Hybrid Power Plants

Status of Operating and Proposed Plants

Data Update: 2025 Edition

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October 2025

Funded by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy under Contract No. DE-AC02-05CH11231. The views and opinions of the authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, or The Regents of the University of California.

Image: Generated by Google Gemini

About this Data Product

This data product presents an annual snapshot of trends in hybrid and co-located power plants, defined as projects that combine two or more generators and/or storage assets at a single point of interconnection. It summarizes public empirical data, especially from the U.S. Energy Information Administration (EIA), the Federal Energy Regulatory Commission (FERC), and transmission provider interconnection queues. This 2025 edition summarizes data for generators and storage systems coming online through the end of 2024 with a focus on the most recent full calendar year. This data product neither directly comments on nor recommends any specific policies – it simply summarizes and explains data trends.

New in this year's update:

– New case study on Fossil+Storage hybrid

– Additional interconnection data on Fossil+Storage hybrids

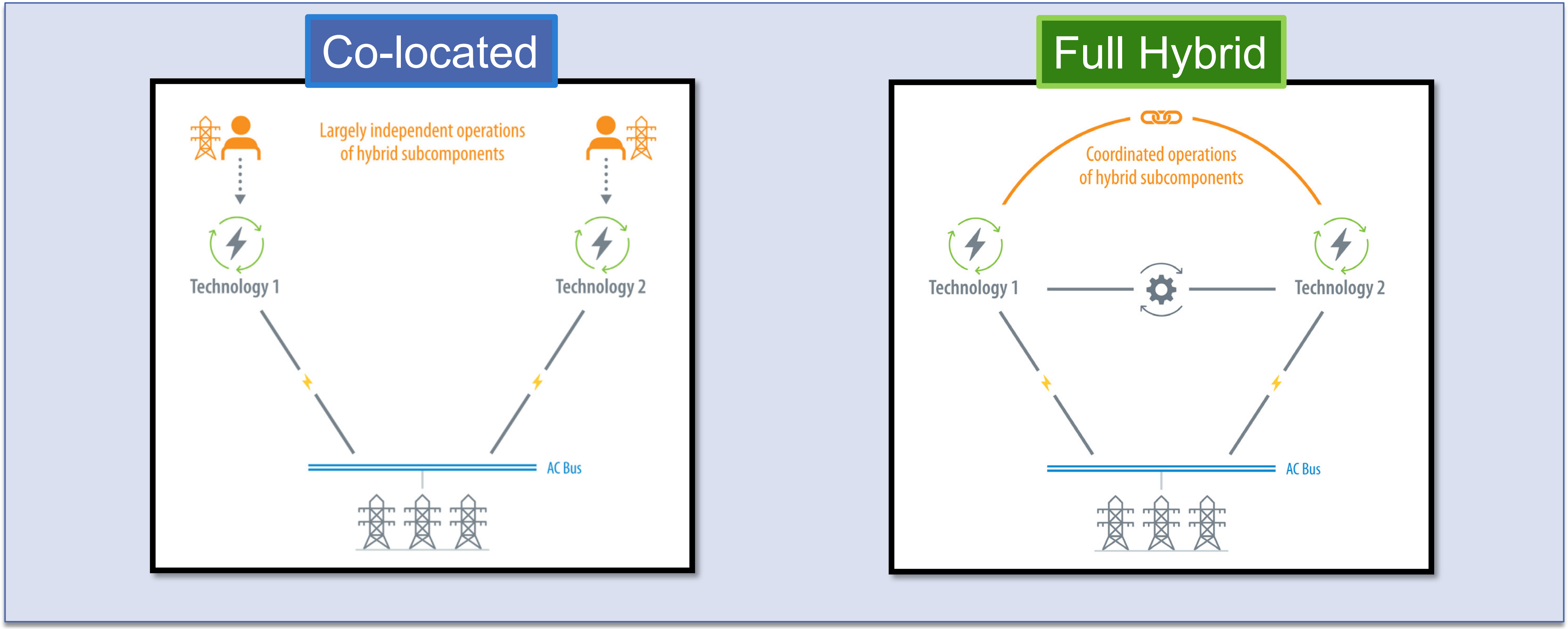
– New interconnection graphics

– Expanded CapEx sample from EIA enabling more refined cost analyses for PV+battery projects

– Increased details on technological design choices for PV+battery projects (i.e. AC/DC coupling)

Data update scope

Scope includes **co-located** plants that pair, but control separately, two or more generators and/or storage assets at a single point of interconnection, and also **full hybrids** that feature co-location and co-control. ‘Virtual’ hybrids are excluded, as are smaller (often behind-the-meter) plants not otherwise visible in data sources used here.



Source: U.S. Department of Energy. 2021. Hybrid Energy Systems: Opportunities for Coordinated Research.

Data update scope (cont.)

We aim to capture U.S. transmission-connected co-located generators. We group “hybrids” into aggregated categories like “fossil hybrids” and “solar hybrids” if the plant has at least one portion of the hybrid plant as fossil or solar, respectively. Therefore, some generators can be both a “fossil hybrid” and a “solar hybrid” (e.g. Fossil+PV plants). Storage technology is predominantly battery technologies. Below is a list of hybrid types considered and relevant notes.

Hybrid Types Considered	Notes
PV+Storage	Incorporates both AC/DC coupled projects (see slide 33/34 for additional coupling details)
Fossil+Storage	In the interconnection queue project data sample, we change the Fossil+Storage to Gas+Storage given gas’s prevalence in queues as compared to the online sample, which also includes oil and coal projects
Wind+Storage	
Wind+PV	
Wind+PV+Storage	Very limited sample
Fossil+PV	
Fossil+PV+Storage	Very limited sample
Fossil+Hydro	
Fossil+Wind+PV	Very limited sample
Fossil+Wind	

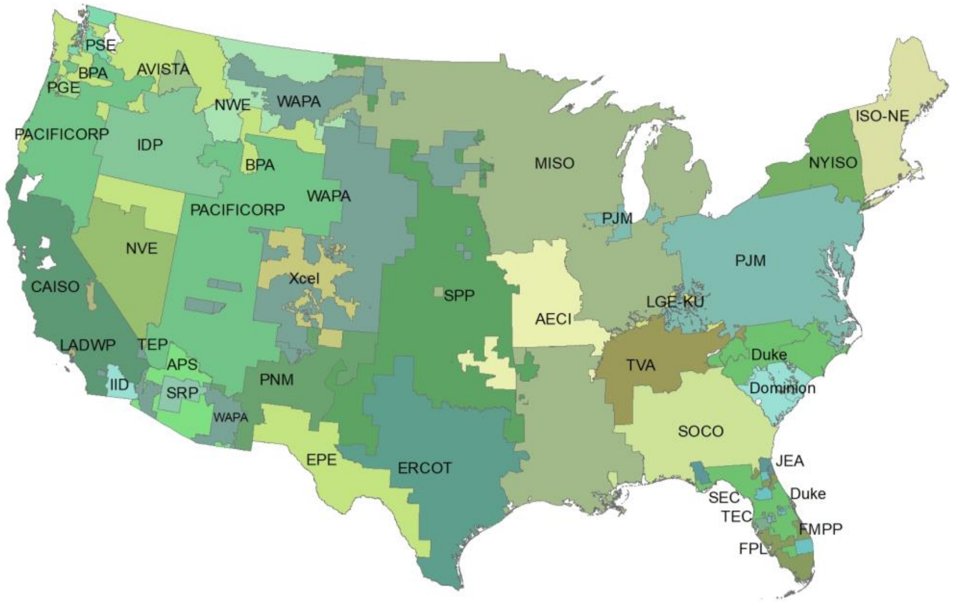
Hybrid Types Considered	Notes
Nuclear+Fossil	Very limited sample
Biomass+Hydro	
Biomass+PV	Very limited sample
Hydro+Storage	
Geothermal+PV	
Geothermal+PV+CSP	Very limited sample
Fossil+Wind+Storage	Very limited sample
Fossil+Wind+PV+Storage	Very limited sample
Biomass+Storage	Very limited sample
Nuclear+Hydro	Very limited sample

Methods and data sources for online project data sample

- Form ***EIA-860 2024 early release*** and ***public announcements***
  - Generator specific information for power plants with ***>1 MW combined*** capacity
  - Limited amount of spot checking for corrections to EIA data
- Hybrids identified by either having the ***same EIA ID*** or, in some cases, through other regulatory filings or trade press articles
  - ***Suggests co-location of generators*** at one plant / point of interconnection, but not necessarily co-controlled generators
  - Virtual hybrids cannot be identified; <1 MW plants also excluded
- Challenges and Limitations:
  - Difficult to separate behind-the-meter/micro-grid resources that could be connected to the distribution system from front-of-the-meter resources connected to the transmission system
  - EIA ID does ***not identify all hybrids or co-located plants*** as some co-located plants could have different IDs
  - We ***exclude dual fuel and CSP units*** which use the same prime mover technology (e.g., steam turbine) but have the capability to change fuels

Methods and data sources for interconnection queue project data sample

- Data collection led by Interconnection.fyi
- Data collected from interconnection queues for 7 ISOs / RTOs and 49 non-ISO balancing areas (including utilities and Power Marketing Administrations), which collectively represent ~97% of currently installed U.S. electric generating capacity
  - Includes all plants connecting to bulk power system (not distribution connections) in queues through the end of 2024
  - Full sample includes 10,303 “active” plants, of which 2,396 (23%) are in a hybrid or co-located configuration
  - Hybrids represent 495 GW (36%) of active generation capacity in queues, and 424 GW (48%) of active storage capacity in queues
- Hybrid / co-located plants identified using two methods:
  - “Generator Type” includes multiple types for a single queue entry; OR,
  - Two or more queue entries (of different generator types) with the same interconnection point and sponsor, queue date, ID number, and/or COD
- Storage capacity for hybrids (distinct from generator capacity) was provided in ~26% of proposed hybrid plants
  - For the remainder, storage capacity was estimated using known storage:generator ratios from other plants



Coverage area of entities for which data was collected
Data source: Homeland Infrastructure Foundation-Level Data (HIFLD)
Note that service areas can overlap
No data collected for Hawaii or Alaska

For more information, see LBNL’s annual interconnection queue data compilation and analysis at emp.lbl.gov/queues

Note that being in an interconnection queue *does not guarantee* ultimate construction. Most plants in the queues are not built.

Key 2024 Data Trends

Numerous configurations of hybrid/co-located power plants were operational as of the end of 2024

543 plants, 57 GW of generating capacity, 14 GW / 41 GWh storage capacity / energy

Operating at end of 2024	# plants	Gen 1* (Total MW)	Gen 2* (Total MW)	Gen 3* (Total MW)	Storage Capacity (Total MW)	Storage Energy (Total MWh)	Weighted Average Storage:Generator Ratio	Average Duration (hrs)
PV+Storage	359	21,952	0	0	11,923	35,742	54%	3.0
Fossil+Storage	27	6,364	0	0	1,381	3,830	22%	2.8
Wind+Storage	20	3,177	0	0	569	683	18%	1.2
Wind+PV	10	860	518	0	0	0	0%	n/a
Wind+PV+Storage	5	526	76	0	69	139	11%	2.0
Fossil+PV	39	8,528	476	0	0	0	0%	n/a
Fossil+PV+Storage	8	2,897	37	0	35	54	1%	1.5
Fossil+Hydro	25	453	71	0	0	0	0%	n/a
Fossil+Wind+PV	4	123	9	4	0	0	0%	n/a
Fossil+Wind	8	50	23	0	0	0	0%	n/a
Nuclear+Fossil	4	6,480	1,355	0	0	0	0%	n/a
Biomass+Hydro	9	327	51	0	0	0	0%	n/a
Biomass+PV	4	102	9	0	0	0	0%	n/a
Hydro+Storage	8	291	0	0	62	77	21%	1.2
Geothermal+PV	8	250	56	0	0	0	0%	n/a
Geothermal+PV+CSP	1	47	22	2	0	0	0%	n/a

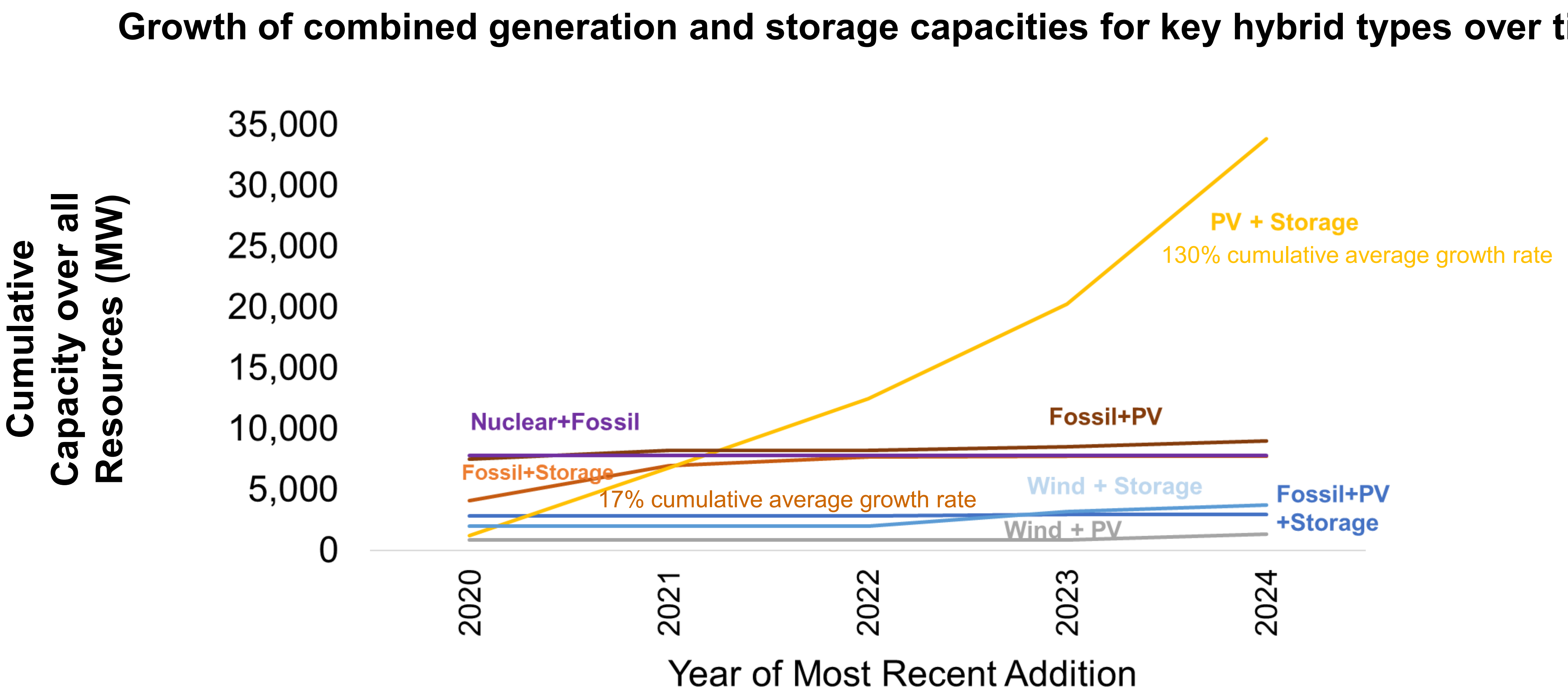
Sources: EIA 860 2024 Early Release, Berkeley Lab

Note: **Pumped hydro** is not considered a hybrid resource for the purpose of this compilation. The hydro plants noted in the table pair hydropower with other technologies.

**Gen order determined by name order in first column, storage capacity broken out separately*

Four categories were dropped from this table due to having limited sizes: (1) Fossil+Wind+Storage, (2) Fossil+Wind+PV+Storage, (3) Biomass+Storage, and (4) Nuclear+Hydro

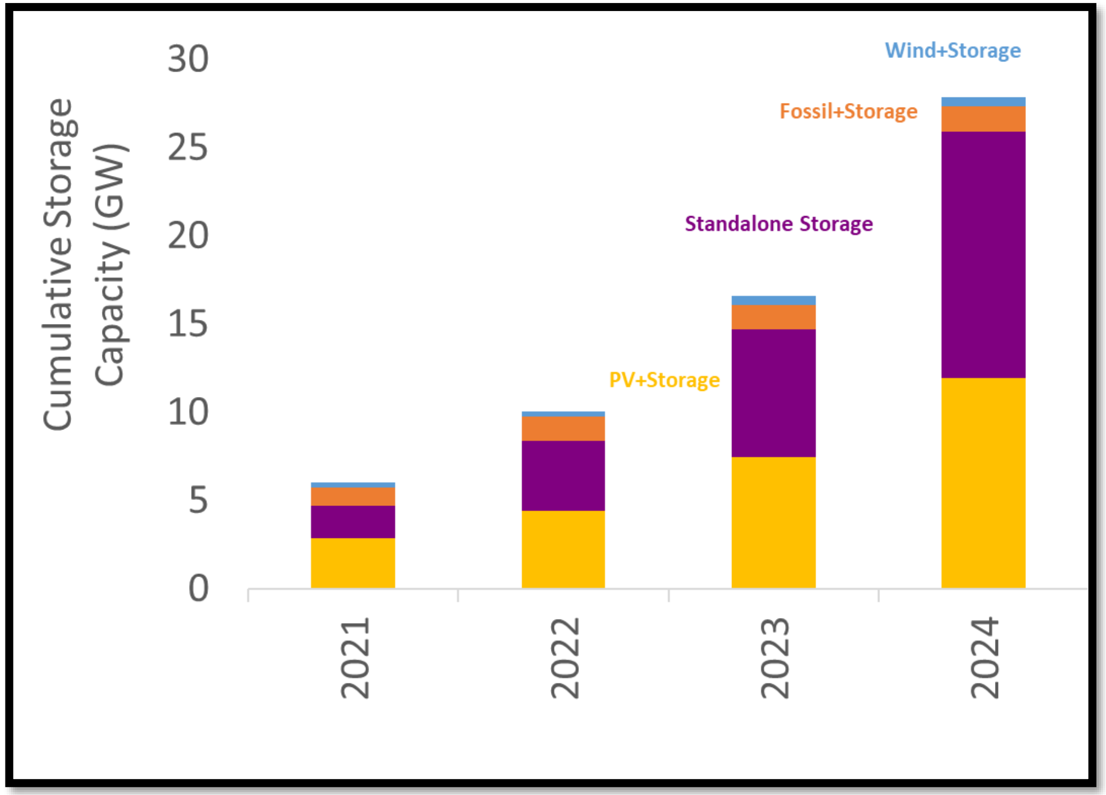
PV+Storage and Fossil+Storage nameplate capacity have grown the most since 2020

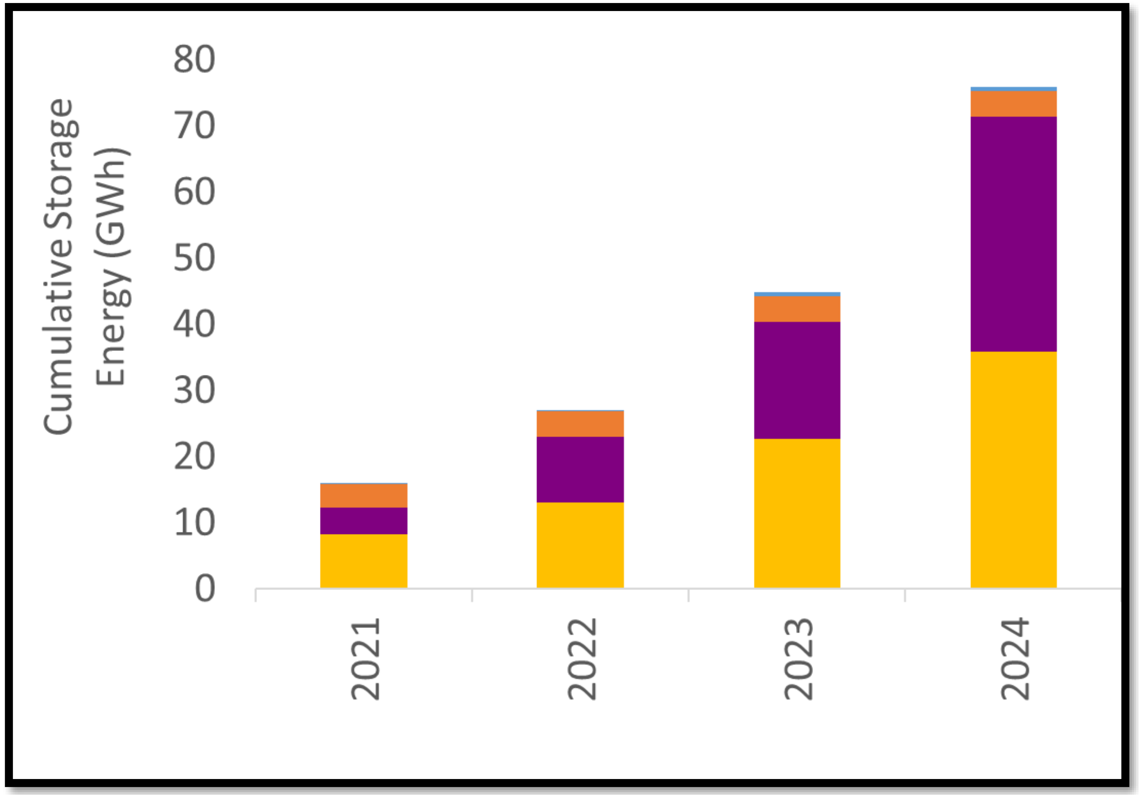


Ignored types: (1) Fossil+PV+Storage, (2) Fossil+Storage+Wind+PV, (3) Fossil+Wind+Storage, (4) Fossil+Wind+PV, (5) Fossil+Wind, (6) Biomass+PV, (7) Geothermal+PV+CSP, (8) Geothermal+PV, (9) Hydro+Storage, (10) Biomass+Storage, (11) Hydro+Biomass

Sources: EIA 860 2024 Early Release, Berkeley Lab

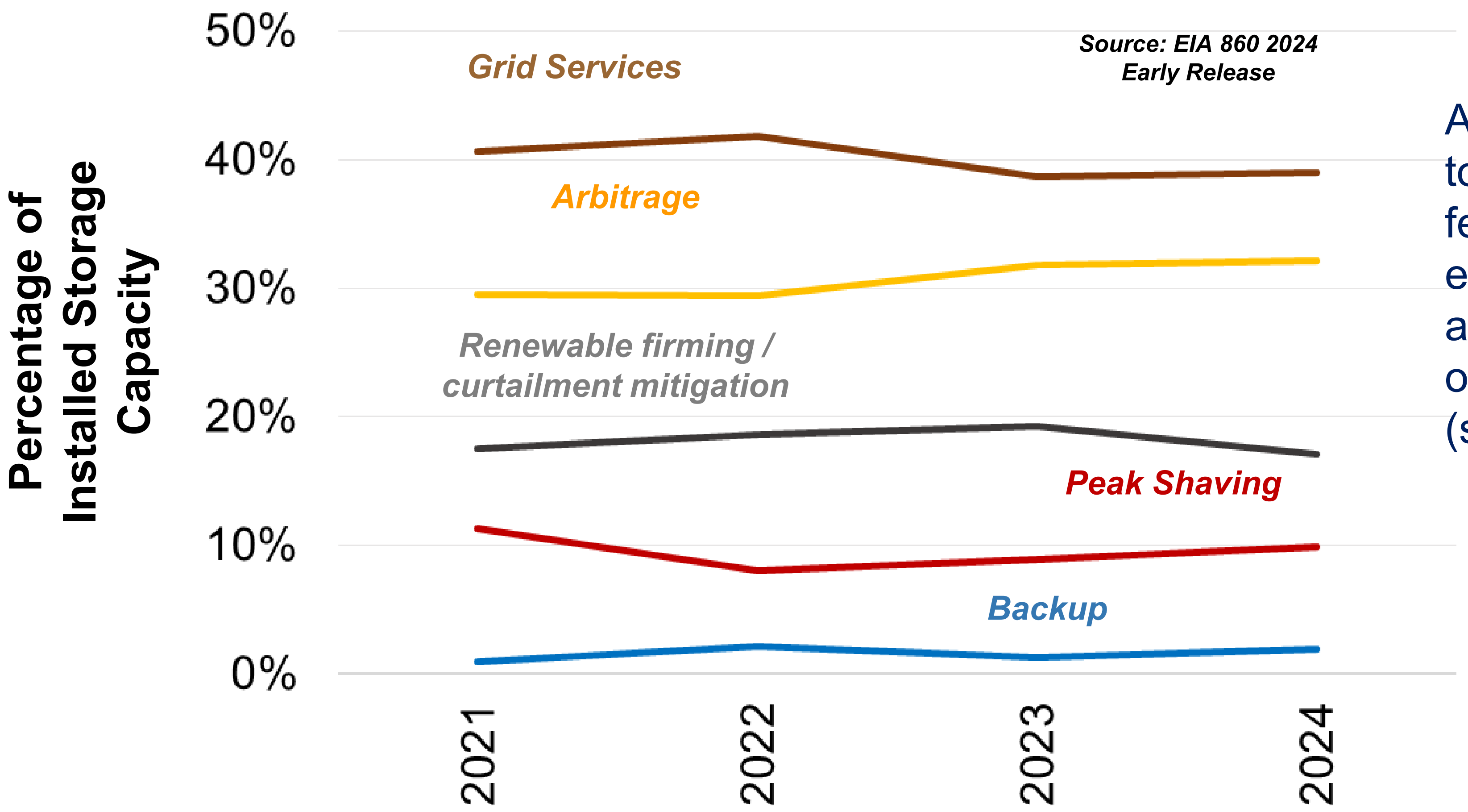
Installed storage capacity and energy increased by 70% in 2024





