Title

Hybrid Power Plants: Status of Operating and Proposed Plants, 2024 Edition

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Hybrid Power Plants

Status of Operating and Proposed Plants

2024 Edition

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Lawrence Berkeley National Laboratory

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Image: Generated by Google Gemini

Presentation content

Operational Hybrid Plants:
Online as of the end of 2023

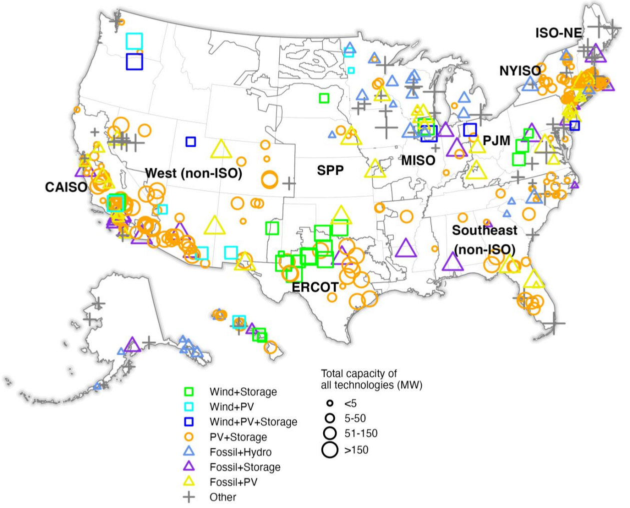
Hybrid PPA Terms:
Among a sample of PV+battery plants with public PPAs

Hybrid Pipeline:
Hybrid plants in interconnection queues at the end of 2023

High-Level Findings:
2023 Saw Growth of Newly Operational and Proposed Hybrids, though with PPA Price Increases

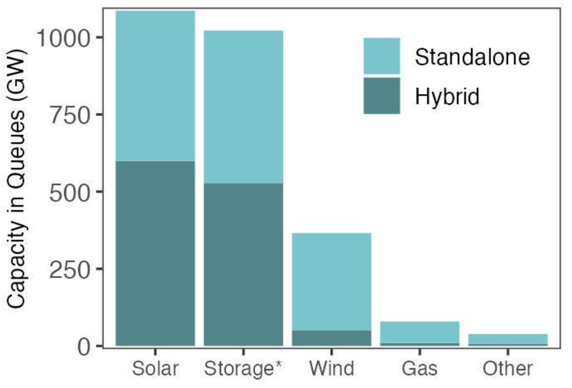
Hybrid plants exist in many configurations

- PV+Storage dominates in terms of number of plants (288), storage capacity (7.8 GW), and storage energy (24.2 GWh)
- As of the end of 2023, roughly the same amount of battery capacity was operating within PV+Battery hybrids as was operating on a standalone basis
- Storage:generator ratios are higher and storage durations are longer for PV+Storage plants than for other hybrids
- Grid services are most reported primary use case for storage in all but PV+Storage hybrid plants
- Battery roundtrip efficiency declines with age, though some projects maintain high efficiency in early years post-COD



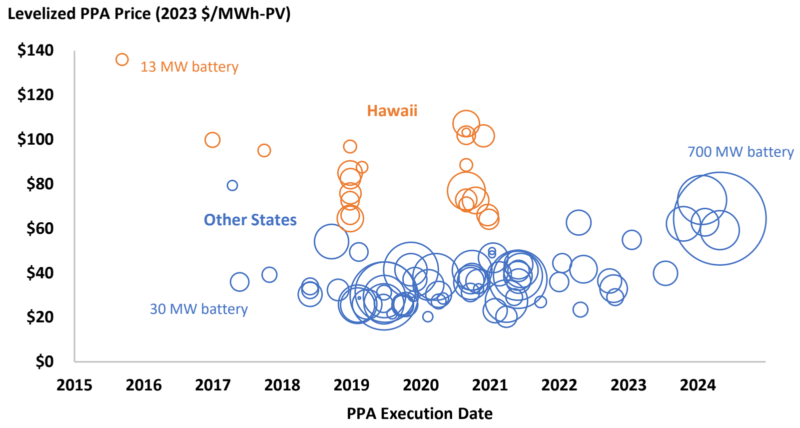
Hybrid plant capacity is increasing

- Hybrids represent 46% of generation capacity in interconnection queues (up from 37% in 2022)
- Hybrid configurations comprise 55% of active solar capacity (599 GW), 52% of storage (528 GW), and 14% of wind (51 GW)
- Proposed plants are concentrated in the West and CAISO



Prices from a sample of 105 PV+Storage PPAs totaling 13 GW PV and 7.8 GW / 30.9 GWh of batteries suggest that:

- Levelized PPA prices have begun to increase since 2020
- This trend aligns with “levelized storage adders” for PV+Battery plants that have recently increased on the U.S. mainland



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Important analytical additions in the 2024 edition of this report

