https://emp.lbl.gov/generation-storage-and-hybrid-capacity

Solar capacity in 37 selected interconnection queues from 2014 to 2019, by region

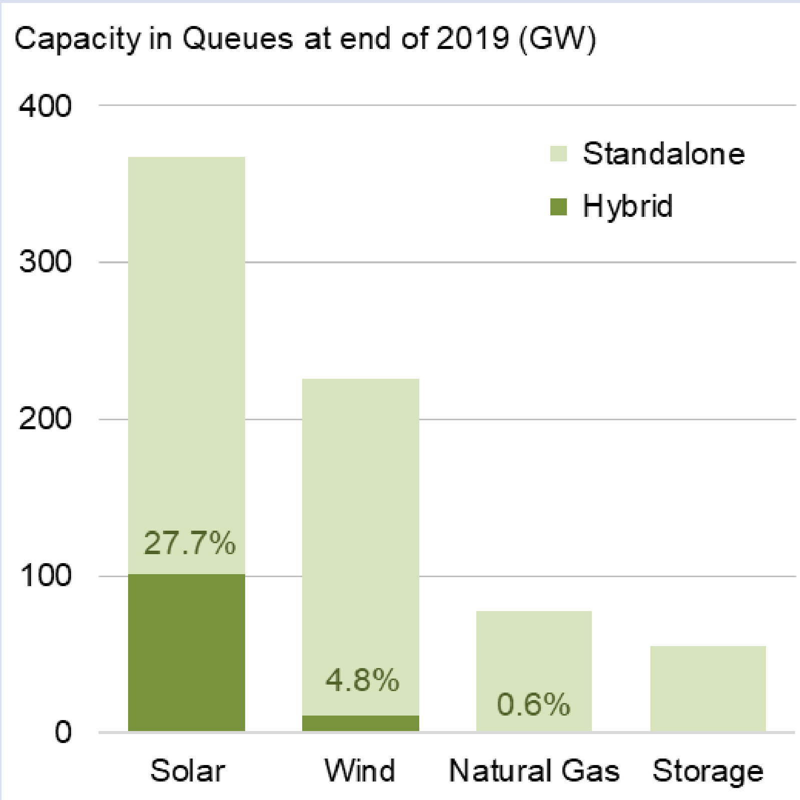


Source: Berkeley Lab review of interconnection queues

Note: Not all of this capacity will be built

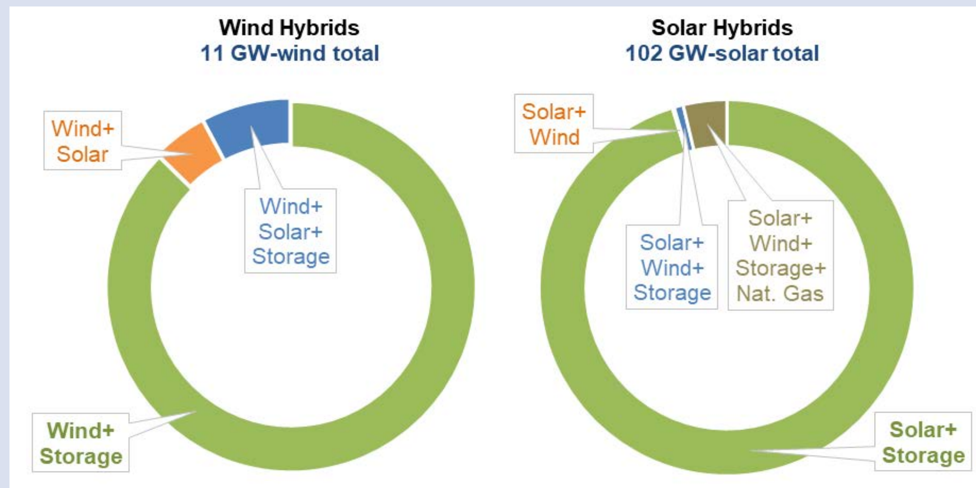
Interactive data visualization: https://emp.lbl.gov/generation-storage-and-hybrid-capacity

Hybrid/co-located capacity within interconnection queues at end of 2019: 102 GW of solar proposed as hybrids, 11 GW of wind



Source: *Berkeley Lab review of interconnection queues*

Solar+Storage and Wind+Storage configurations are more common than other hybrid types[1]



[1] Emphasis was placed on identification of solar+storage and wind+storage: other hybrid configurations are likely undercounted.