**These comparisons do not include pumped storage capacity or thermal storage from CSP plants. Rather, they only incorporate installed battery storage capacities, and limited amounts of flywheel and compressed air energy storage. Furthermore, they largely do not consider behind-the-meter storage, given our focus on EIA data for projects >1MW*

Self-selected use cases for operational batteries in hybrid and standalone configurations held steady in 2024 with grid services as prominent use case

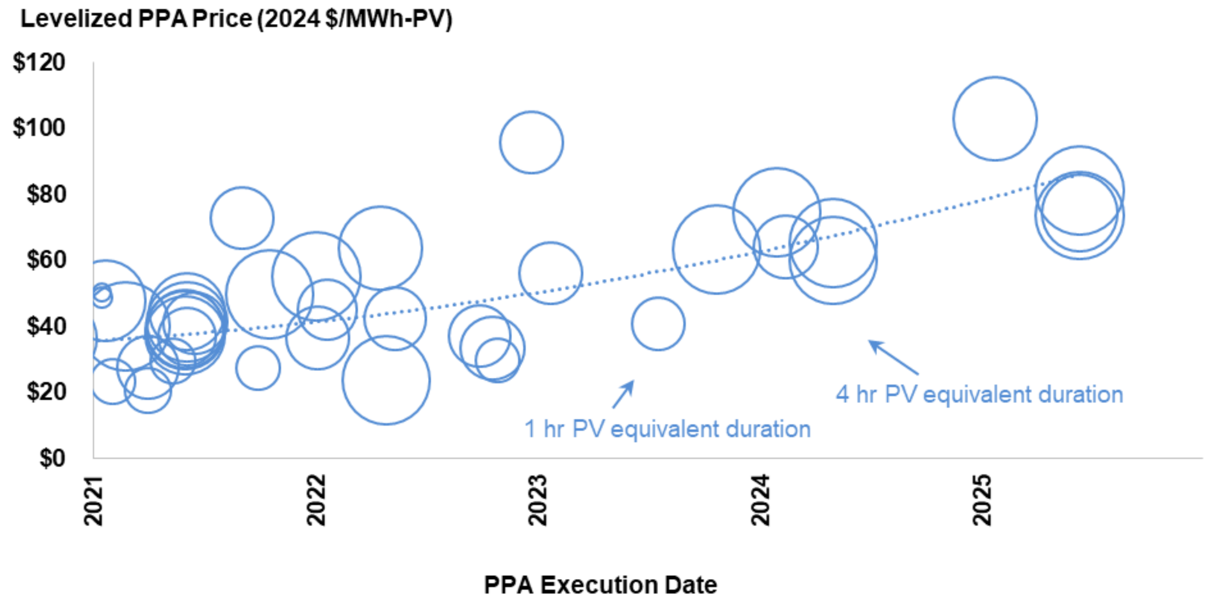


Arbitrage has continued to creep up in the last few years, but has not experienced as large of an increased in use as occurred in 2020/2021 (see Appendix, slide 29)

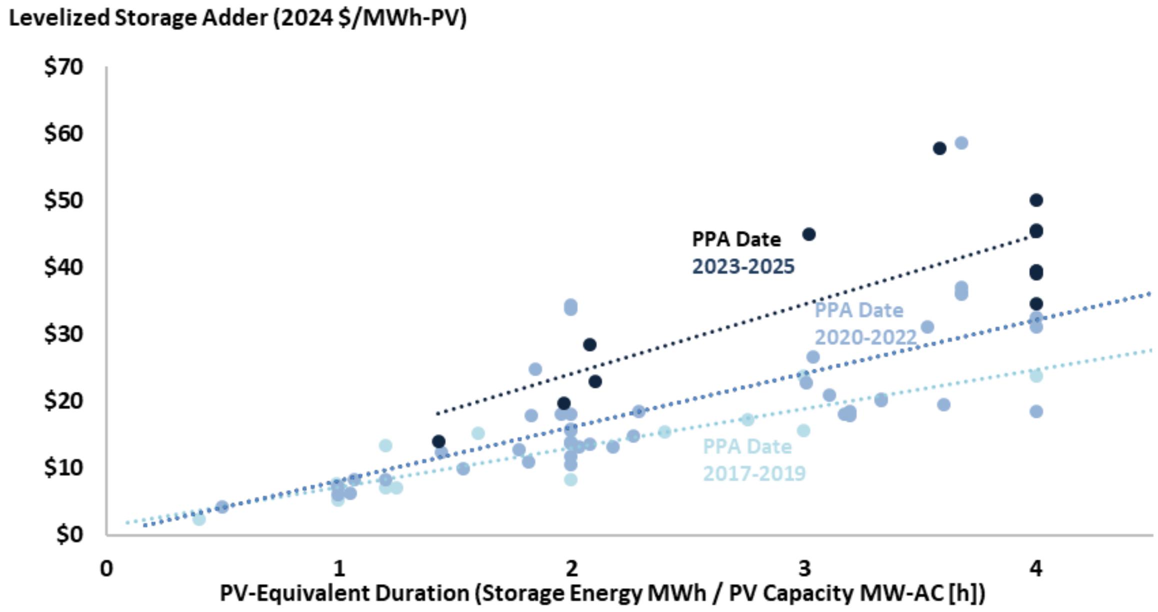
Notes:
Percentages can add up to more than 100% because projects can select more than one use-case
We do not have a historical record of primary use-case over time (EIA began reporting primary use-case in EIA 860 2023 Early Release)
Grid services category includes the following: frequency regulation, load following, ramping/spinning reserve, load management, and voltage/reactive power support

PV+Storage PPA prices increased in 2024/2025 ($75/MWh avgerage) from lows in 2021/2022 ($40/MWh average)

Bubble area = PV-equivalent duration:
Storage Energy [MWh] / PV Capacity [MW-AC]



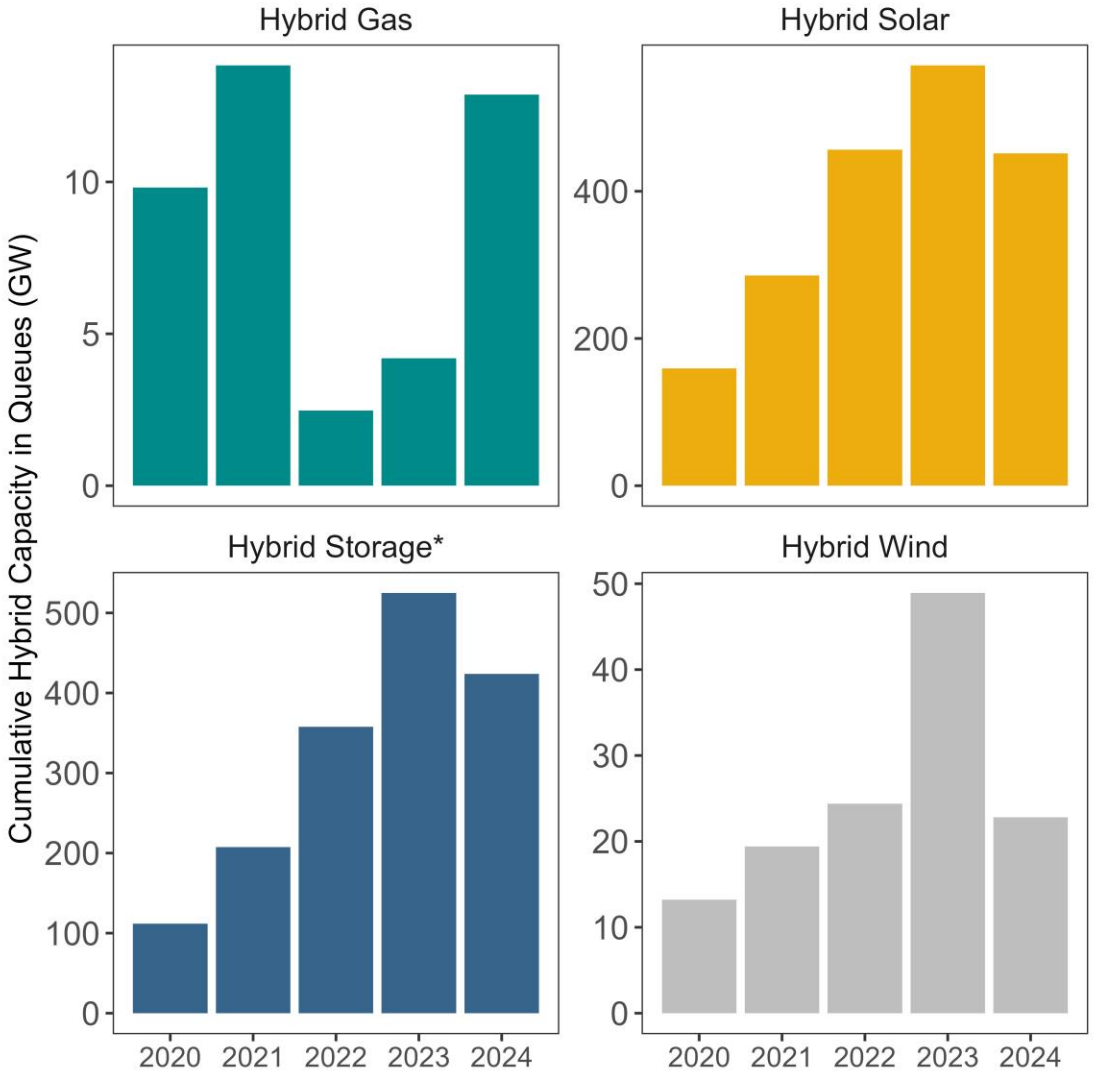
Color change based on PPA execution date



Left graph is sample of plants from the continental U.S. PPA sample for Hawaii projects found in the Appendix, slide 42.

Right graph is sub-sample of plants that provide enough information to calculate a levelized storage adder, which represents the incremental price from inclusion of the storage component

Given new interconnection requests and project withdrawals, gas projects were only hybrid type that increased in interconnection queues in 2024



(1) In 2024, ~87% of the hybrid generation capacity in the queues is in solar+battery configurations

(2) Some hybrids shown may represent storage capacity added to existing generation; only the net increase in capacity is shown for a given year

(3) Capacity for hybrid plants (e.g., Wind+Solar+Storage) is captured in each generator category (i.e., the solar component shows up in hybrid solar, storage in hybrid storage), presuming the capacity is known for each type.

Hybrid storage capacity is estimated using storage:generator ratios from projects that provide separate capacity data. Hybrid storage includes **only the storage capacity from proposed hybrid plants that include storage. Similar for other categories in that they only include the gas, solar, wind capacity of the hybrid plant in their respective charts.*

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The data file and visualizations can be found at:

- https://emp.lbl.gov/hybrid

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Funded by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy under Contract No. DE-AC02-05CH11231. The views and opinions of the authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, or The Regents of the University of California.

Image: Generated by Google Gemini

Full dataset and timeseries provided in following appendix material

Organization of appendix slides

Operational Hybrid Plants:

Online as of the end of 2024

Hybrid Costs:

A sample of PV+battery plants with PPAs or CapEx data

Hybrid Pipeline:

Hybrid plants in interconnection queues at the end of 2024

Operational Hybrid Plants: Online as of the end of 2024

Methods and data sources for online project data sample (same as slide 5)

- Form ***EIA-860 2024 early release*** and ***public announcements***
  - Generator specific information for power plants with ***>1 MW combined*** capacity
  - Limited amount of spot checking for corrections to EIA data
- Hybrids identified by either having the ***same EIA ID*** or, in some cases, through other regulatory filings or trade press articles
  - ***Suggests co-location of generators*** at one plant / point of interconnection, but not necessarily co-controlled generators
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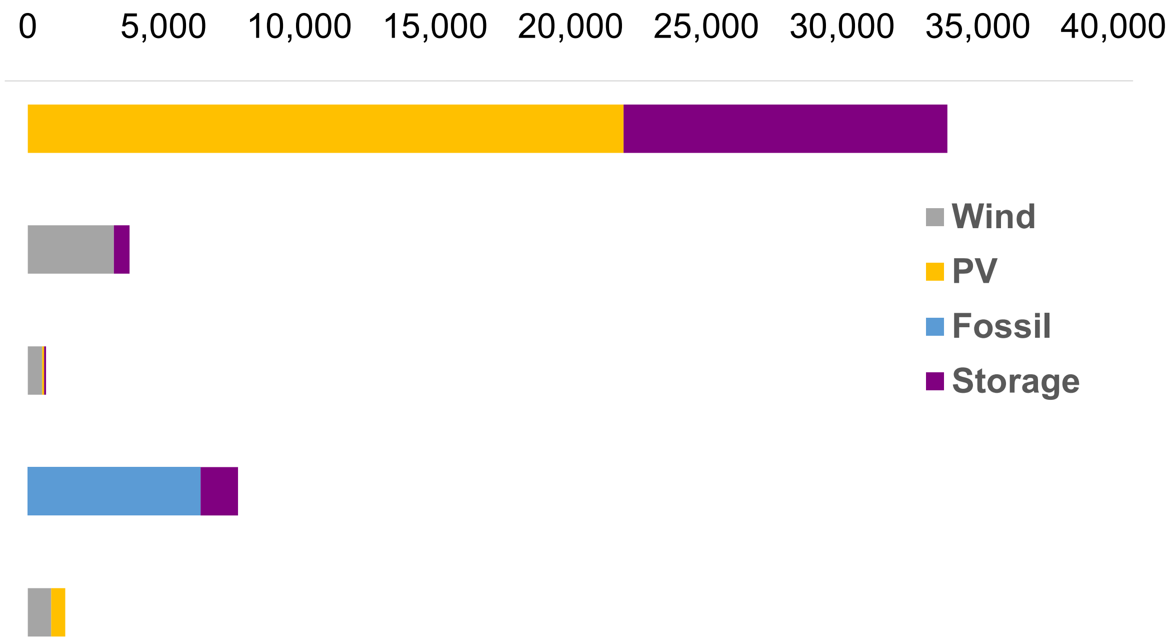
Fossil+Storage and PV+Storage hybrids have the most nameplate capacity paired together

Cumulative Statistics Year End 2024

	# projects	Weighted Average Storage Ratio	Duration (hrs)
PV+Storage	359	54%	3.0
Wind+Storage	20	18%	1.2
Wind+PV+Storage	5	11%	2.0
Fossil+Storage	27	22%	2.8
Wind+PV	10	n/a	n/a

Total capacity (MW)

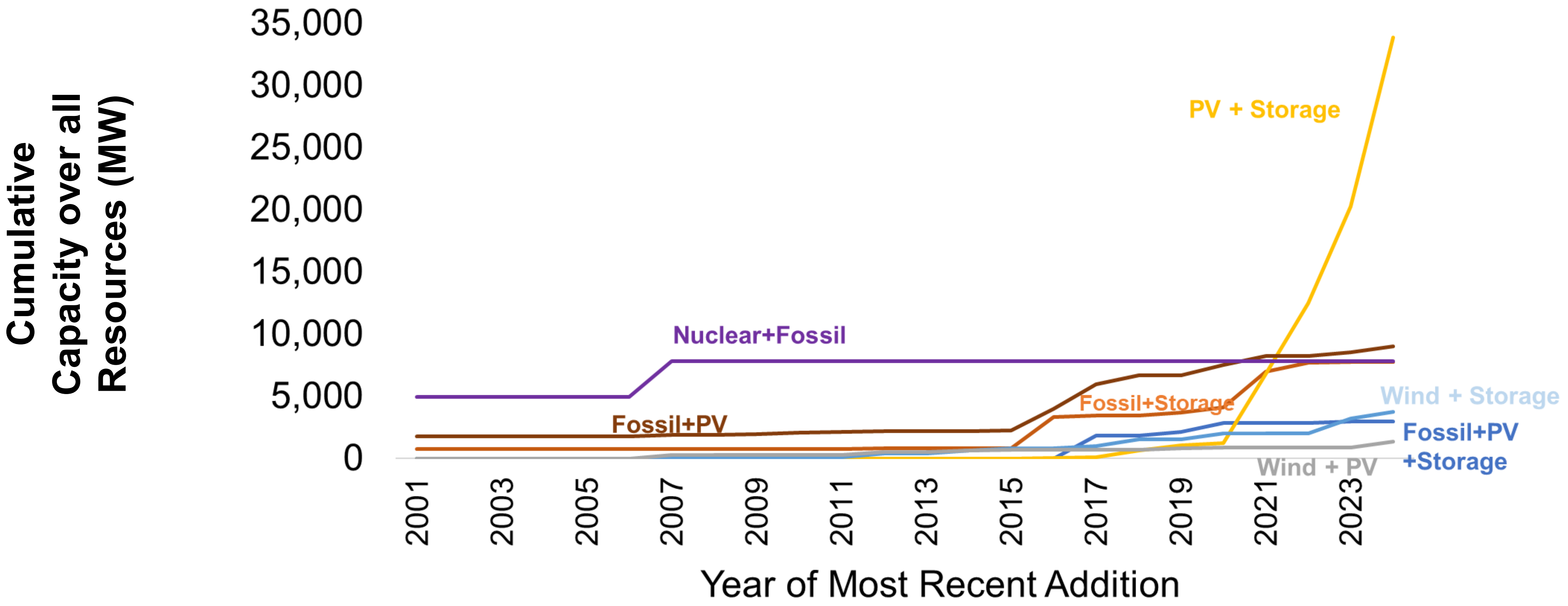


Notes: Not included in the figure are 122 other hybrid / co-located plants with other configurations; details on those plants are provided in the table on slide 7. ***Storage ratio*** *is defined as total storage capacity divided by total generation capacity within a hybrid type.* ***Duration*** *is defined as total MWh of storage divided by total MW of storage within a hybrid type.*

Sources: EIA 860 2024 Early Release, Berkeley Lab

Growth of nameplate capacity for operational hybrid projects overtime

Growth of combined generation and storage capacities for key hybrid types overtime



Ignored types: (1) Fossil+PV+Storage, (2) Fossil+Storage+Wind+PV, (3) Fossil+Wind+Storage, (4) Fossil+Wind+PV, (5) Fossil+Wind, (6) Biomass+PV, (7) Geothermal+PV+CSP, (8) Geothermal+PV, (9) Hydro+Storage, (10) Biomass+Storage, (11) Hydro+Biomass

Sources: EIA 860 2024 Early Release, Berkeley Lab

Operational hybrid plants are scattered across the United States

Fossil Hybrid Plants

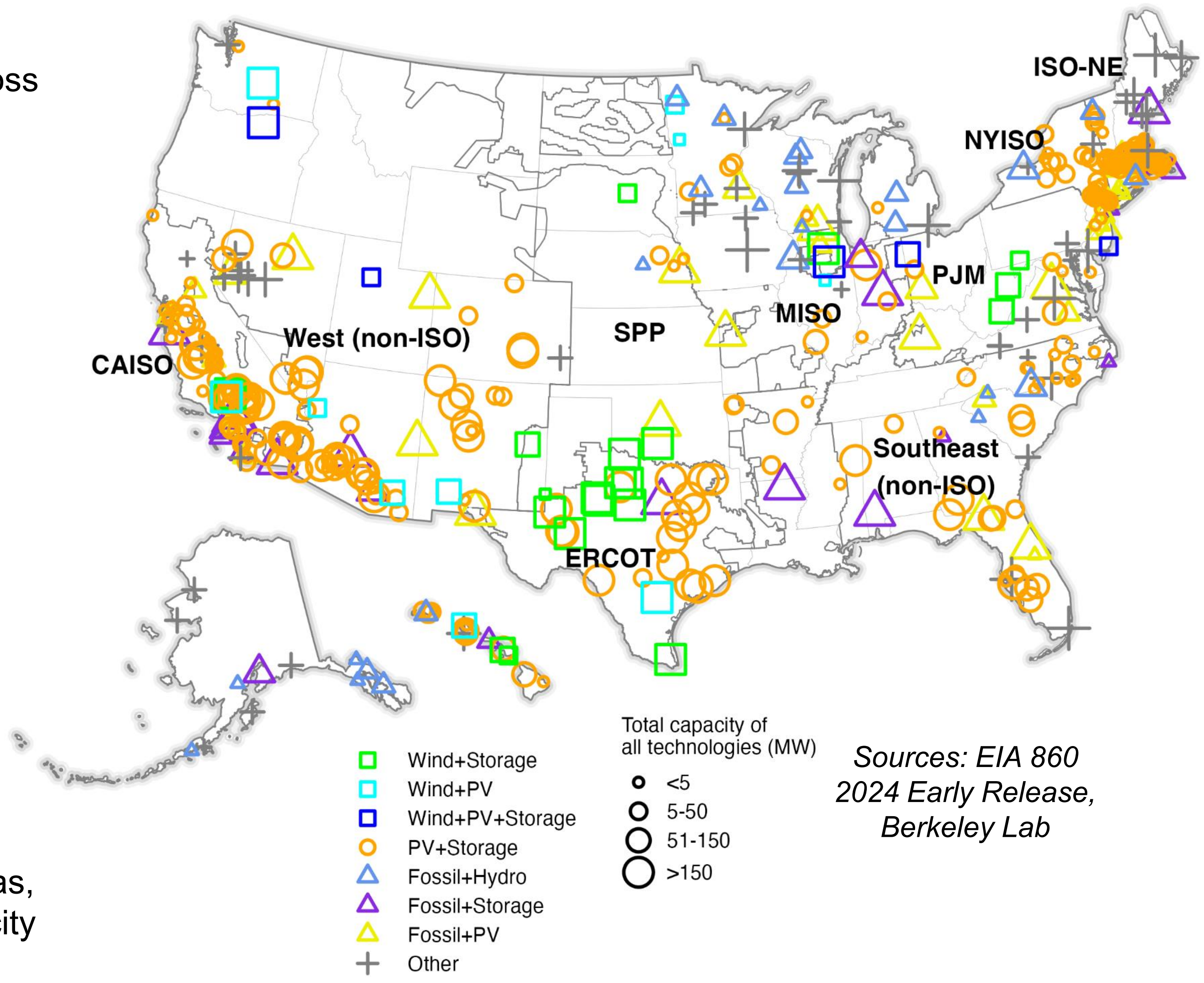
- California has the majority of Fossil+Storage hybrids across the country (10), the next closest state has 4 installations
- Fossil+PV is relatively spread out across the county with small amounts of PV added to larger fossil units

Solar Hybrid Plants

- Massachusetts contains the most (100) PV hybrid plants, though the PV portions are all <7 MW
- With 97 total plants (24 new in 2024), California has the second highest number of PV hybrid plants across the United States, 37 of which have installed PV capacities ≥100 MW

Wind Hybrid Plants

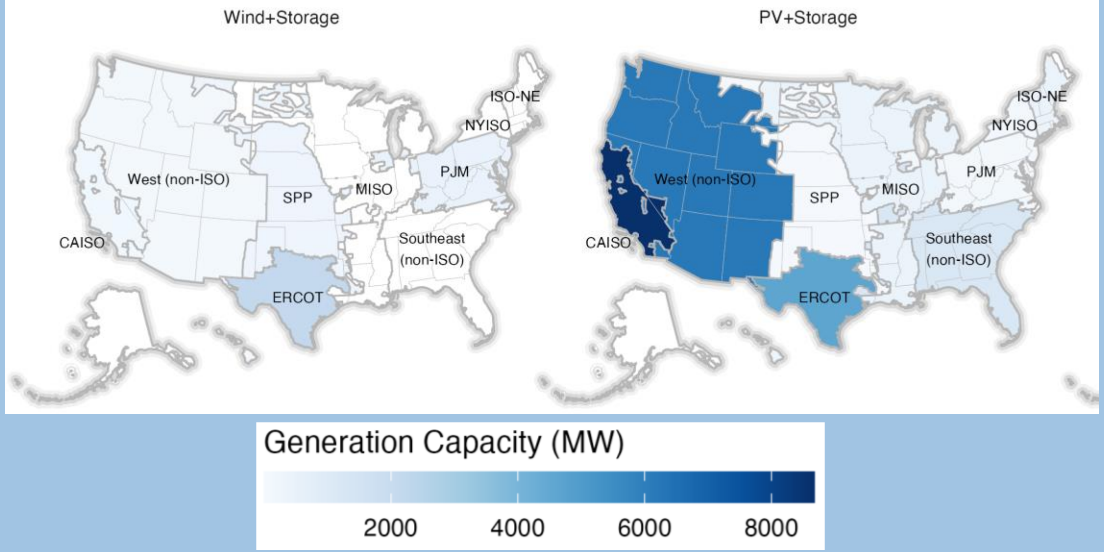
- Wind hybrids are relatively sparse across the U.S. compared to solar
- 3 of the 4 new wind hybrids installed in 2024 were in Texas, which contains 10 of the 19 wind hybrids with wind capacity ≥100 MW

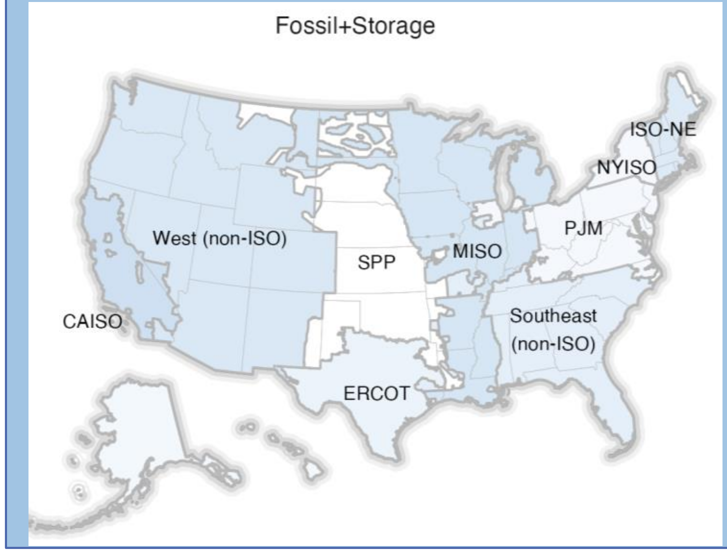


Sources: EIA 860 2024 Early Release, Berkeley Lab

Hybrid capacity broken out by larger regions

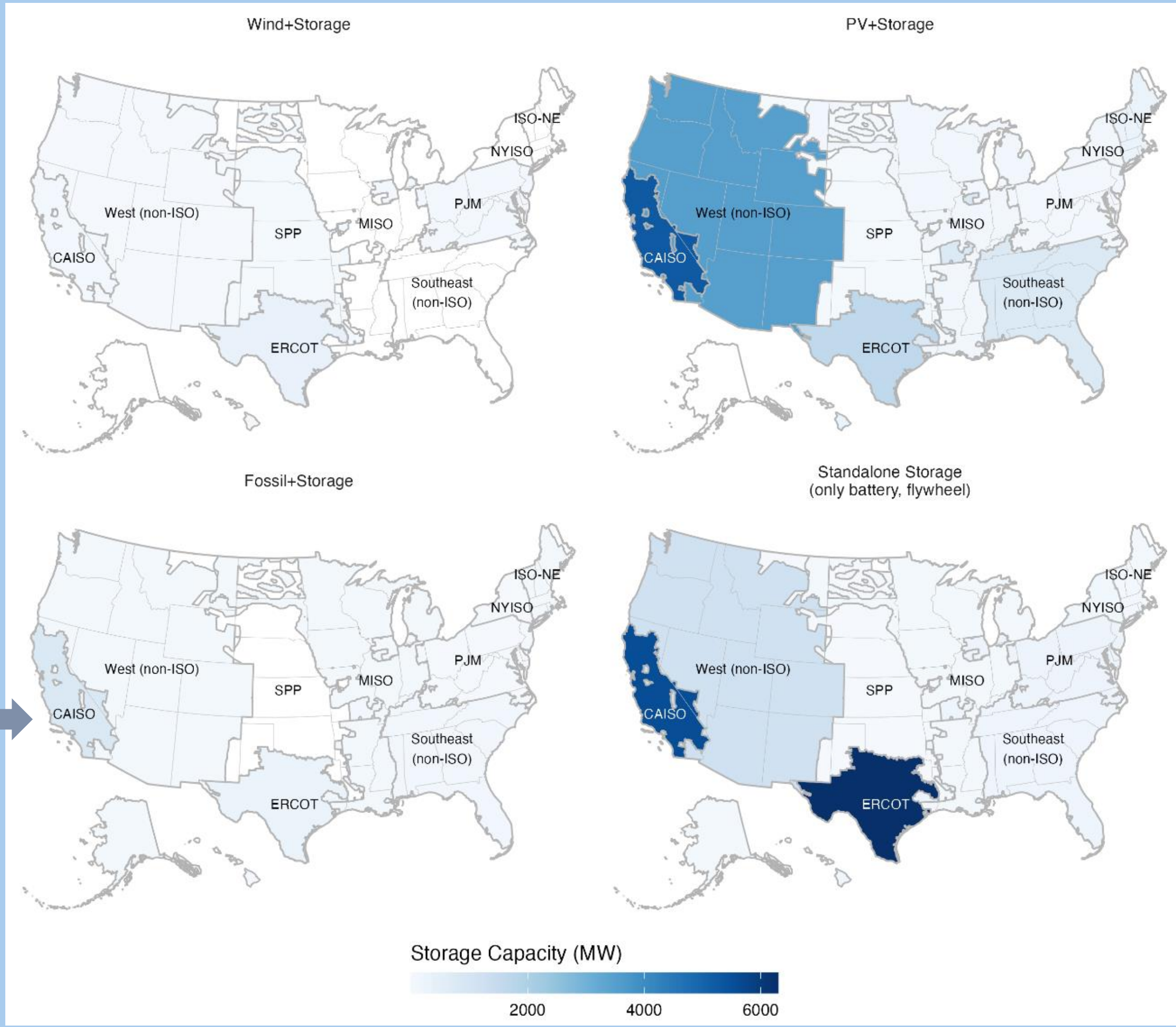
Aggregate Generator Capacity by Hybrid Type and ISO





Inclusive of standalone storage, CAISO and ERCOT account for 73% of installed storage capacity across the regions on the right (20.2 GW combined) but CAISO has more storage energy capacity than all other regions combined (40 GWh vs. 35 GWh)

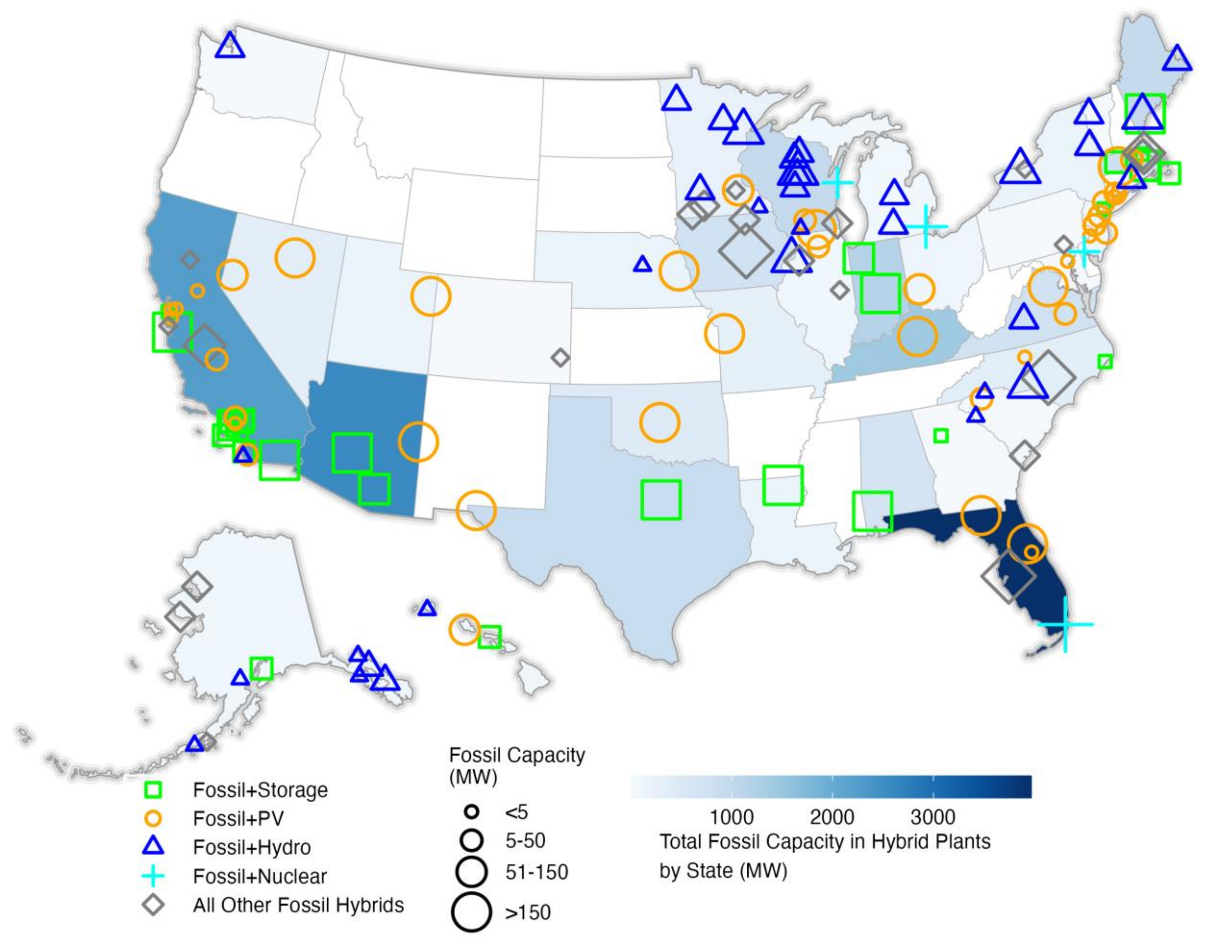
Aggregate Storage Capacity by Plant Type and ISO



Sources: EIA 860 2024 Early Release, Berkeley Lab

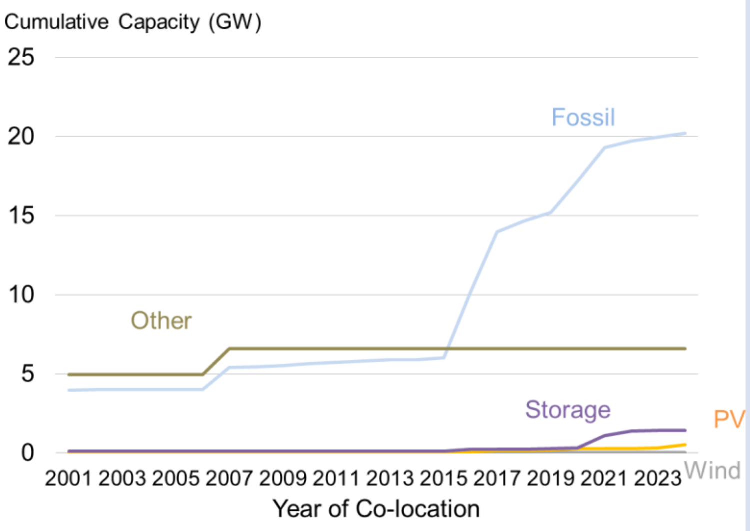
Fossil Hybrids: Summary of plant location and growth over time

Online Fossil Hybrid / Co-located Plants



Growth in Fossil Hybrid Capacity over Time

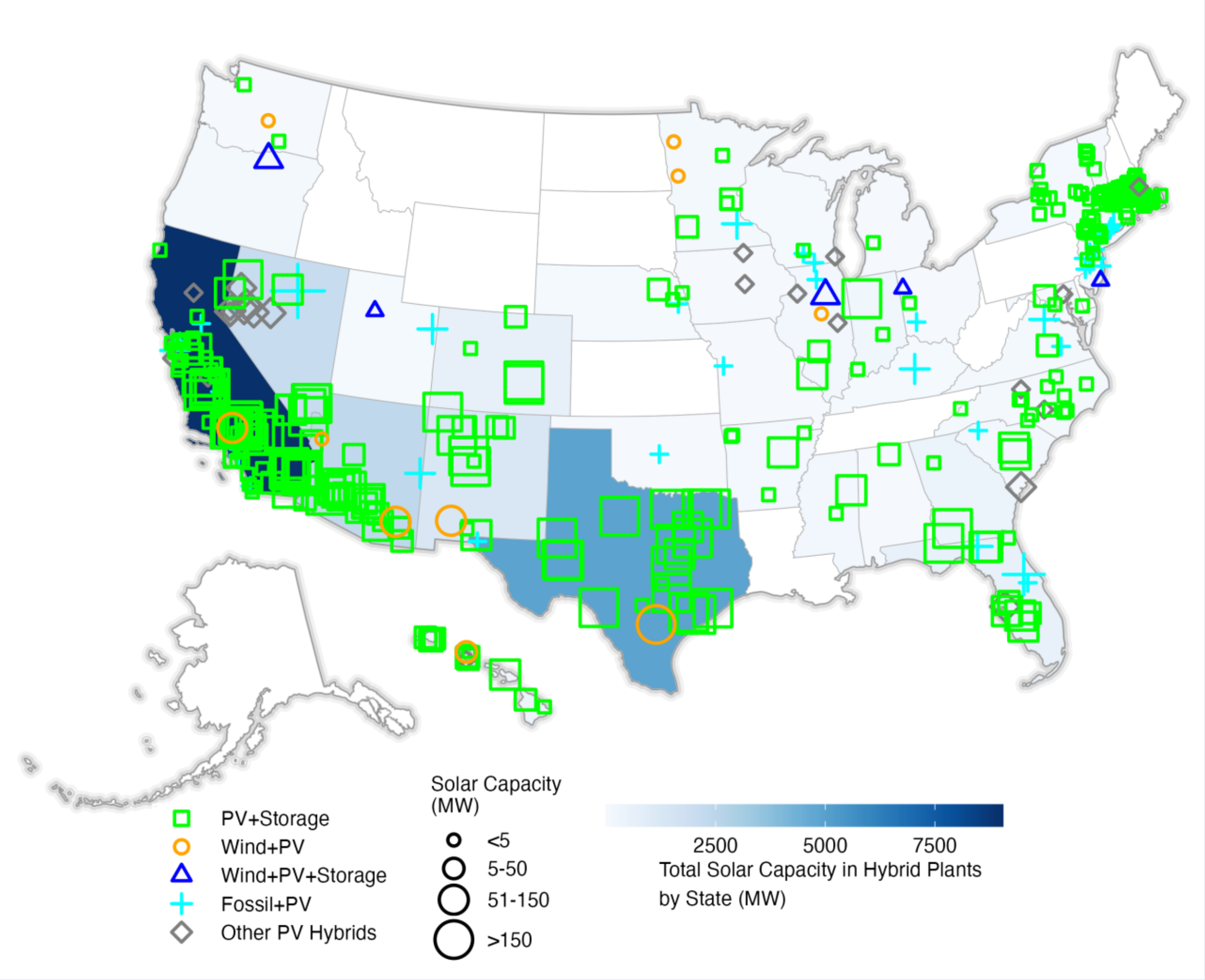
depicts amount of fossil and other types of generation and storage being paired with fossil, over time



Sources: EIA 860 2024 Early Release, Berkeley Lab

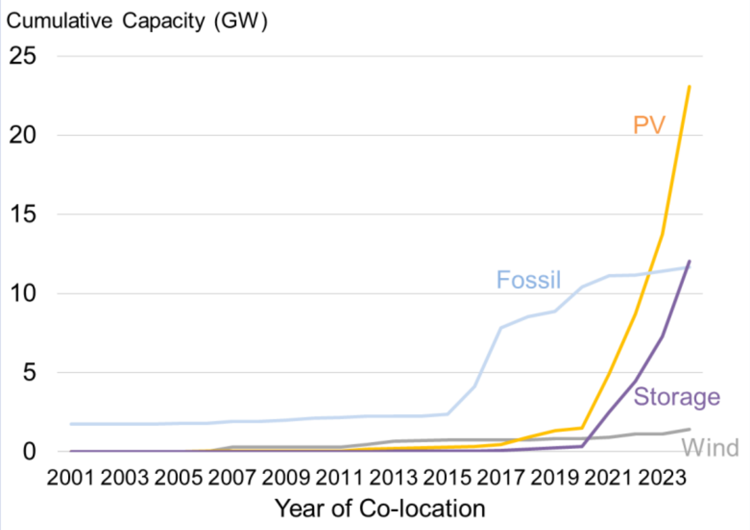
Solar Hybrids: Summary of plant locations and growth overtime

Online Solar Hybrid / Co-located Plants



Growth in Solar Hybrid Capacity over Time

depicts amount of PV and other types of generation and storage being paired with PV, over time

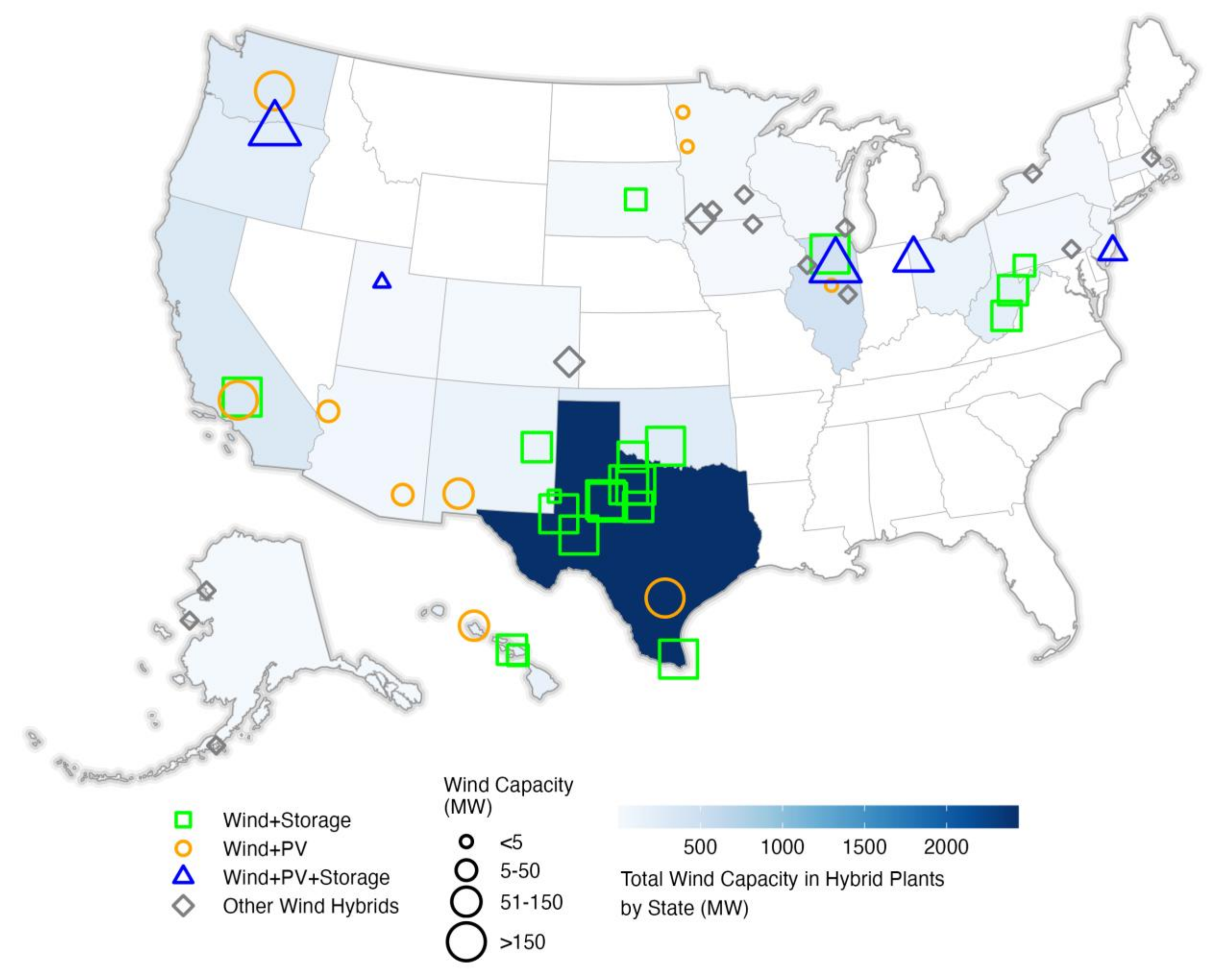


Note: Fossil+PV typically involves minor amounts of PV added to existing (and often much larger) fossil units at the point of interconnection; thus, the fossil category has a large presence in the figure.

Sources: EIA 860 2024 Early Release, Berkeley Lab

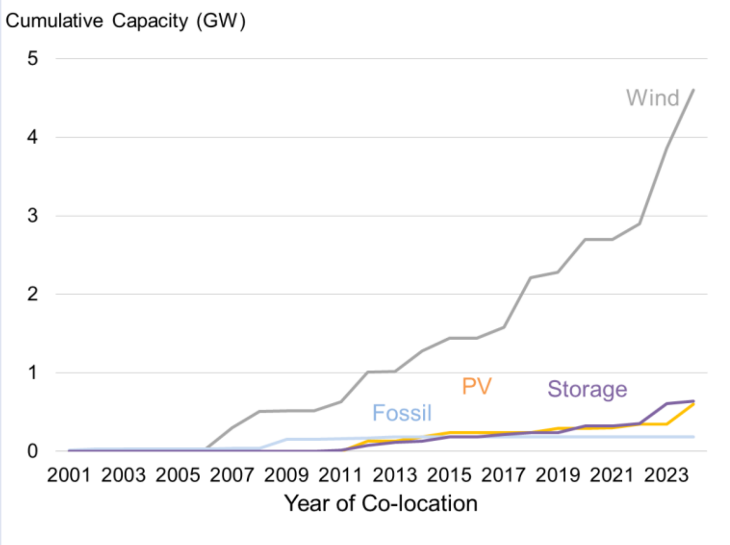
Wind Hybrids: Summary of plant location and growth over time

Online Wind Hybrid / Co-located Plants



Growth in Wind Hybrid Capacity over Time

depicts amount of wind and other types of generation and storage being paired with wind, over time

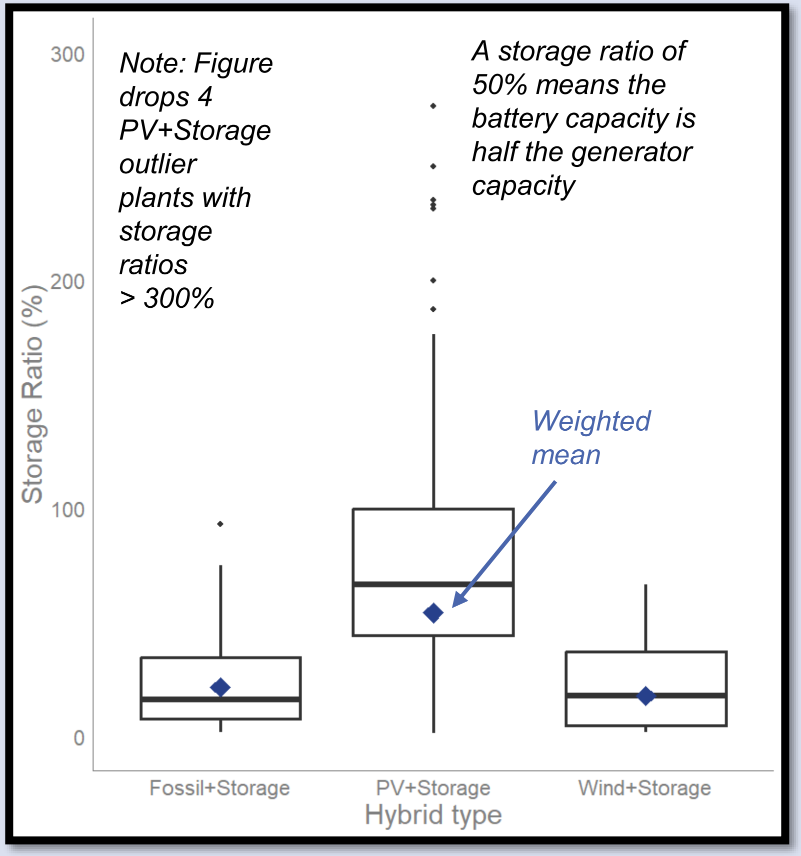


Note: Duration of storage for wind hybrids tends to be limited (typically ~1 hr)