Notes: (1) Not all of this capacity will be built; (2) Hybrid plants involving multiple generator types (e.g., wind+PV+storage, wind+PV) show up in all generator categories, presuming the capacity is known for each type.

Interactive data visualization: https://emp.lbl.gov/generation-storage-and-hybrid-capacity

Location of hybrid/co-located capacity within interconnection queues at end of 2019

Region	Percentage of Proposed Generators Hybridizing in Each Region		
	Wind	Solar	Nat. Gas
CAISO	50%	67%	0%
ERCOT	3%	13%	0%
SPP	1%	22%	0%
MISO	2%	17%	0%
PJM	0%	17%	1%
NYISO	1%	5%	4%
ISO-NE	6%	0%	0%
West (non-ISO)	6%	50%	0%
Southeast (non-ISO)	0%	6%	0%
TOTAL	**4.8%**	**27.7%**	**0.6%**

Source: Berkeley Lab review of interconnection queues

Solar hybridization is more evenly distributed across queues than wind hybridization

Notes: (1) Not all of this capacity will be built; (2) Hybrid plants involving multiple generator types (e.g., wind+PV+storage, wind+PV) show up in all generator categories, presuming the capacity is known for each type; (3) Emphasis was placed on identification of solar+storage and wind+storage in queues: other hybrid / co-located projects are likely undercounted.

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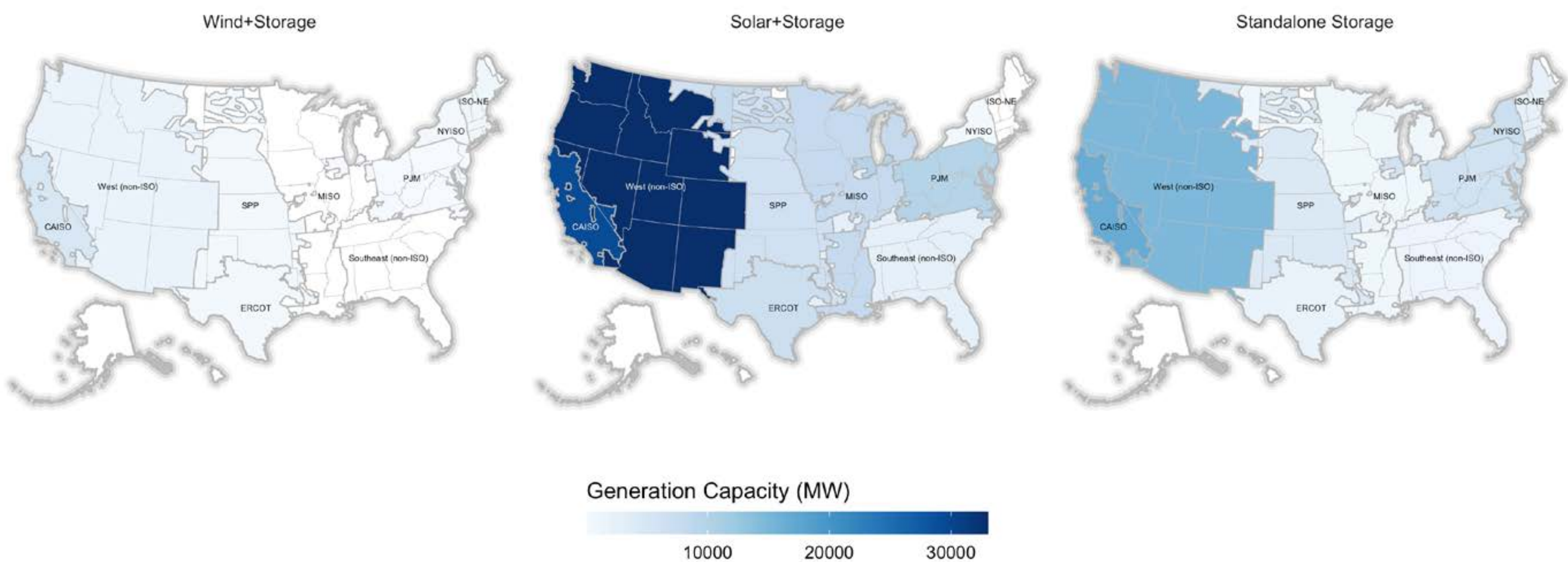
Interactive data visualization: https://emp.lbl.gov/generation-storage-and-hybrid-capacity