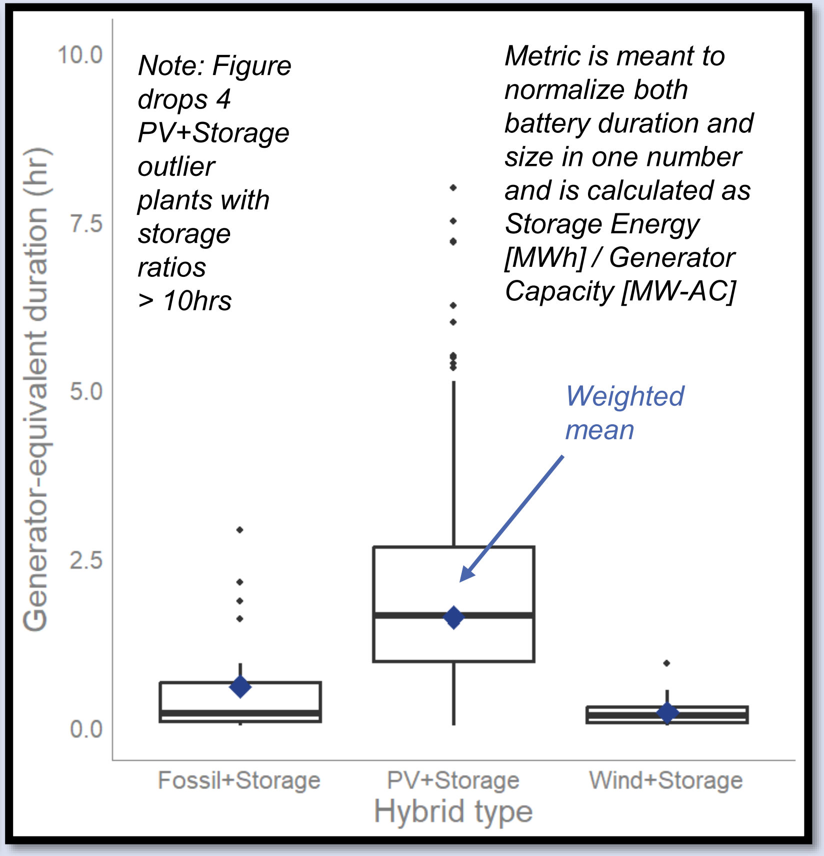
Sources: EIA 860 2024 Early Release, Berkeley Lab

Storage-to-generator ratios, generator equivalent durations, and storage durations for common hybrid and standalone storage types

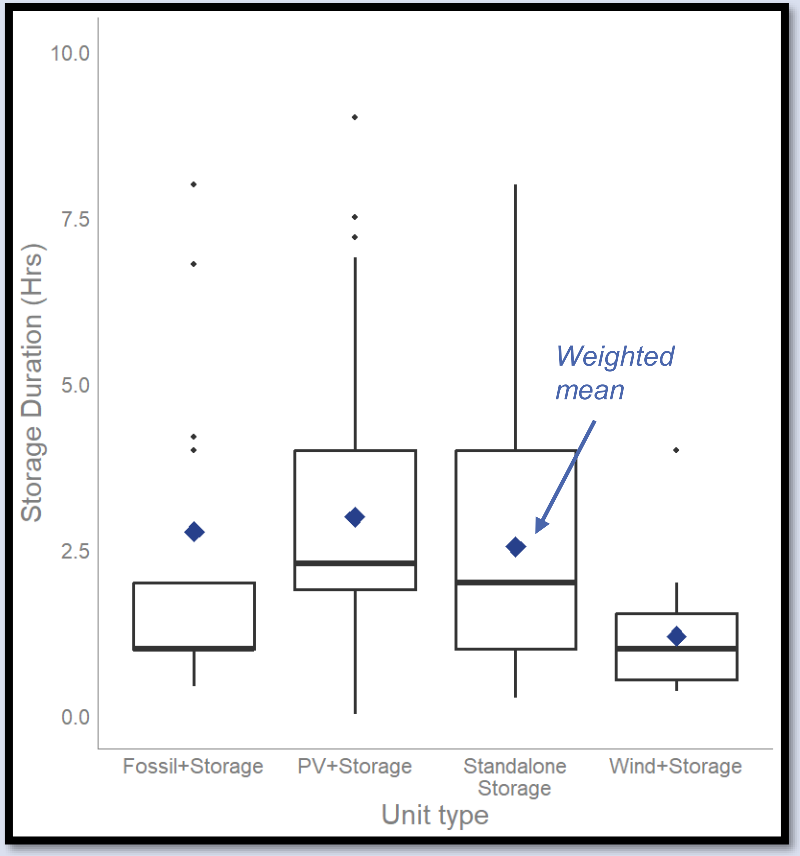
Storage-to-generation ratio



Generator equivalent duration

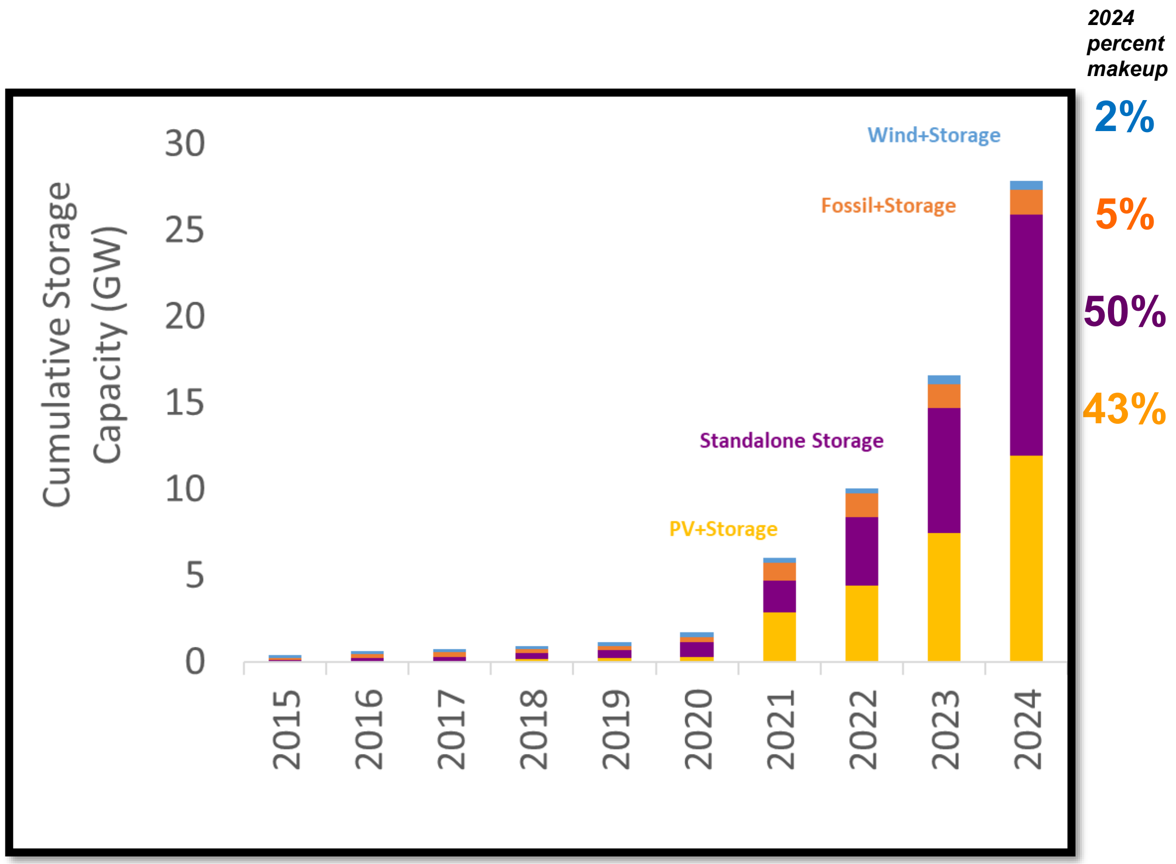


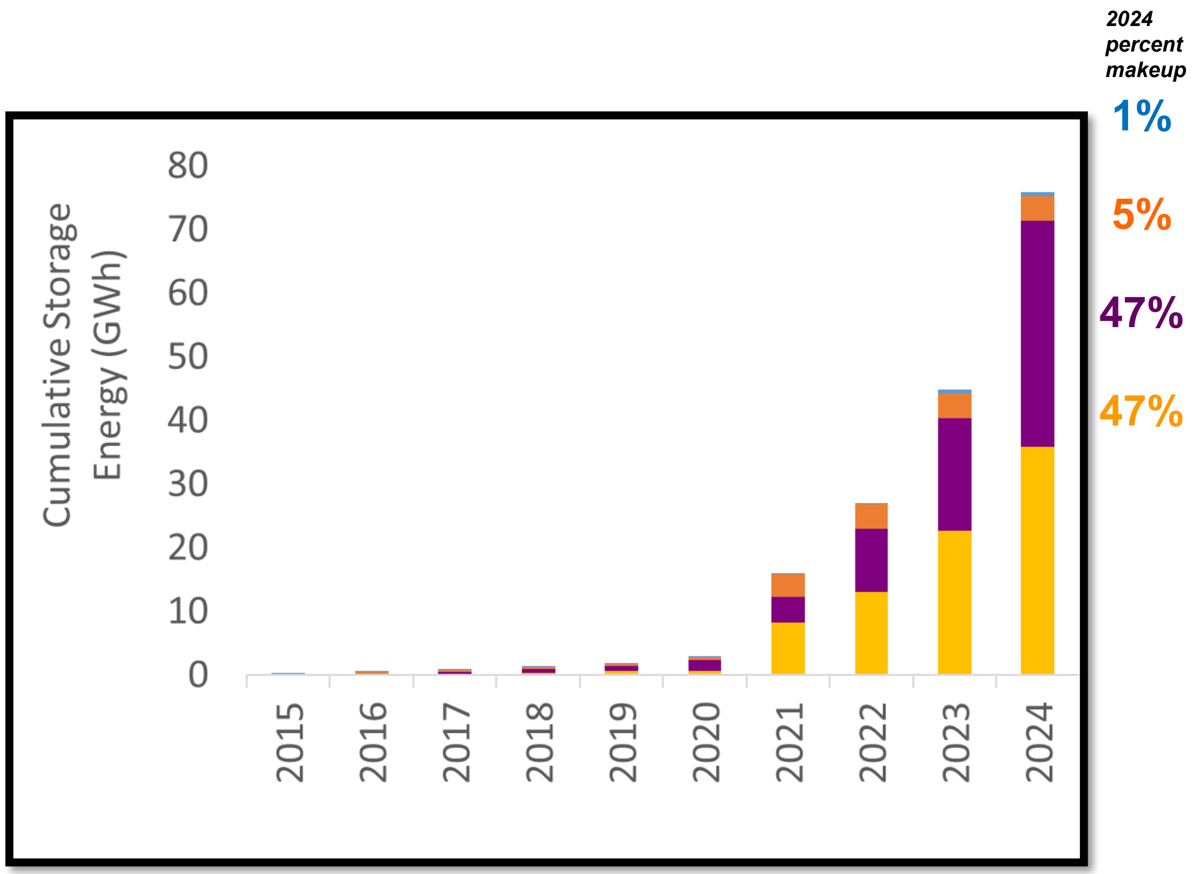
Storage durations



Sources: EIA 860 2024 Early Release, Berkeley Lab

Storage capacity (left) and energy (energy) amounts in select hybrid plants and for standalone storage

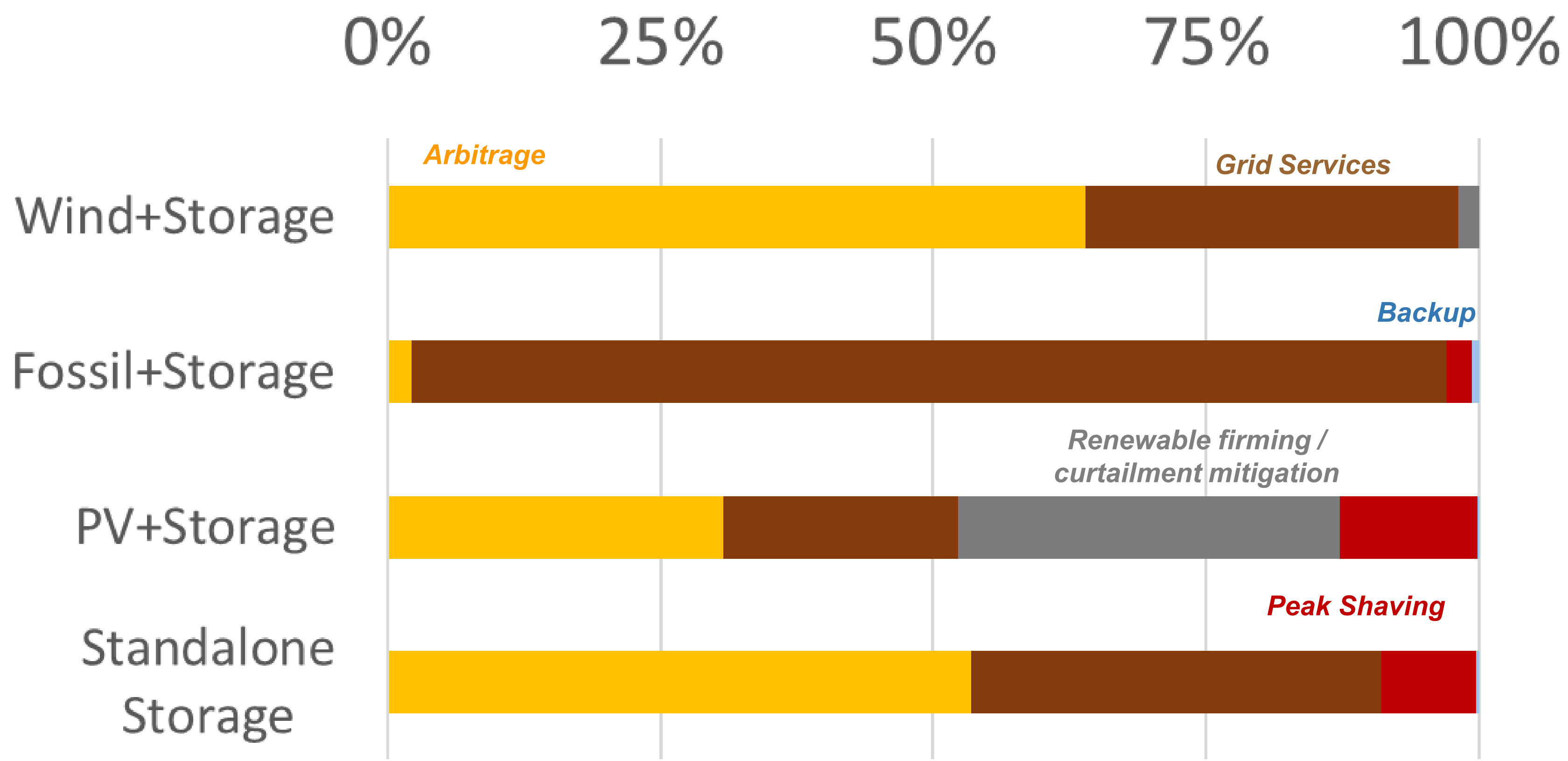




**These comparisons do not include pumped storage capacity or thermal storage from CSP plants. Rather, they only incorporate installed battery storage capacities, and limited amounts of flywheel and compressed air energy storage. Furthermore, they largely do not consider behind-the-meter storage, given our focus on EIA data for projects >1MW*

Breakdown of self-reported use cases for battery storage in hybrids and in standalone storage assets in 2024

Breakdown of primary battery use-case among certain hybrid configurations and standalone storage in 2024 (% of capacity)



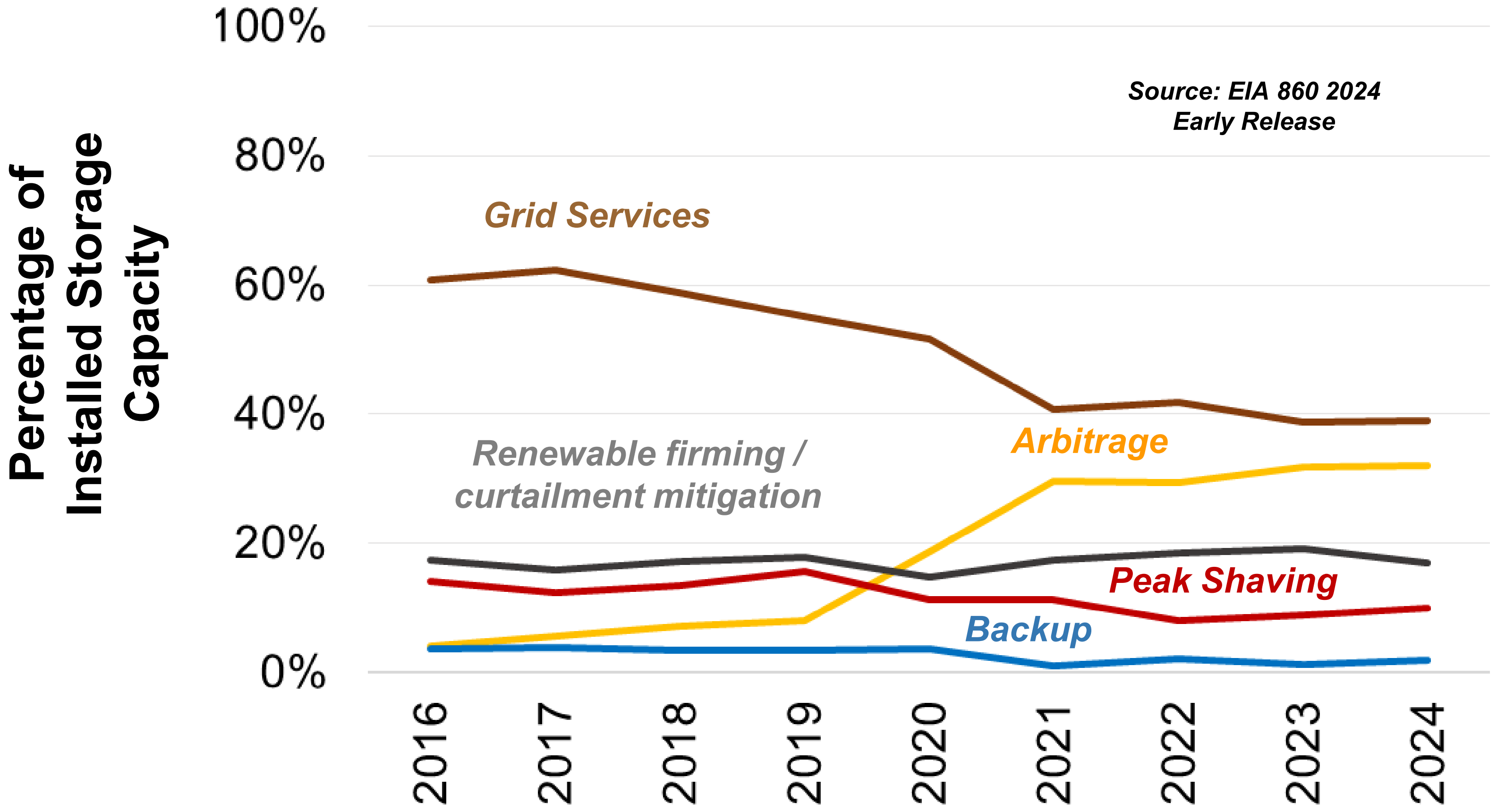
Source: EIA 860 2024 Early Release

Note:

Operators self-report use cases to EIA; individual plants can indicate multiple use cases, though in 2023 EIA began reporting primary use case

Grid services category includes the following: frequency regulation, load following, ramping/spinning reserve, load management, and voltage/reactive power support. Additional details about all categories can be found in the EIA 860 Instruction form on page 18.

Self-selected use cases for operational batteries in hybrid and standalone configurations overtime



Notes:
Percentages can add up to more than 100% because projects can select more than one use-case
We do not have a historical record of primary use-case over time (EIA began reporting primary use-case in EIA 860 2023 Early Release)
Grid services category includes the following: frequency regulation, load following, ramping/spinning reserve, load management, and voltage/reactive power support

Case studies of battery charge and discharge monthly patterns (methods)

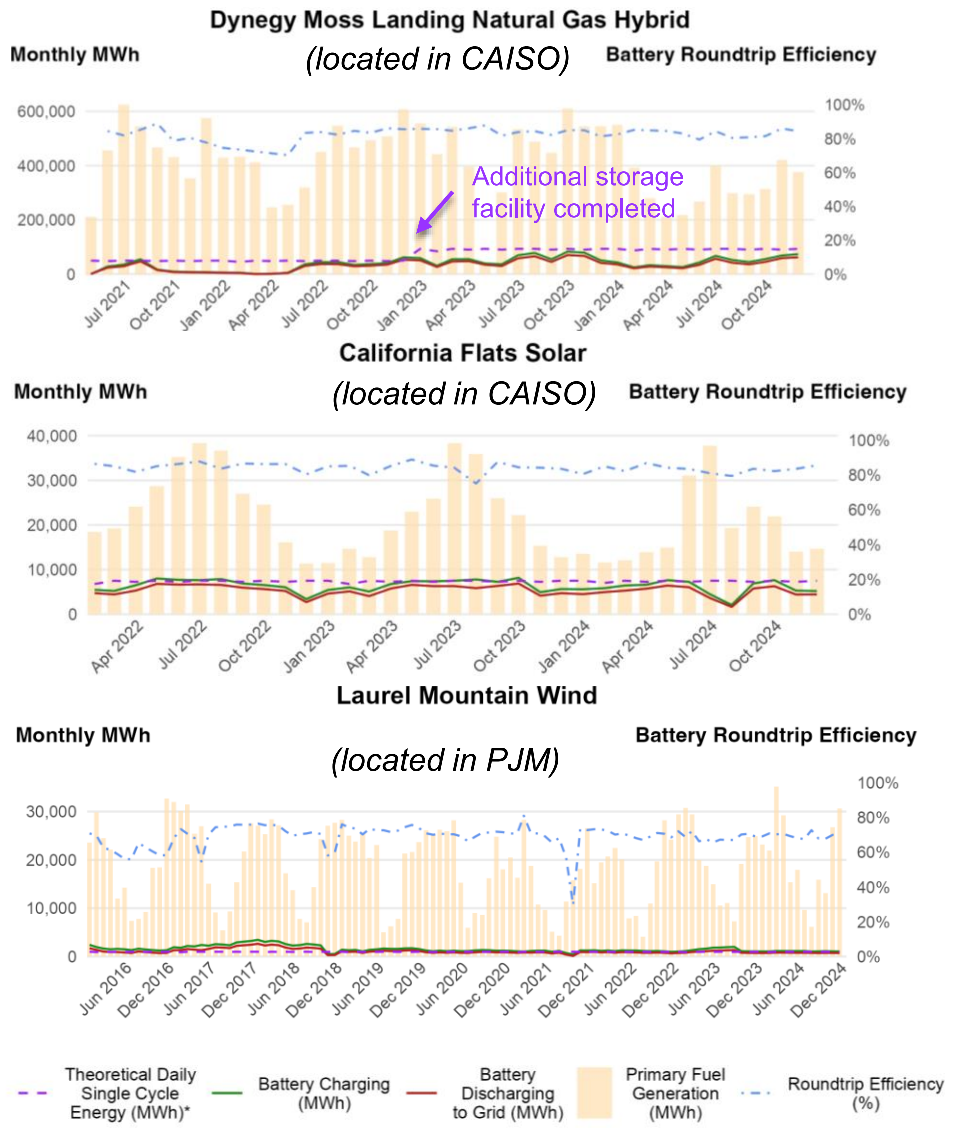
Data Sources and Methods

- Form EIA 923 reports battery ***charging*** (from grid or generator) and ***discharging*** (to the grid)
- The battery's ***roundtrip efficiency*** is calculated by dividing the discharged energy by the charged energy

Case Studies Metadata (dispatch summaries presented on next slide)

Plant Names	Generator Capacity (MW AC)	Storage Capacity (MW)	Storage Energy (MWh)	Storage Duration (hr)	Storage:Generator Ratio (%)	Online Year
Moss Landing *fossil hybrid*	1,398	750	3000	4	54%	2021
California Flats *solar hybrid*	130	60	240	4	46%	
Laurel Mountain *wind hybrid*	98	16	16	1	16%	2011

Case studies of battery charge and discharge monthly patterns (results)



Dynegy

- Operates above 80% efficiency
- Average of 0.82 daily cycles throughout plant lifetime
- Primary reported function of frequency regulation, though also provides arbitrage

California Flats

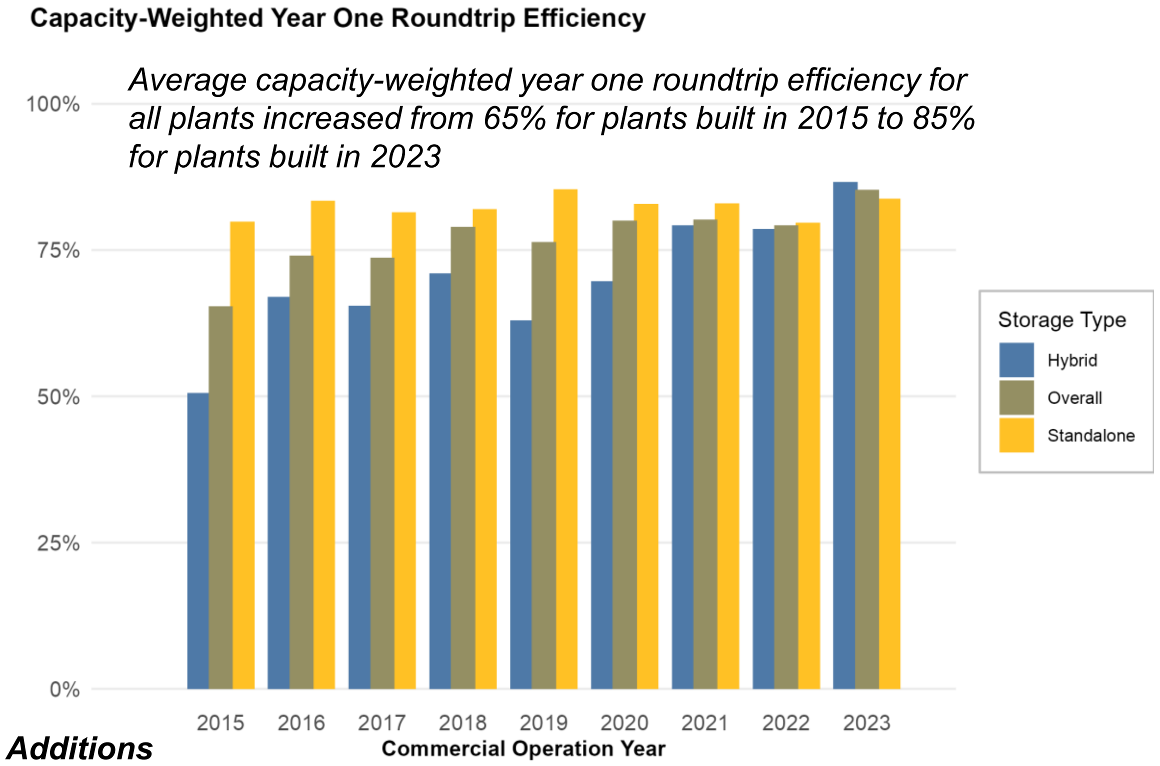
- Operates above 80% efficiency
- Average of 0.83 daily cycles throughout plant lifetime
- Primary reported function of arbitrage

Laurel Mountain

- Operates below 70% roundtrip efficiency
- Average of 1.6 daily cycles throughout plant lifetime
- Primary reported function of delivering frequency response.

**Theoretical daily single cycle energy (MWh) is equal to the battery energy capacity (MWh) multiplied by the days in the month, to provide a reference for expected charging amount if the battery cycled once per day.*

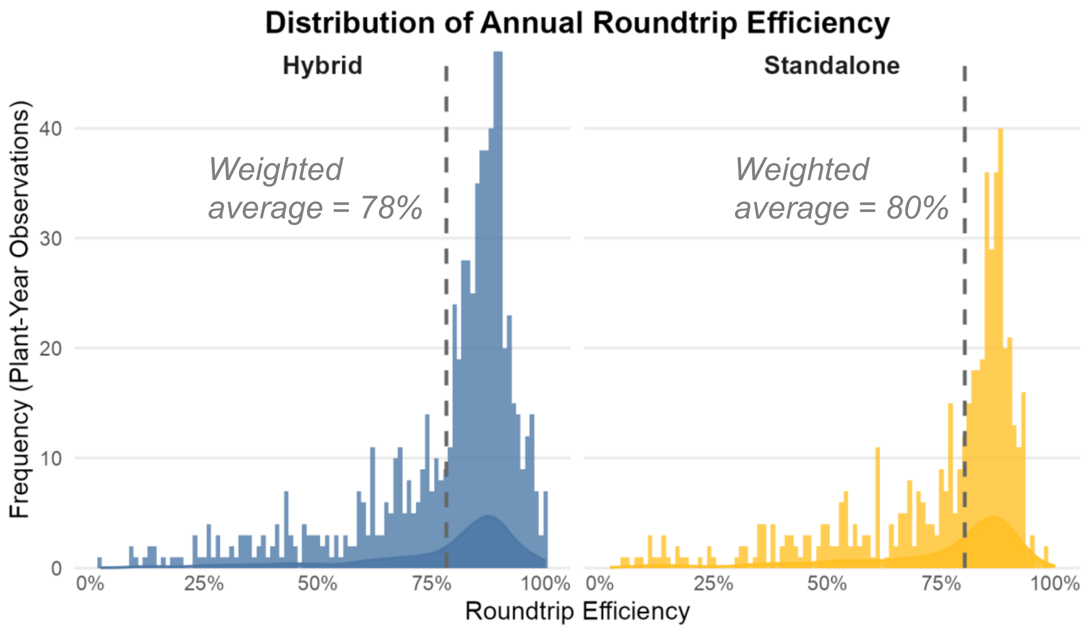
Battery roundtrip efficiency considering hybrid and standalone storage plants



Annual Additions

	2015	2016	2017	2018	2019	2020	2021	2022	2023
Hybrid Projects:	3	4	4	11	8	23	60	46	56
Hybrid Capacity (MW):	52	68	42	50	43	75	2,164	1,763	3,185
Standalone Projects:	5	6	5	14	16	4	11	27	49
Standalone Capacity (MW):	54	50	44	130	64	279	835	2,237	2,916

Annual storage capacity additions prior to 2021 were small



Annual efficiencies for most batteries range from 75% to 95%, with a **capacity-weighted average of 79%**, but a sizable portion operate below 50% efficiency in some years

Notes:
Year one roundtrip efficiency shows the efficiency in the first calendar year after commercial operation.
Hybrid capacity refers to storage capacity.
Batteries that do not report operational data to EIA 923 are excluded.

AC versus DC coupling for PV+Storage plants

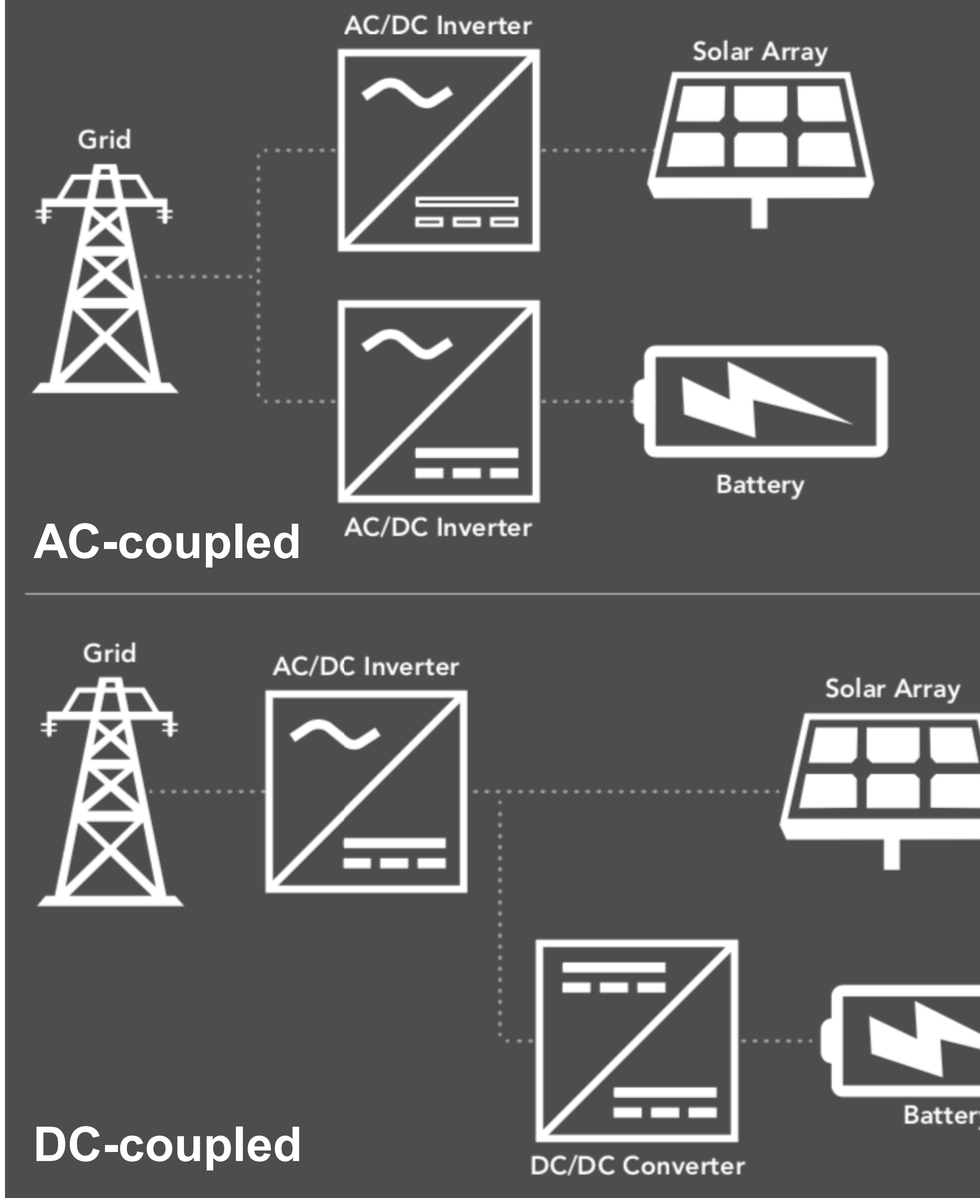
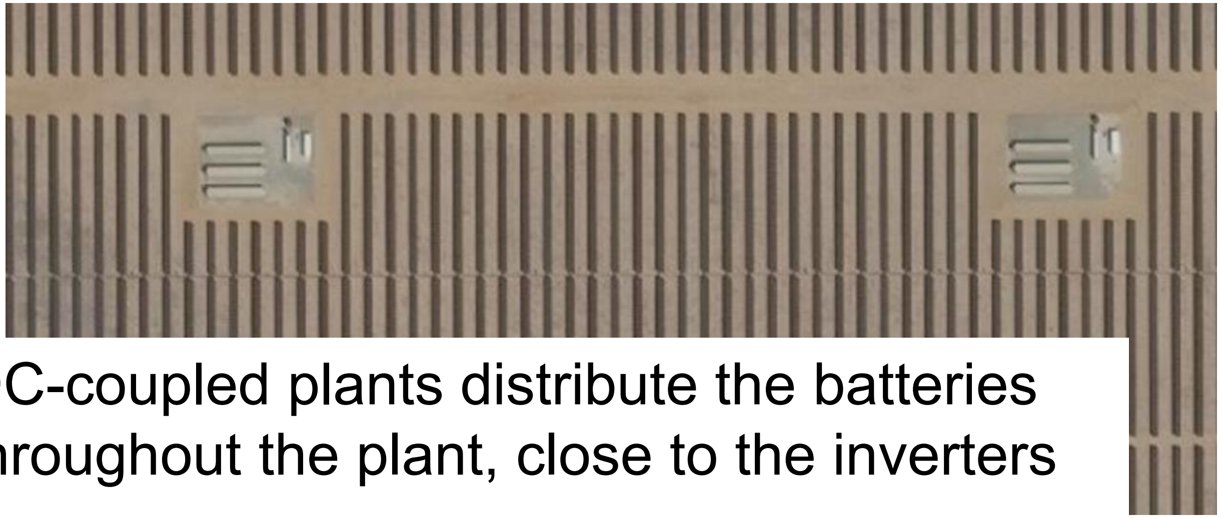


Figure credit: Verbruggen, S. 2019. "Go big, go DC: an in-depth look at DC-coupled solar-plus-storage." Energy Storage News, October 9, 2019, https://www.energy-storage.news/go-big-go-dc-an-in-depth-look-at-dc-coupled-solar-plus-storage/

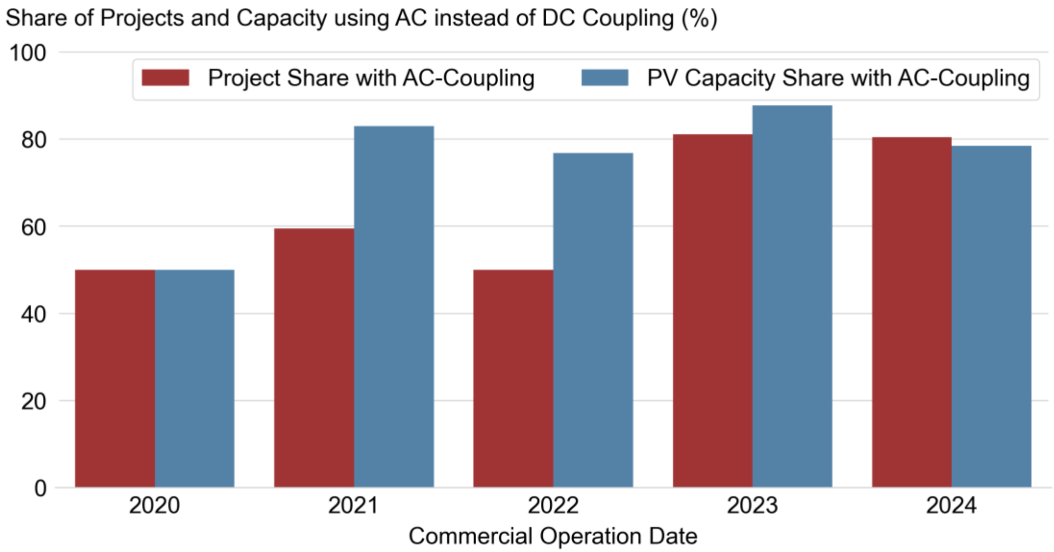
AC-coupled plants have a centralized battery yard

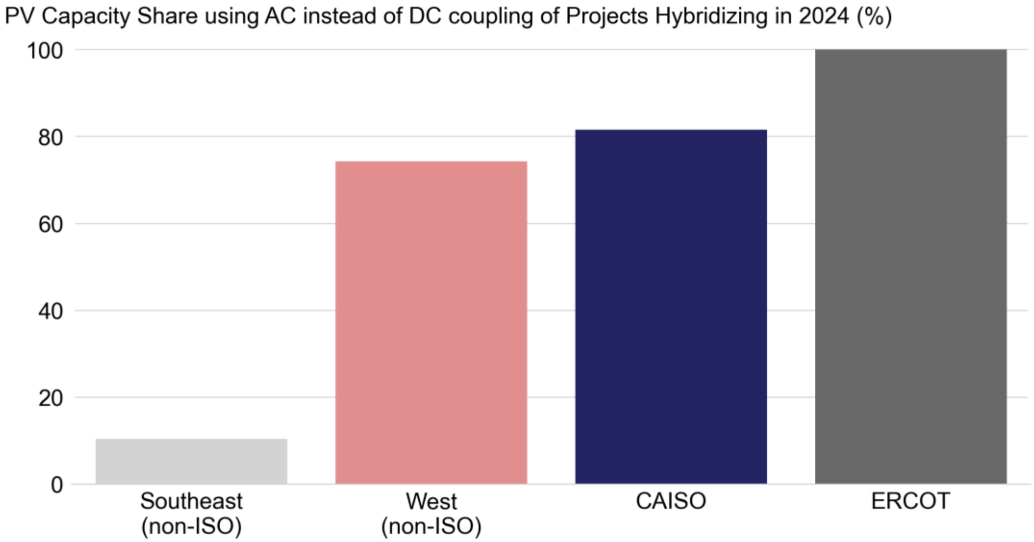
Photo credit: Goldman Sachs Renewable Power



DC-coupled plants distribute the batteries throughout the plant, close to the inverters

AC vs. DC coupling amongst utility-scale solar+storage project sample





Solar and batteries can be **AC-coupled**

- □ requiring separate dedicated inverters
- □ often featuring a centralized battery yard
- □ common among retrofits

or **DC-coupled**

- □ using a combined inverter setup but a separate DC/DC converter
- □ often having higher ILR as battery can capture clipped energy

Despite theoretical cost savings of DC-coupling, most of the recent projects use AC-coupling (except in Florida)

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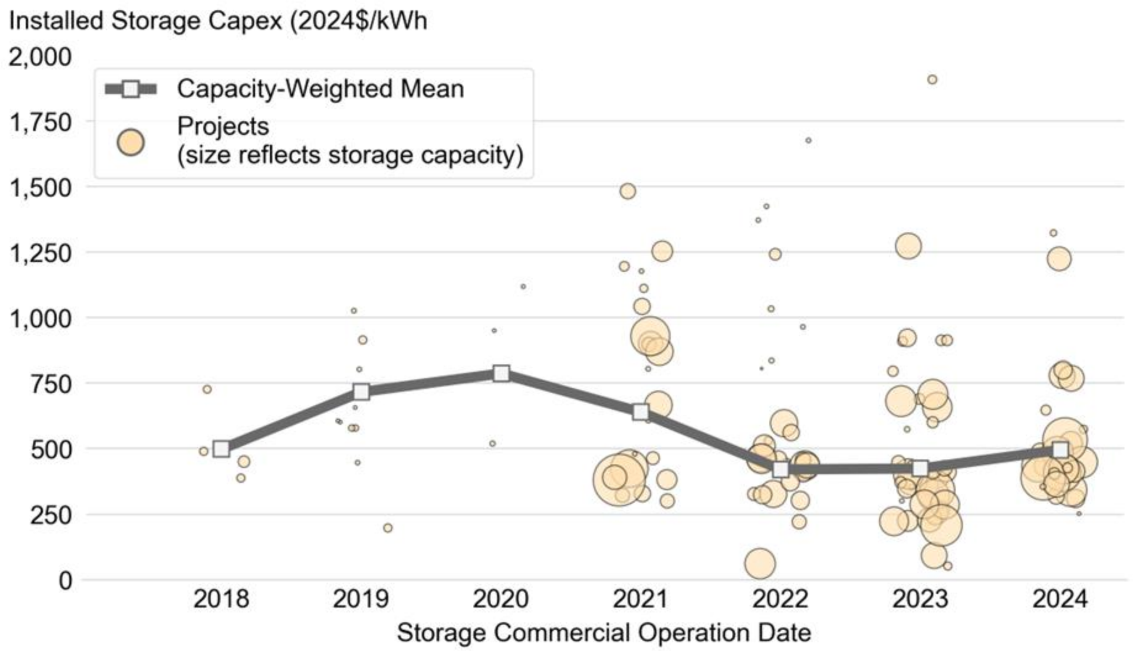
Hybrid Costs:
A sample of PV+battery plants with CapEx or PPA data

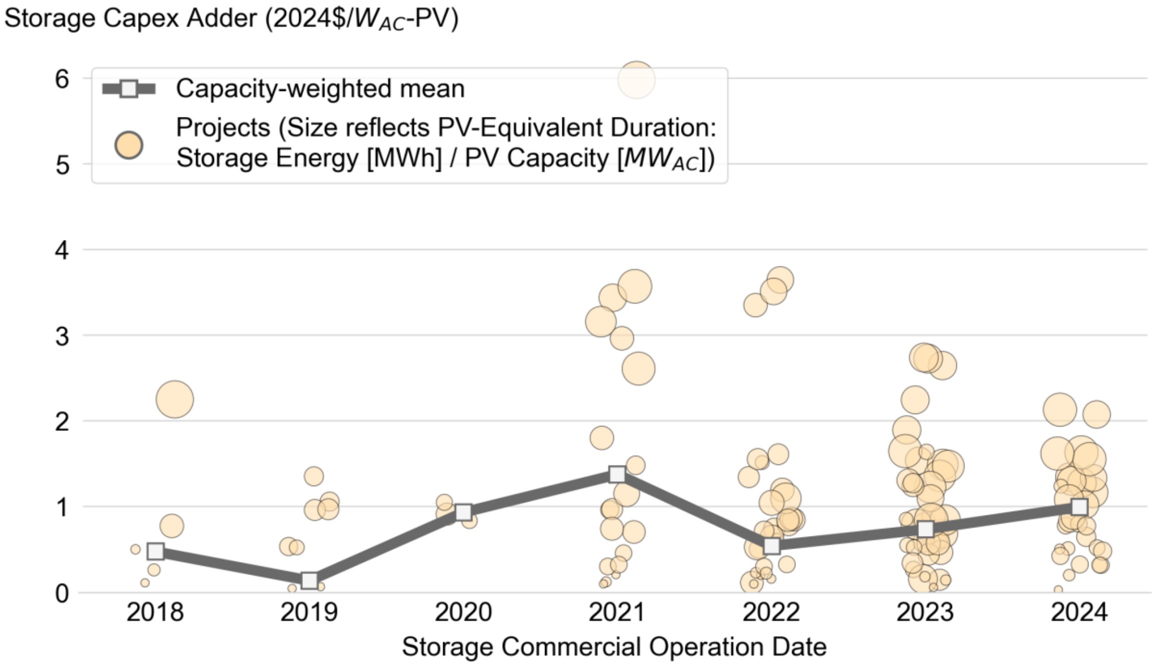
Installed storage CapEx and CapEx adder associated with PV+battery plants

Sample: 138 projects totaling 8.5 GW and 29.5 GWh of batteries



Capacity-weighted average costs increased from \$381/kWh in 2023 to \$458/kWh in 2024. Costs are lowest in MISO (\$351/kWh) and greatest in the non-ISO Southeast (\$473/kWh). Longer duration storage is cheaper on a per kWh basis, indicating economies of scale.

Sample: 131 projects totaling 8 GW and 27.4 GWh of batteries



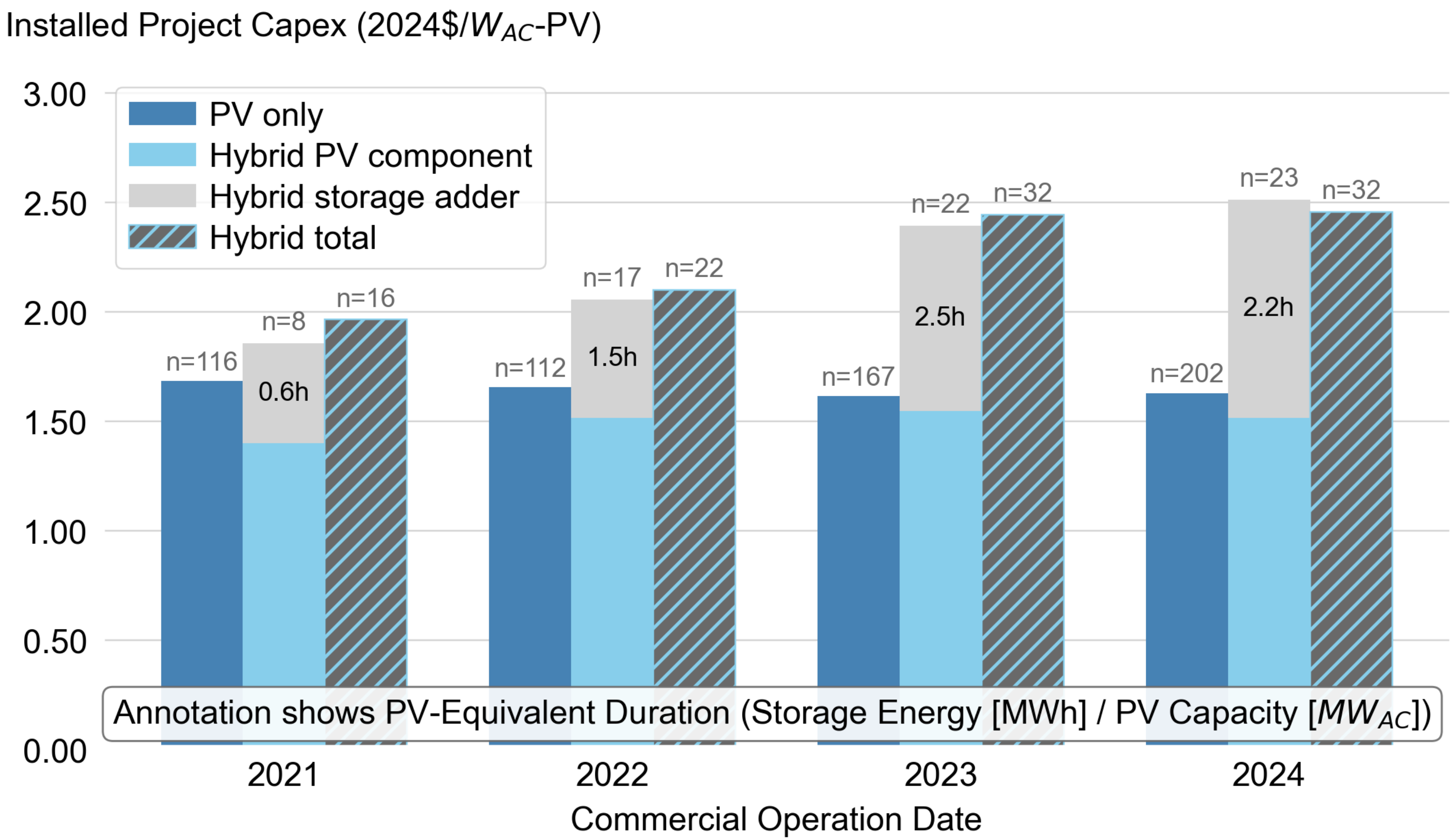
Storage CapEx adder describes the increased costs relative to the solar portion of the project and is denominated in PV capacity (W_{AC}). The costs have grown to \$1.00/$W_{AC\text{-}PV}$ in 2024, driven in part by longer duration and greater capacity ratios.