Generator+storage hybrid/co-located projects and standalone storage in interconnection queues



For hybrid/co-located plants, the generation capacity is depicted. For standalone storage, the storage capacity is depicted.

In the subset of ISO queues shown here, solar hybrids plan to install more storage capacity relative to generation capacity than do wind hybrids

	Storage:Generation Capacity Ratio	
Region	**Wind+Storage**	**Solar+Storage**
CAISO	25%	78%
ERCOT	54%	38%
SPP	23%	38%
NYISO	7%	49%
Combined	**27%**	**66%**

Source: Berkeley Lab review of interconnection queues

Note: Not all of this capacity will be built

Data and Methods

Summary of Data and Methods (1)

Much of the analysis in this report is based on primary data, the sources of which are listed below (along with some general secondary sources) by data set. We collect data from a variety of unaffiliated and incongruous sources, often resulting in data of varying quality that must be synthesized and cleaned in multiple steps before becoming useful for analytic purposes. In some cases, we essentially create new and useful data by piecing together various snippets of information that are of less consequence on their own.

Technology Trends: Project-level metadata are sourced from a combination of Form EIA-860, FERC Form 556, state regulatory filings, interviews with project developers and owners, and trade press articles. We independently verify much of the metadata—such as project location, fixed-tilt vs. tracking, azimuth, module type—via satellite imagery. Other metadata are indirectly confirmed (or flagged, as the case may be) by examining project performance—e.g., if a project's capacity factor appears to be an outlier given what we think we know about its characteristics, then we dig deeper to revisit the veracity of the metadata.

Installed Prices: Project-level CapEx estimates are sourced from a combination of Form EIA-860, Section 1603 grant data from the U.S. Treasury, FERC Form 1, data from applicable state rebate and incentive programs, state regulatory filings, company financial filings, interviews with developers and owners, trade press articles, and data previously gathered by NREL. CapEx estimates for projects built from 2013-2018 have been cross-checked against confidential EIA-860 data obtained under a non-disclosure agreement (and we expect to receive similar data for 2019 projects and successive years going forward). The close agreement between the confidential EIA data and our other sources in most cases provides comfort that our normal data collection process (i.e., the process that we go through prior to receiving the confidential EIA data with a one-year lag) does, in fact, yield reputable CapEx estimates. That said, we do caution readers to focus more on the overall trends rather than on individual project-level data points.

Capacity Factors: We calculate project-level capacity factors using net generation data sourced from a combination of FERC Electric Quarterly Reports, FERC Form 1, Form EIA-923, and state regulatory filings. Because many projects file data with several of these sources, we are often able to cross-reference (and correct, if needed) odd-looking data across several sources, thereby providing higher confidence in the veracity of the data.

Summary of Data and Methods (2)

PPA Prices: We gather PPA price data from a combination of FERC Electric Quarterly Reports, FERC Form 1, Form EIA-923, state regulatory filings, company financial filings, and trade press articles. We only include a PPA within our sample if we have high confidence in all of the key variables such as execution date, starting date, starting price, escalation rate (if any), time-of-day factor (if any), and term. By this process of exclusion, there is very little chance for erroneous PPA price data to enter our sample. Instead, this winnowing process results in our PPA price sample being somewhat smaller than it might otherwise be—though we are typically able to add back in any “incomplete” PPAs in subsequent years, once more data have become available with the passage of time.

LCOE: Our project-level LCOE calculations draw upon the empirical project-level data presented throughout this report, including installed prices, O&M costs, and capacity factors, and are supplemented with assumptions about financing and other items, as described in more detail in earlier slides.

An accessible data file and multiple visualizations can be found at utilityscalesolar.lbl.gov

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