Note: Estimates for projects with 2024 COD are still preliminary both in scope and accuracy of individual data points and may not be representative of final numbers that will be published later by EIA.

Installed project CapEx between standalone PV and PV+storage hybrids

Sample: 597 PV-standalone projects (52.2 GW)

102 greenfield hybrid projects (12.4 GW_{AC} of PV, 6.6 GW / 23.1 GWh of batteries)



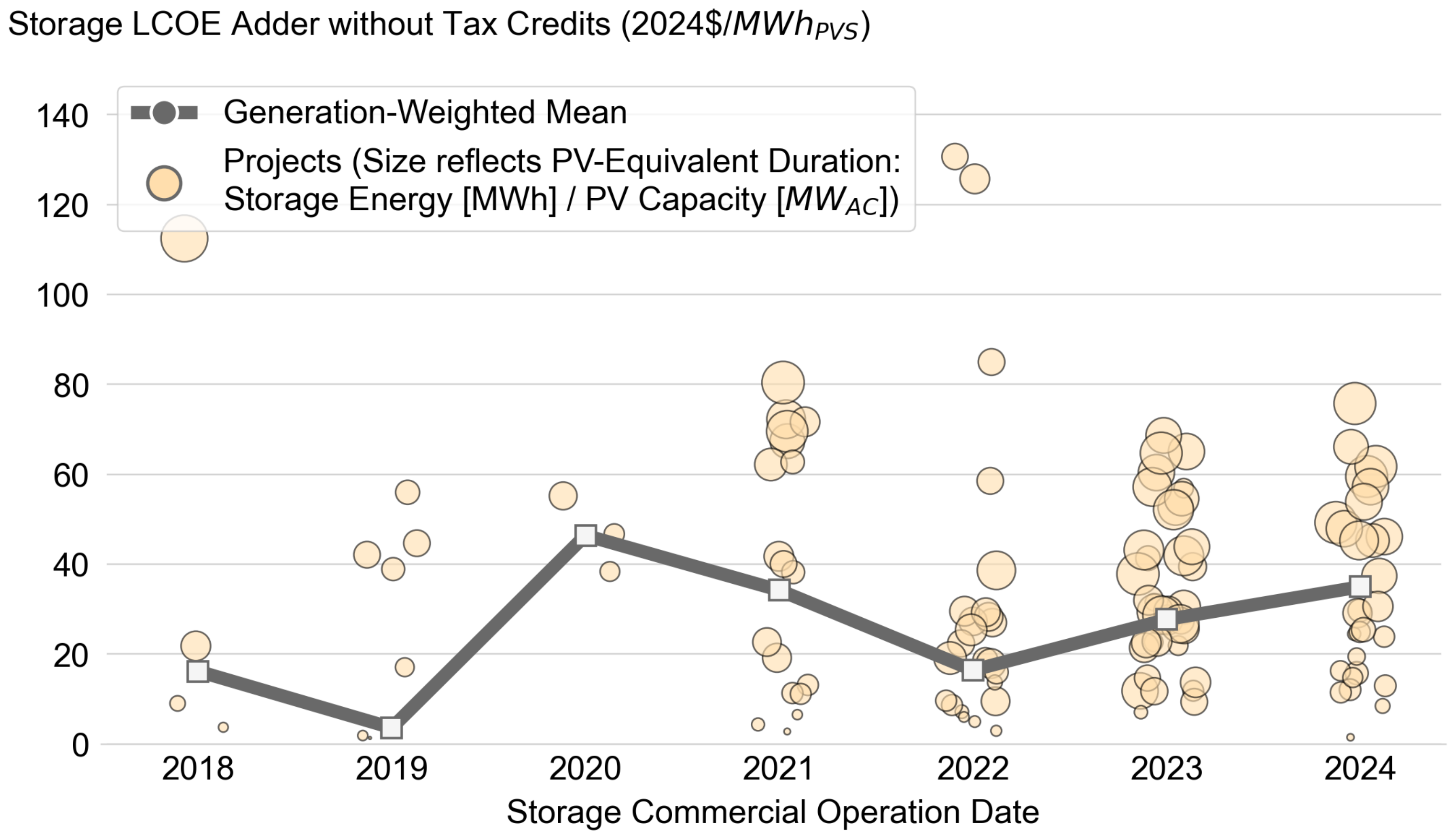
This slide compares costs of PV-standalone with greenfield PV+storage projects (excluding retrofits). Average cost of PV components are slightly lower for hybrid projects (driven by project size, geographies, or shared infrastructure with storage component).

For some hybrid projects we lack component-level costs and can only report total system costs (hatched). These sample differences explain slightly diverging trends (cost increase in center bars vs. stability in right-most bars for the years 2023 vs. 2024).

Note: Estimates for projects with 2024 COD are still preliminary both in scope and accuracy of individual data points and may not be representative of final numbers that will be published later by EIA.

Installed storage LCOE adder associated with PV+battery plants

Sample: 122 projects totaling 7.5 GW and 26.9 GWh of batteries (including storage retrofits)



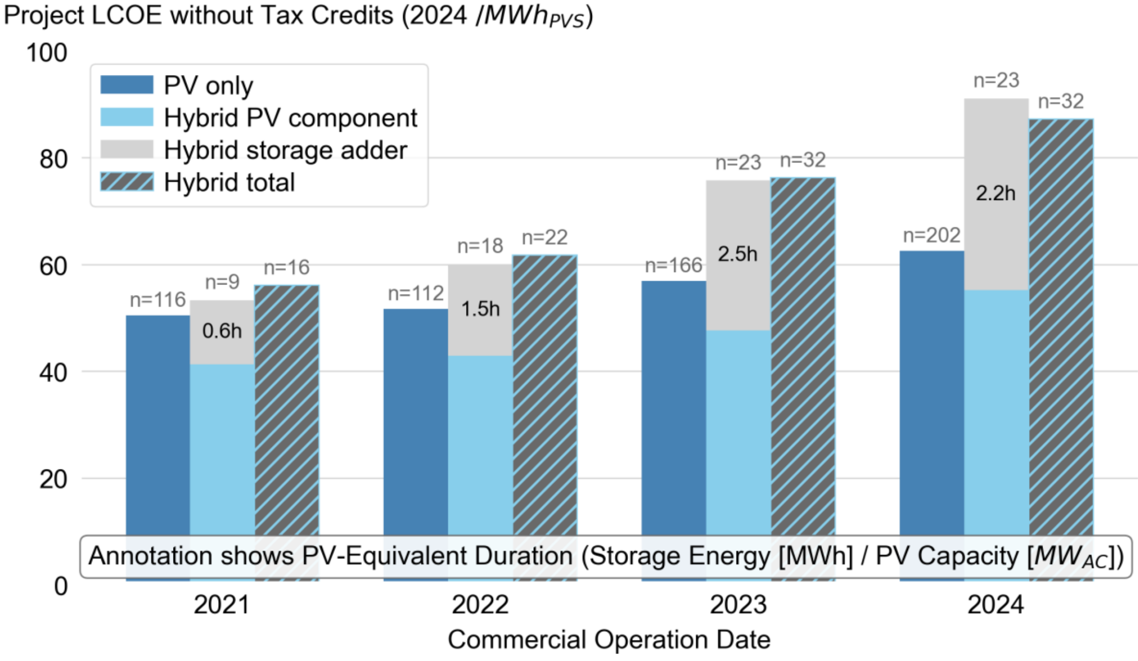
Battery LCOE adders (for both newly built co-located projects and retrofits to existing PV projects) have grown since 2022, driven by larger battery sizes and increased financing costs.

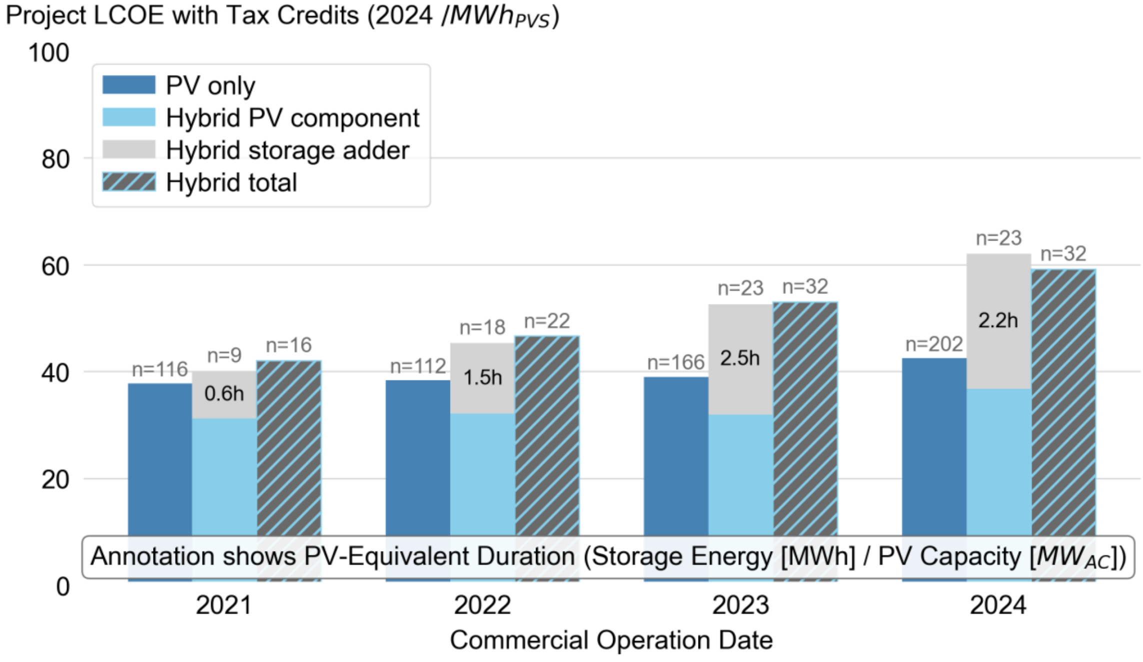
In 2024 the adder was \$35/MWh_{PVS} before tax credits (shown in graph) and \$25/MWh_{PVS} after tax credits.

Note: LCOE estimates shown in graph here do not include tax credit benefits. Findings may shift as final EIA Capex and project-specific performance data become available.

Installed project LCOE between standalone PV and PV+storage hybrids

Sample: 102 greenfield plants totaling 12.4 GW_{AC} of PV and 6.6 GW / 23.2 GWh of batteries (excluding retrofits)



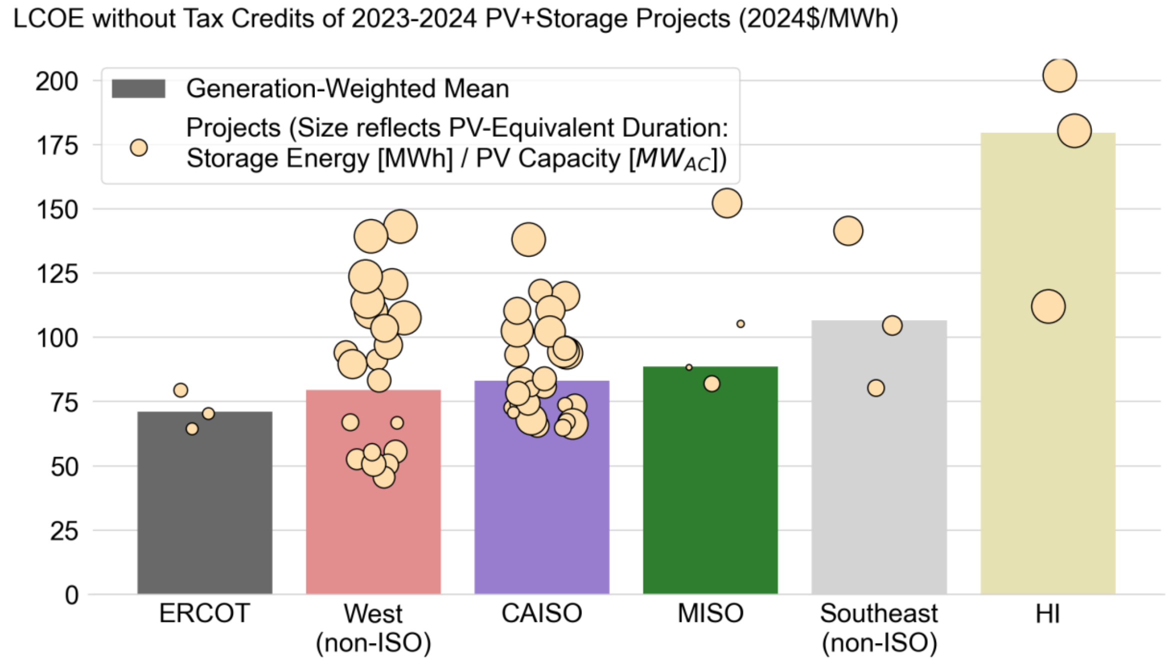


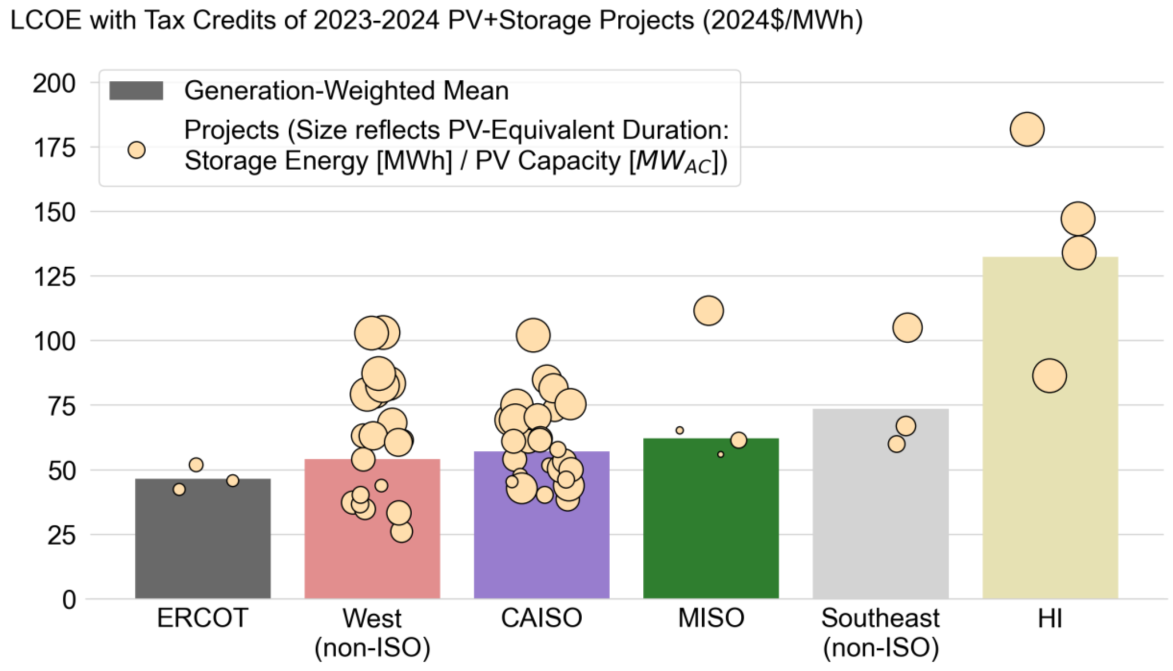
This sample excludes projects with storage retrofits. PV component LCOE of a co-located project is lower than PV-standalone as hybrids are usually in sunnier regions. The storage LCOE adder is $36/MWh, the total LCOE of hybrids is $87/MWh without tax credits.

Accounting for tax credits, the battery LCOE adder is $25/MWh, the total LCOE of hybrids is $59/MWh in 2024.

Installed project LCOE of PV+storage hybrids by region

Sample: 63 greenfield plants totaling 9.4 GW_{AC} of PV and 5.5 GW / 19.7 GWh of batteries (excluding retrofits)





Average PV+battery LCOE in ERCOT was $71/MWh compared to $180/MWh in Hawaii in 2023/2024 (HI storage is sized to 100% PV capacity with 4h duration).

After accounting for available tax credits (excluding potential domestic content bonuses), average LCOE fell to a range $47/MWh to $132/MWh.

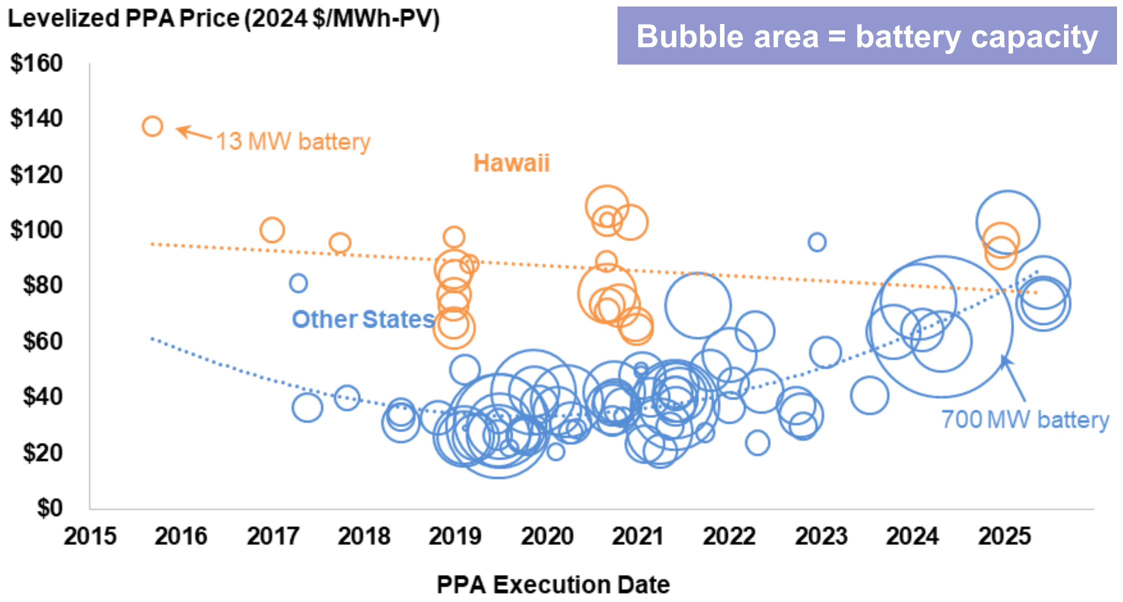
Sample for PV+Storage PPAs

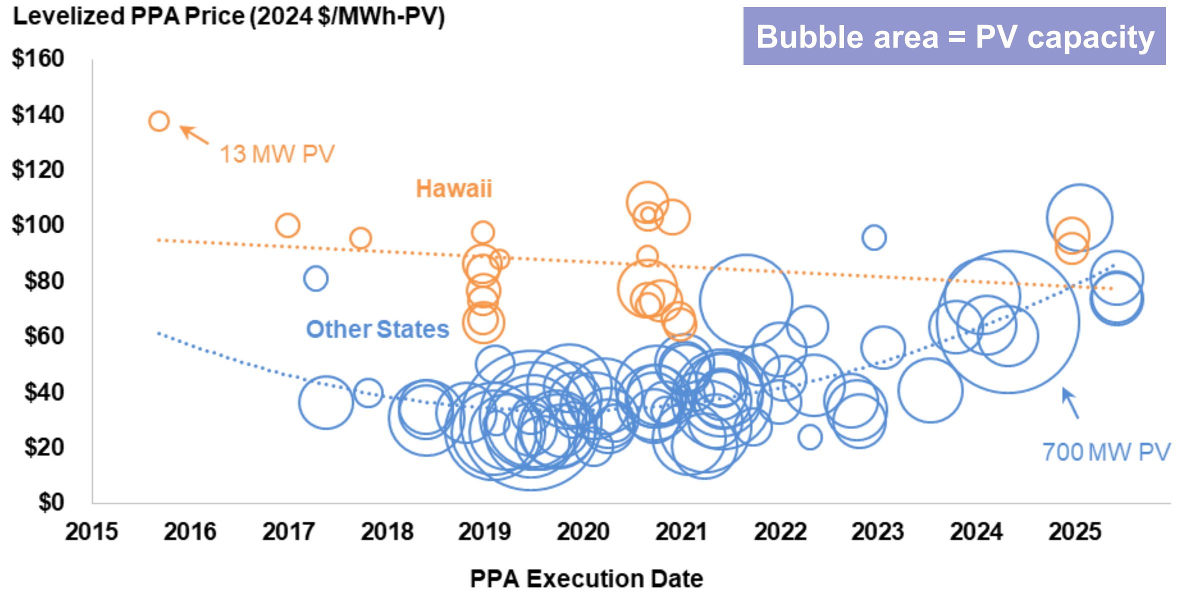
113 PPAs in 10 states totaling 13.9 GW_{AC} of PV and 8.5 GW_{AC} / 33.7 GWh of batteries

		Total Capacity (MW-AC)		Average Battery:PV Capacity	Battery Storage	
State	# of plants	PV	Battery		Avg Duration	Total MWh
AZ	8	691	568	75%	3.9	2,184
CA	39	4,793	2,825	56%	4.0	11,271
CO	3	595	226	28%	3.3	902
FL	1	50	12	24%	2.0	24
GA	2	409	80	20%	2.0	160
HI	24	869	869	100%	4.2	3,565
NM	16	2,290	1,223	59%	4.0	4,890
NV	17	3,922	2,651	62%	4.0	10,574
NY	2	213	10	5%	4.0	40
OR	1	50	30	60%	4.0	120
Total	113	13,880	8,493	65%	4.0	33,730

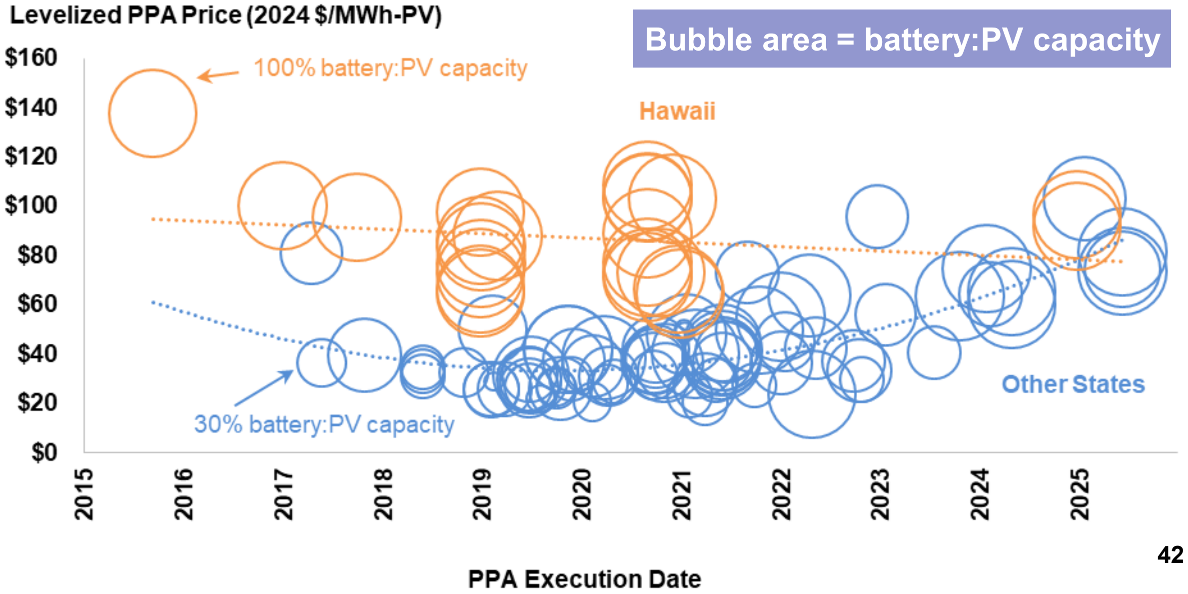
- Sample dominated by CA, NV, NM, and HI
- 11 plants are battery retrofits to pre-existing PV plants (9 in CA, 2 in NM)

PPA prices for PV+battery plants over time



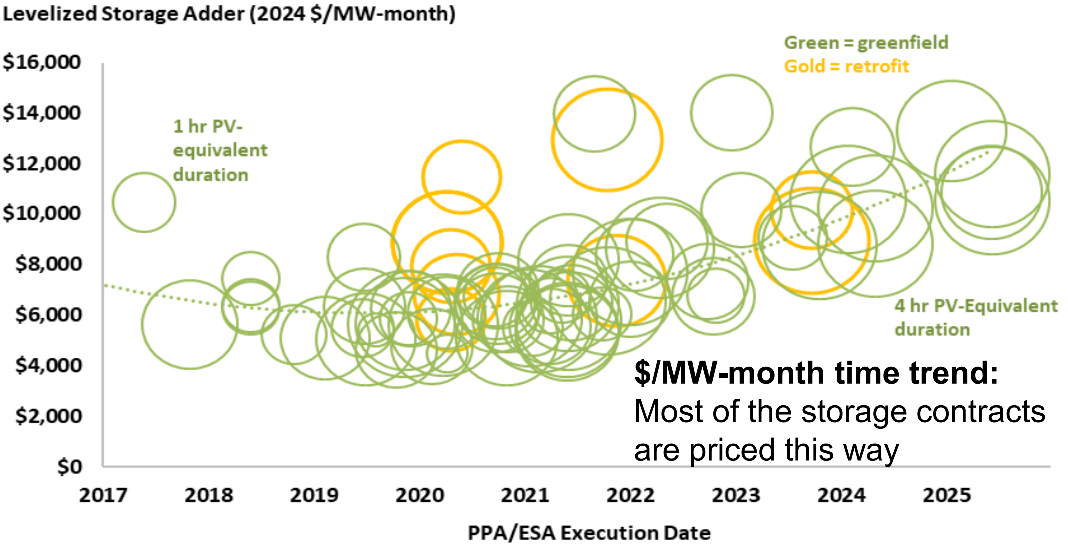


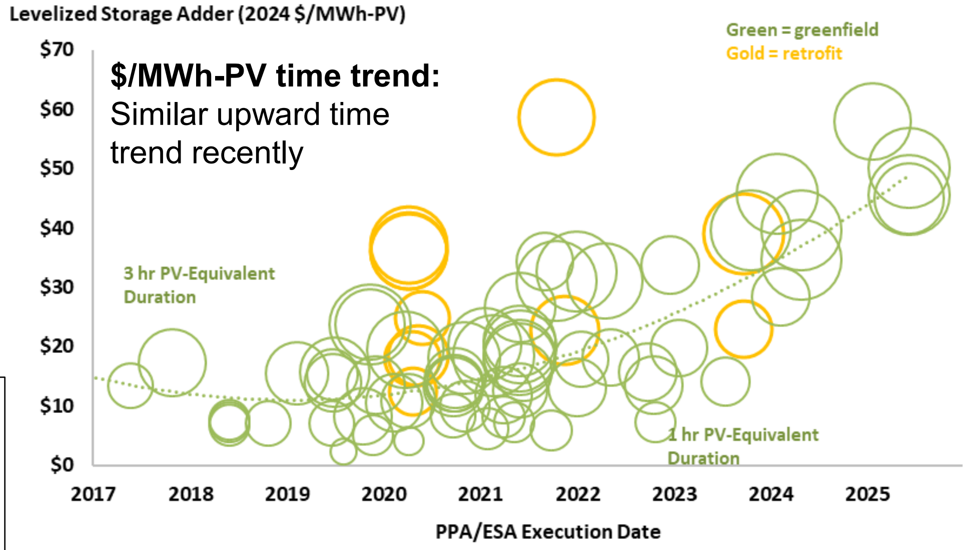
- All 3 graphs show the same data from a sub-sample of 102 plants (retrofits not included); the only difference is what the bubble size represents
  - ➢ Hawaii (orange): 24 plants, 0.9 GW_{AC} PV, 0.9 GW_{AC} battery
  - ➢ Other States (blue): 78 plants, 11.3 GW_{AC} PV, 6.5 GW_{AC} battery
- Battery:PV capacity ratio always at 100% in HI, but is often lower on the mainland from 2019-2023, though has increased in 2024 and 2025 (lower right graph)
- Storage duration ranges from 2-8 hours; 89 of the 102 plants have 4-hr duration (other 13 are 5x2 hr, 1x2.5, 1x3, 1x3.7, 4x5, & 1x8 hr)



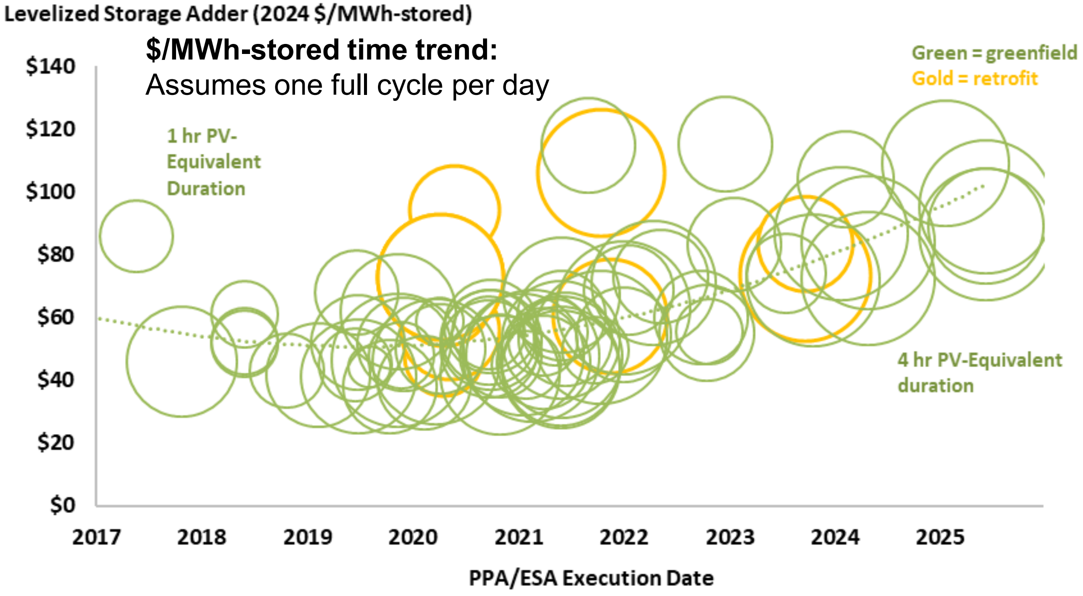
Levelized storage adder for a subsample of the PPAs overtime

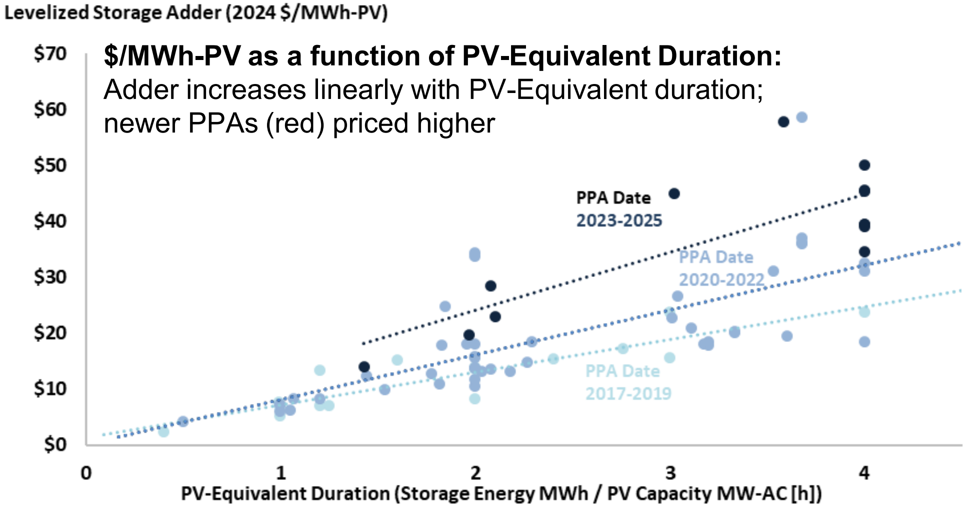
Graphs show adders from 74 PV hybrids in CA (38), NV (14), NM (16), AZ (5) & OR (1) totaling 6.6 GW_{AC} of batteries, all 4-hr duration





Bubble size corresponds to PV-Equivalent Duration (hr) for all but bottom-right chart [Storage MWh / PV Capacity MW-AC]

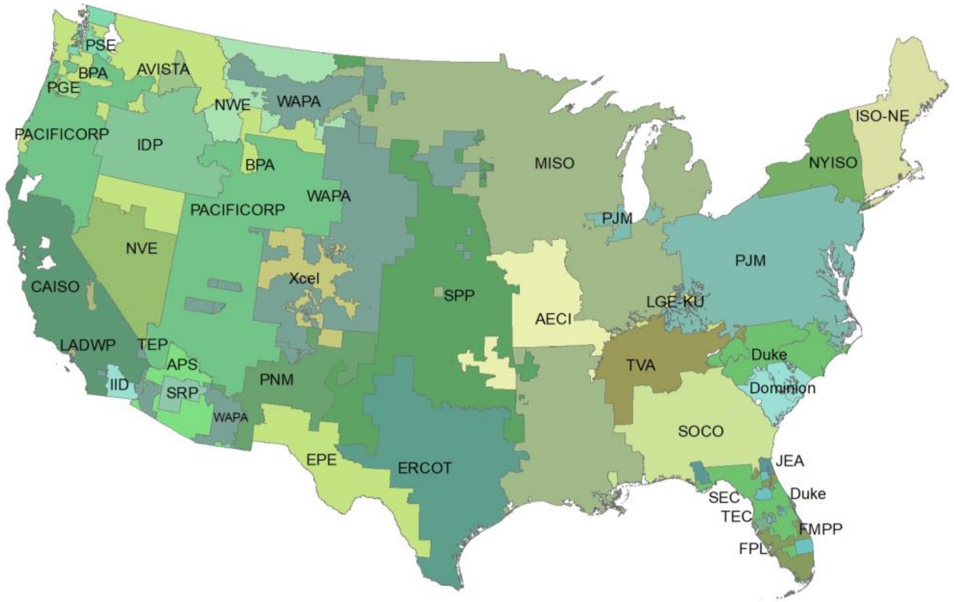




Hybrid Pipeline:
Hybrid plants in interconnection queues at the end of 2024

Methods and data sources for interconnection queue data sample (same as slide 6)

- Data collection led by Interconnection.fyi
- Data collected from interconnection queues for 7 ISOs / RTOs and 49 non-ISO balancing areas (including utilities and Power Marketing Administrations), which collectively represent ~97% of currently installed U.S. electric generating capacity
  - Includes all plants connecting to bulk power system (not distribution connections) in queues through the end of 2024
  - Full sample includes 10,303 “active” plants, of which 2,396 (23%) are in a hybrid or co-located configuration
  - Hybrids represent 495 GW (36%) of active generation capacity in queues, and 424 GW (48%) of active storage capacity in queues
- Hybrid / co-located plants identified using two methods:
  - “Generator Type” includes multiple types for a single queue entry; OR,
  - Two or more queue entries (of different generator types) with the same interconnection point and sponsor, queue date, ID number, and/or COD
- Storage capacity for hybrids (distinct from generator capacity) was provided in ~26% of proposed hybrid plants
  - For the remainder, storage capacity was estimated using known storage:generator ratios from other plants

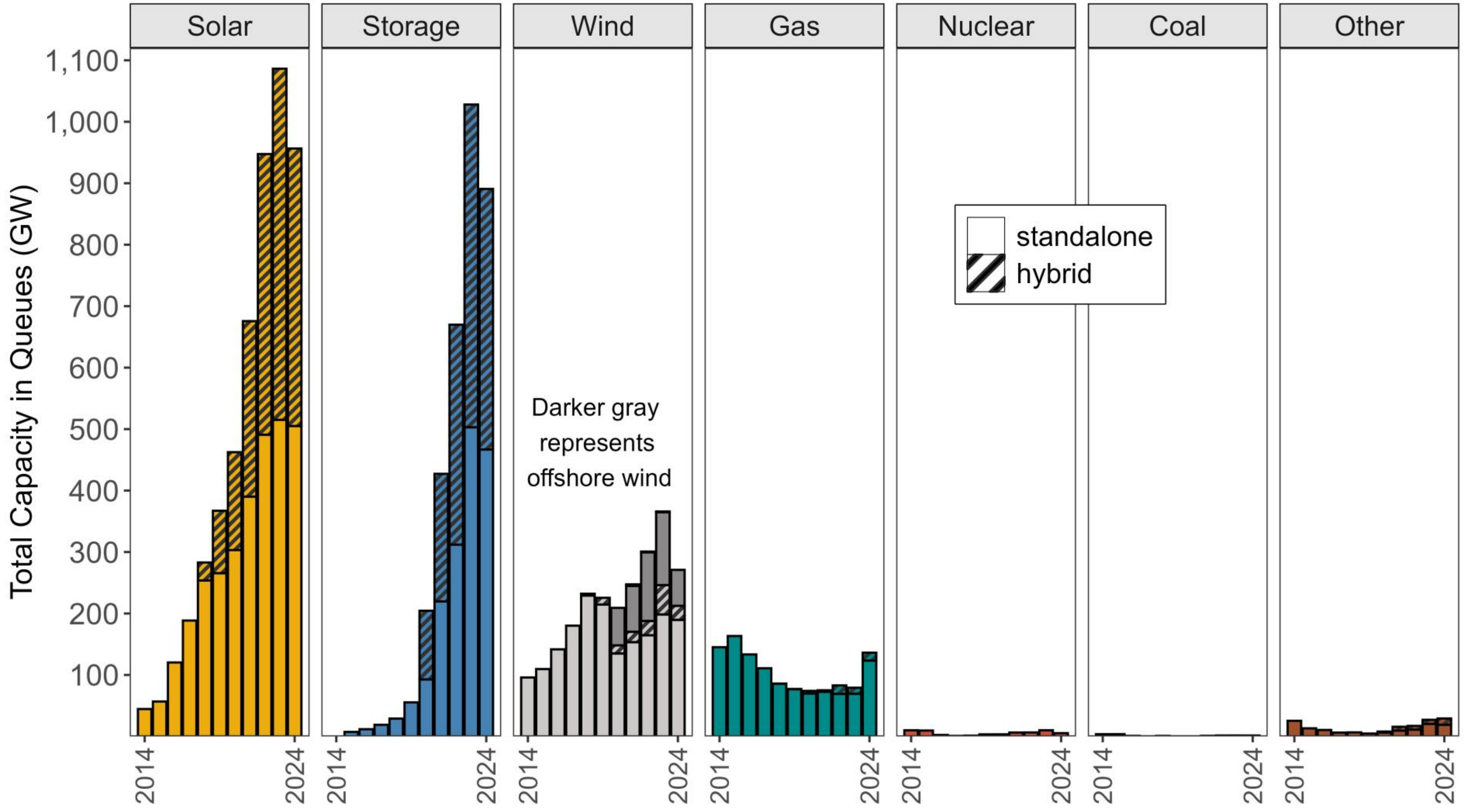


Coverage area of entities for which data was collected
Data source: Homeland Infrastructure Foundation-Level Data (HIFLD)
Note that service areas can overlap
No data collected for Hawaii or Alaska

For more information, see LBNL’s annual interconnection queue data compilation and analysis at emp.lbl.gov/queues

Note that being in an interconnection queue *does not guarantee* ultimate construction. Most plants in the queues are not built.

Overall, active capacity seeking interconnection decreased by 12% from 2023 to 2024, but natural gas increased 72%



- “Wind” includes both onshore and offshore
- “Other” includes
  - Hydropower
  - Geothermal
  - Biomass/biofuel
  - Landfill gas
  - Solar thermal
  - Oil/diesel
- “Storage” is primarily (99%) battery, but also includes pumped storage hydro, compressed air, gravity rail, and hydrogen.

See https://emp.lbl.gov/queues to access an interactive data visualization tool.

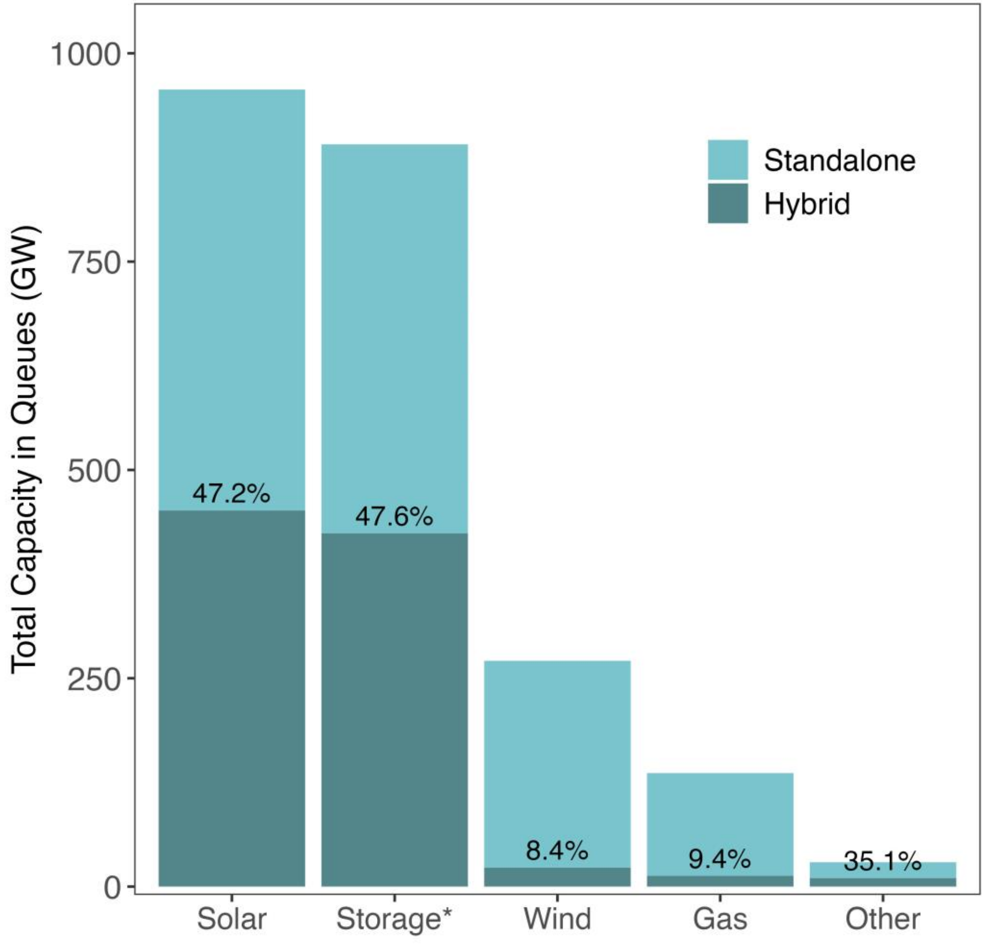
Notes: (1) Hybrid storage capacity is estimated for some projects using storage:generator ratios from projects that provide separate capacity data, and that value is only included starting in 2020. Storage duration is not provided in interconnection queue data. (2) Wind capacity includes onshore and offshore for all years, but offshore is only broken out starting in 2020. (3) Hybrid generation capacity is included in all applicable generator categories. (4) Not all of this capacity will be built.

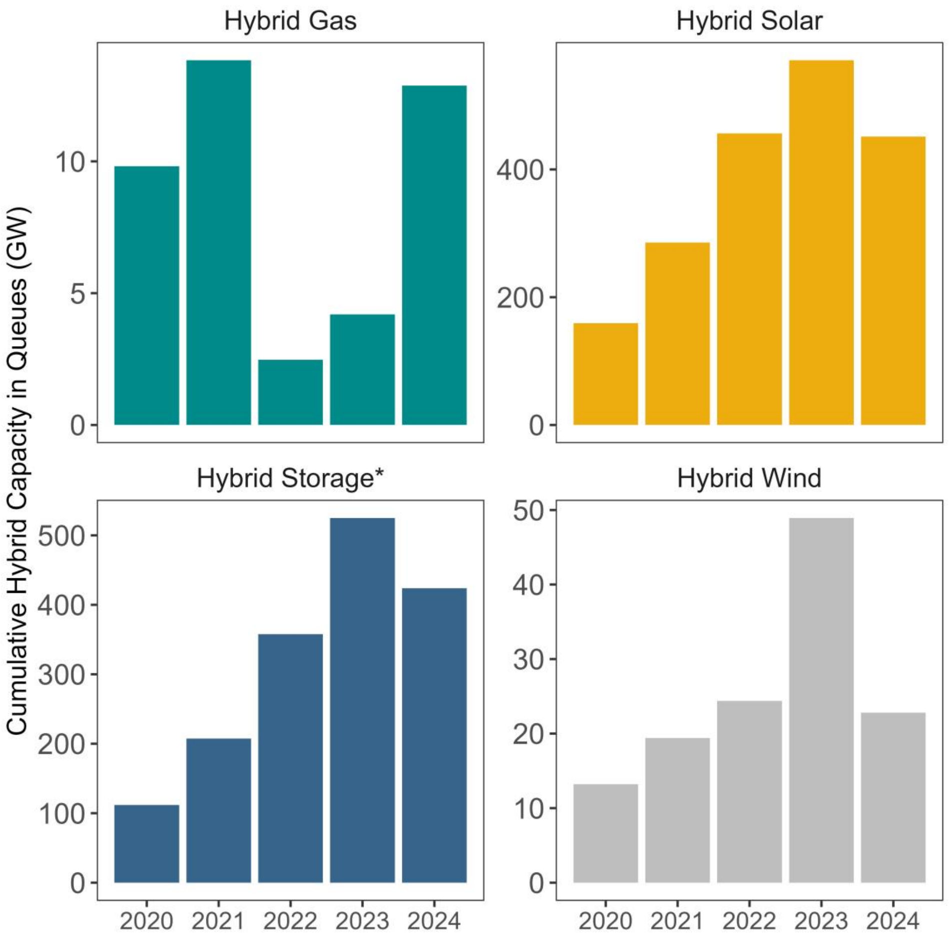
Numerous hybrid configurations exist in the queues, but Solar+Battery has largest number of proposed plants and total capacity

Hybrid Type	Number of Plants	Generator(s) Capacity (MW)
Solar+Battery	2,178	432,223
Other+Battery	62	8,720
Wind+Battery	51	17,423
Solar+Wind+Battery	37	15,754
Gas+Battery	20	6,871
Solar+Other	17	2,627
Gas+Other	7	4,491
Solar+Wind	6	1,344
Gas+Oil	4	1,031
Solar+Gas+Battery	4	2,223
Wind+Other	4	1,409
Geothermal+Battery	1	9
Hydro+Battery	1	7
Solar+Gas	1	200
Solar+Geothermal	1	1
Solar+Hydro	1	4
Solar+Other+Battery	1	250
Hybrid Total	**2,396**	**494,588**
Non-Hybrid Total	**8,142**	**1,372,483**

- 91% of all hybrid plants are Solar+Battery, representing 87% of all known hybrid generation capacity in the queues
- The next two largest configurations, Wind+Battery & Solar+Wind+Battery, account for ~4% and ~3% of known hybrid capacity in the queues, respectively
- There were 12% fewer proposed hybrid plants – representing 26% less generating capacity – in the queues at the end of 2024 compared to 2023
  - This decrease was primarily driven by requests withdrawn from CAISO’s Cluster 15
- By comparison, storage capacity in hybrid configurations in the queues decreased by 19% year-over-year (storage capacity in standalone configuration went down by 5%)

Hybrids comprise 47% of active solar capacity (452 GW), 48% of storage (424 GW), 8% of wind (23 GW), and 9% of natural gas (13 GW)

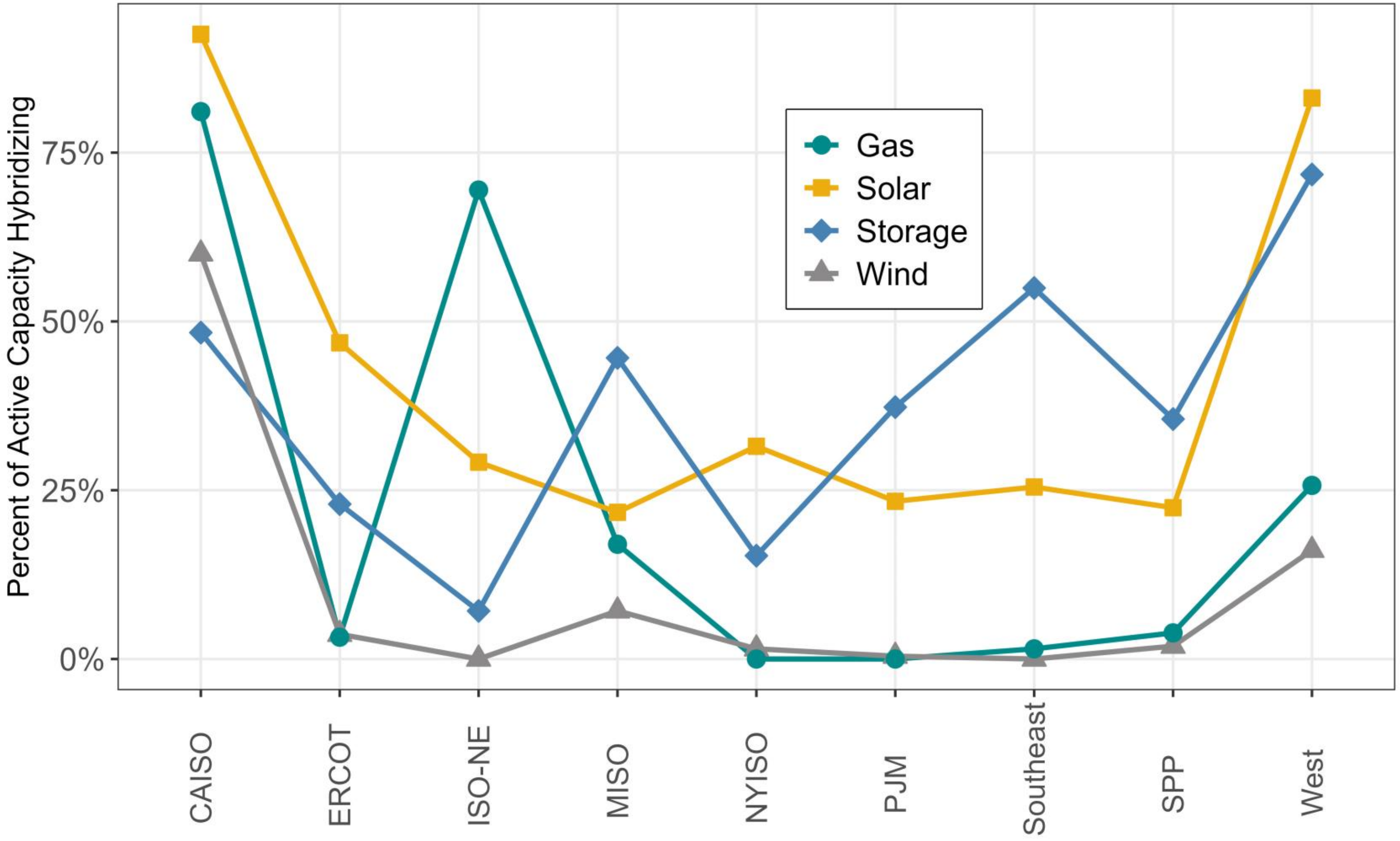




Hybrid storage capacity is estimated using storage:generator ratios from projects that provide separate capacity data. ~93% of the hybrid storage capacity in the queues is in solar+battery configurations.

*Notes: (1) Some hybrids shown may represent storage capacity added to existing generation; only the net increase in capacity is shown; (2) Capacity for hybrid plants (e.g., Wind+Solar+Storage) is captured in each generator category (i.e., the solar component shows up in hybrid solar, storage in hybrid storage), presuming the capacity is known for each type. In other words, hybrid storage includes **only** the storage capacity from proposed hybrid plants that include storage. Similar for other categories in that they only include the gas, solar, wind capacity of the hybrid plant in their respective charts.*

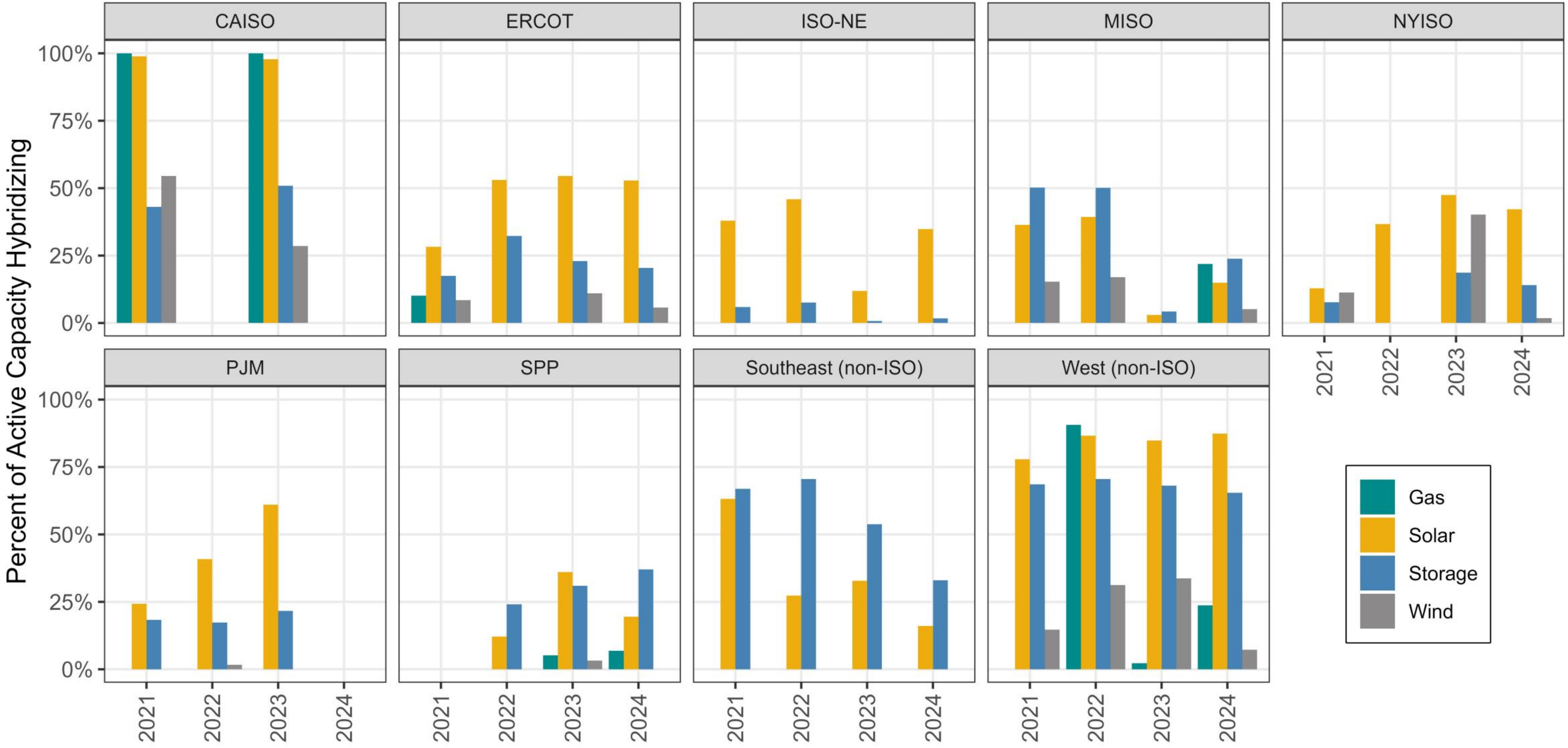
Hybrids comprise a major fraction of all proposed solar plants in multiple regions; wind and gas hybrids are less common overall but still a large proportion in CAISO



- **Solar** hybridization relative to total amount of solar in each queue is highest in CAISO (93%) and non-ISO West (83%), and is above 20% in all regions
- **Wind** hybridization relative to total amount of wind in each queue is highest in CAISO (60%) and the non-ISO West (16%), and is less than 10% in all other regions
- **Gas** hybridization relative to total amount of gas in each queue is highest in CAISO (81%) and ISO-NE (69%), and is less than 30% in all other regions

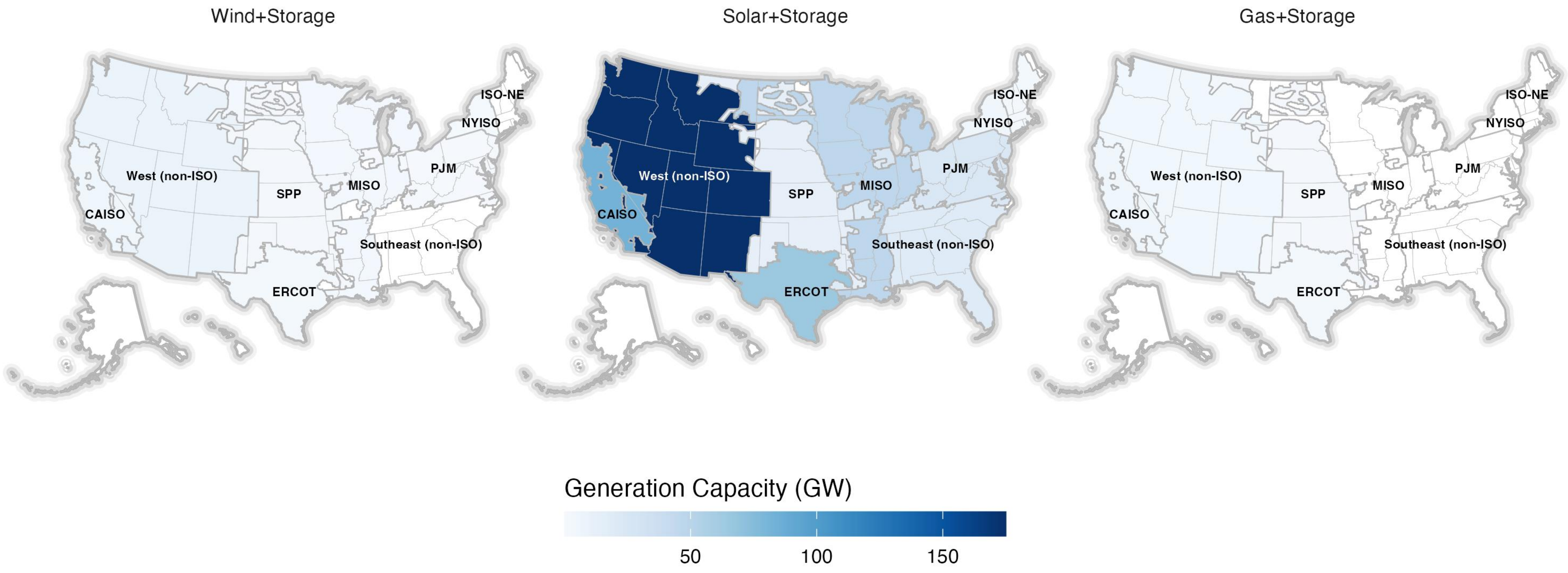
**Hybrid storage capacity is estimated for some projects. Hybrid percentages in jurisdictions containing a number of unknown / unclassified hybrid plants are likely undercounted*

The percentage of new interconnection requests electing a hybrid configuration has varied somewhat over the last 4 years with no predominant trend



**CAISO paused their queue in 2022 and 2024, MISO paused their queue in 2023, and data are unavailable in SPP for 2021; PJM has a very limited sample of new requests in 2023 and none in 2024 due to queue processing pauses/delays.*

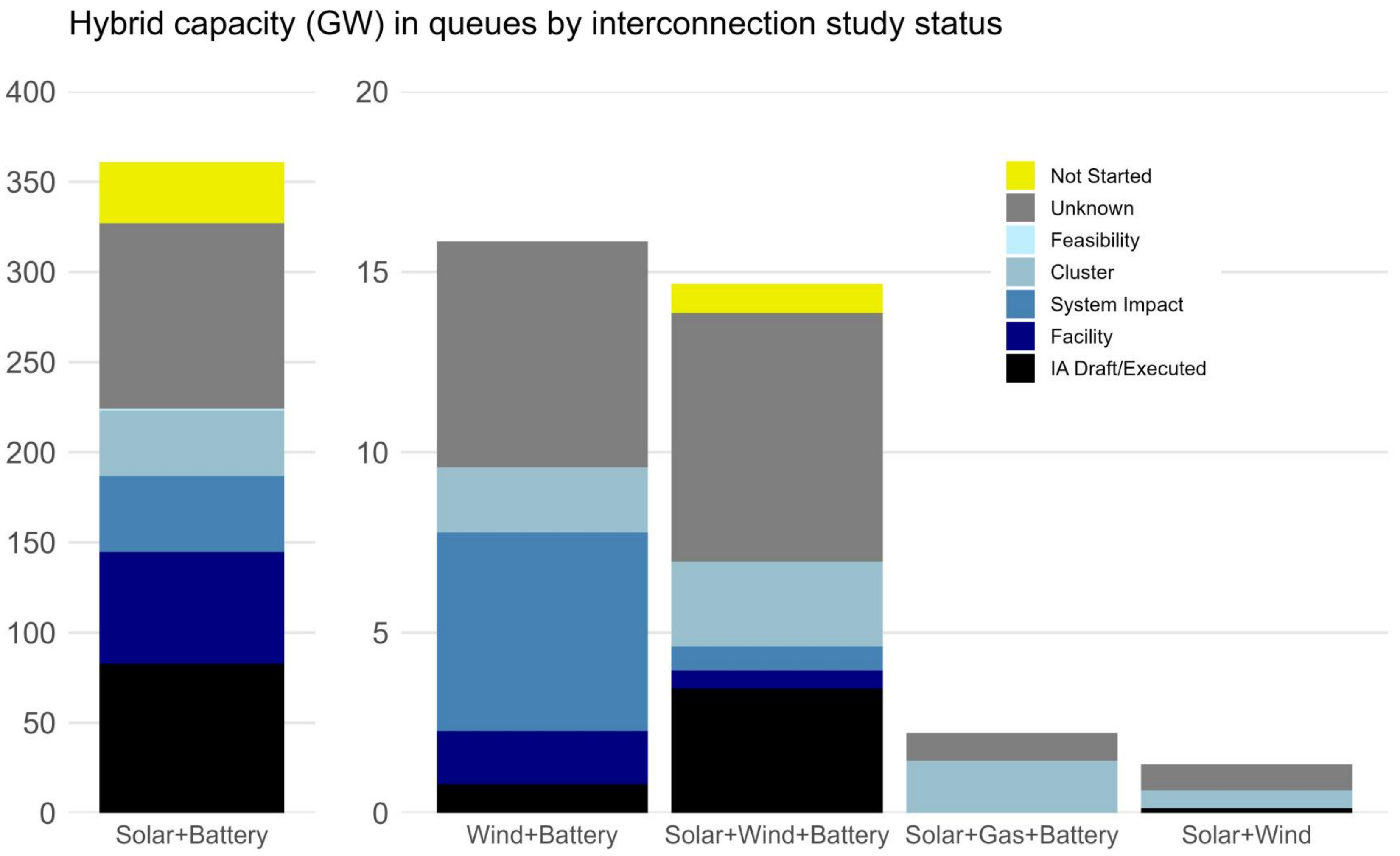
Solar+Storage is dominant hybrid type in queues, with over 15x the proposed capacity of Wind+Storage

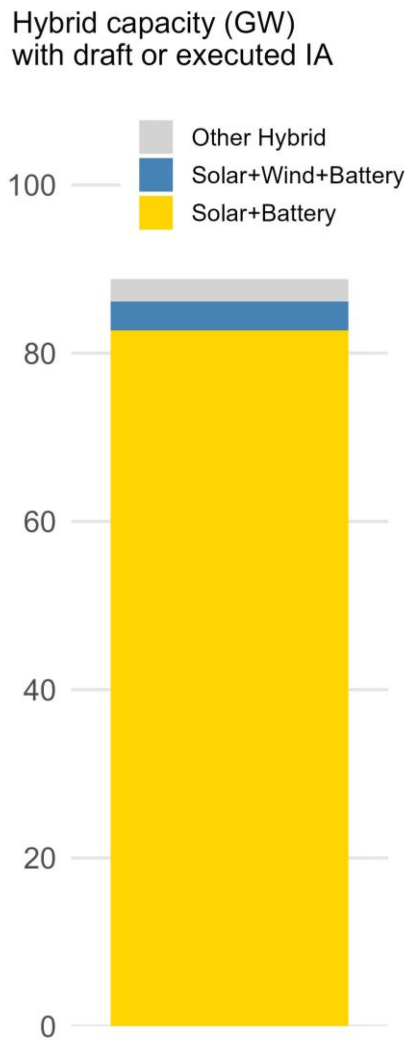


For hybrid/co-located plants, the generation capacity is depicted.

Note: Not all of this capacity will be built

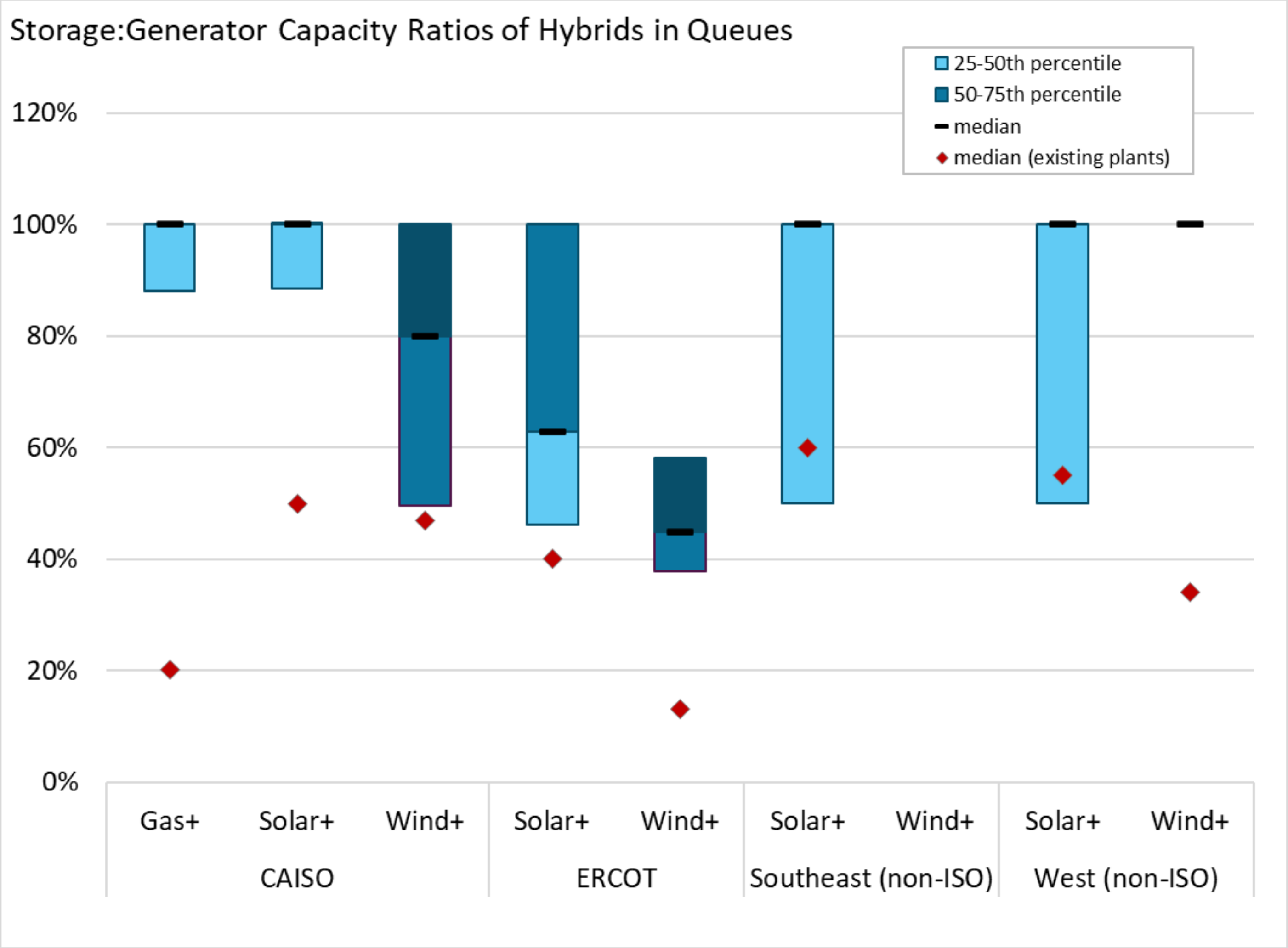
The majority of hybrid (generator) capacity in the queues is in earlier study phases, but 18% (89 GW) has a draft or executed interconnection agreement (IA)





Note: Even after signing an interconnection agreement, many requests ultimately withdraw. Historically, 43% of capacity withdrew after signing an IA. See emp.lbl.gov/queues for more detail.

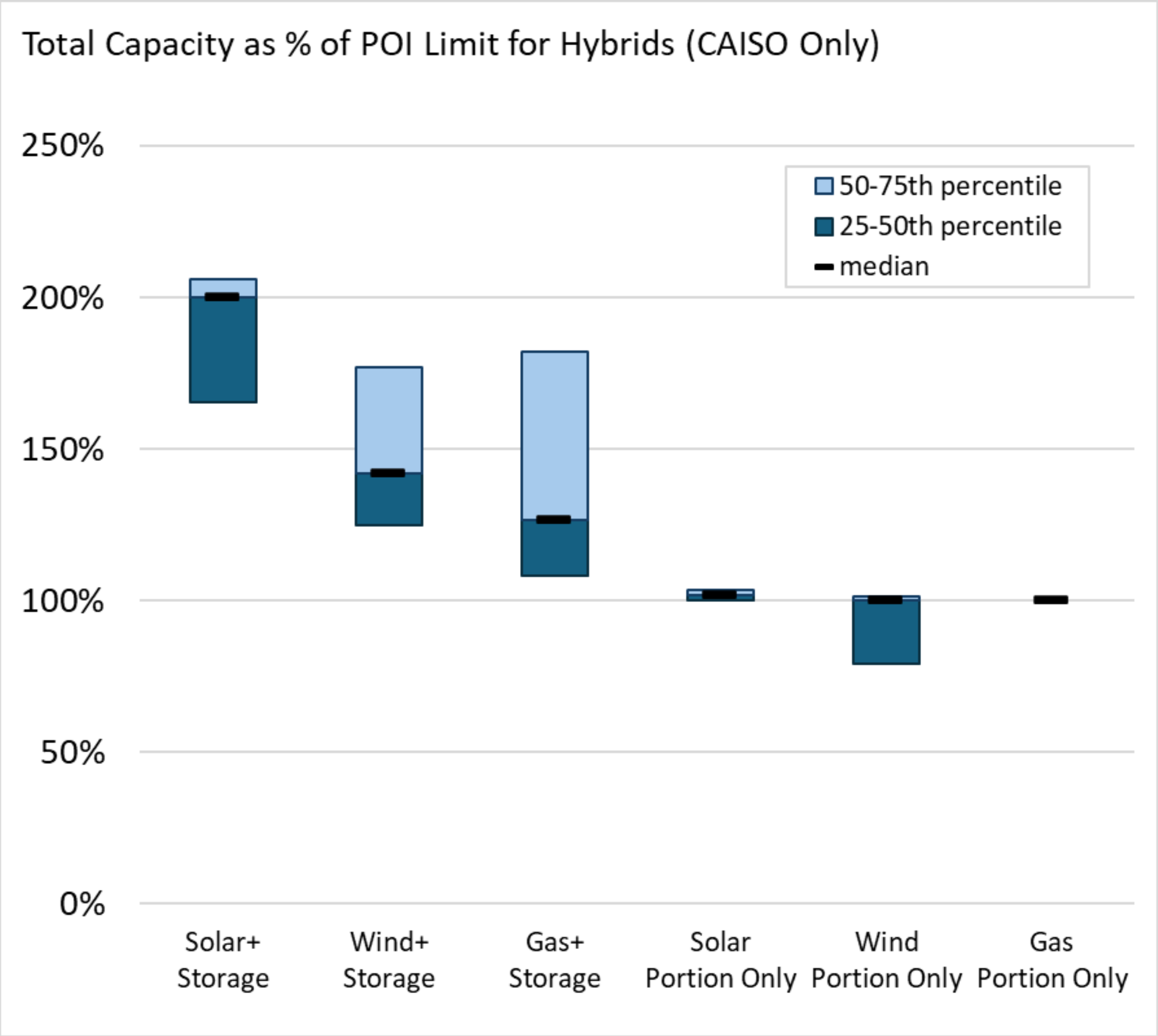
Proposed hybrid plants typically feature a higher storage contribution than existing hybrids



- Storage capacity for hybrid plants was provided in a subset of queues. Where available, we calculated the ratio of storage capacity to generator capacity
- Median storage:generator capacity ratio for solar+storage is higher than for wind+storage in areas where solar penetration is higher (e.g., CAISO)
- The ratios shown here for *proposed* plants are higher than those for *existing* plants of the same type in most cases (see red diamonds in plot)

Note: This chart only includes interconnection requests that provide both generator and storage capacity. Many requests only include the generator capacity, so those cannot be included. For example, Gas+Battery requests exist in the West, but their storage:generator ratio could not be calculated.

Solar+storage, wind+storage, and gas+storage plants in CAISO base POI limits on generator capacity; generator portion of hybrids in the queue are equivalent to their POI limits



- Point of interconnection (POI) capacity limits alongside separate capacity for generators and storage were only provided in CAISO's queue
- For solar+storage plants, the median combined (solar+storage) capacity is 200% of the POI limit
- For wind+storage plants, the median combined (wind+storage) capacity is 142% of the POI limit
- For gas+storage plants, the median combined (gas+storage) capacity is 126% of the POI limit
- The generator capacity alone equals or exceeds the POI limit in 92%, 73%, and 67% of solar, wind, and gas hybrid plants, respectively
- These values suggest that these plants expect to dispatch the battery only when the generator is operating at less than full output

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The data file and visualizations can be found at:

- https://emp.lbl.gov/hybrid

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Funded by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy under Contract No. DE-AC02-05CH11231. The views and opinions of the authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, or The Regents of the University of California.

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