Incorporation of New Data from EIA

- We integrate new data from EIA 860, which now reports the primary use-case of storage technologies, rather than providing solely a list of all storage use-cases (slide 19)
- EIA 923 now reports monthly battery charging and discharging data, which we use to analyze case studies of individual hybrid power plants (slide 22), calculate the distributions of round-trip battery efficiencies in the battery fleet (slide 23), and assess battery degradation over time (slide 23)

Summary of Capacity Market Rules for Hybrids

- Given the importance of resource adequacy on hybrid revenue, we have outlined key qualitative features and recent changes to capacity market rules for hybrid resources (slide 21)

Interconnection Queue Analysis

- In addition to reporting the overall fraction of projects choosing hybridization in the queue, we now additionally report how the fraction of new queue requests proposing hybridization has changed over the last 3 years (slide 37)

Preface: Two important policy updates we continue to track

The Inflation Reduction Act (IRA) in August 2022

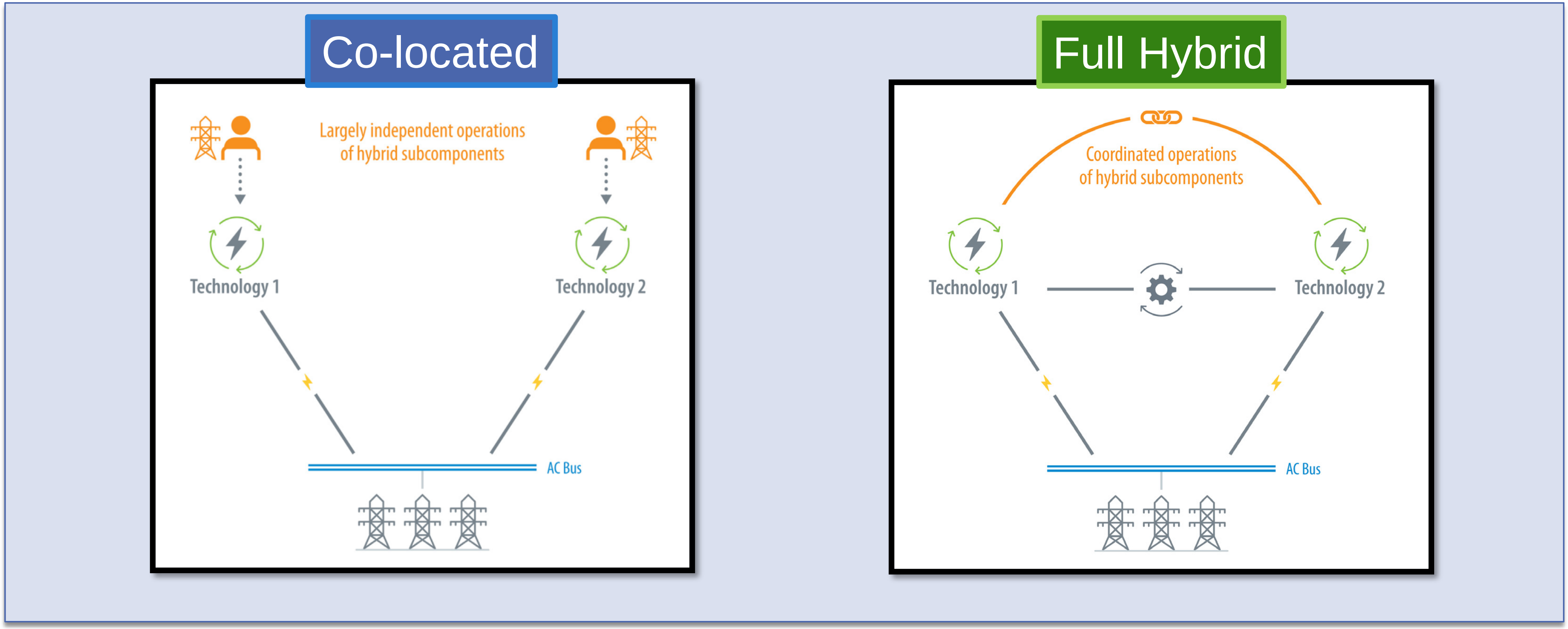
- The IRA provides standalone storage with access to the investment tax credit (ITC)
  - Previously, storage had to be paired with solar in order to access the ITC—no longer (starting in 2023)
  - This removes some of the impetus to couple batteries with solar
- Like last year's report, we don't see this policy shift slowing the hybridization trend (see slide 36), if anything we continue to see growing interest in hybrids. These trends could be explained by the following considerations:
  - The IRA was passed in August 2022 and the market naturally takes time to react (Guidance on standalone storage was issued by the IRS at the end of 2023 as a notice of proposed rulemaking)
  - Queues from some of the bigger regions had either already closed their open application season by the time the IRA passed (SPP), or else did not accept or discouraged new interconnection requests in 2022 (CAISO, PJM) or 2023 (MISO, PJM)
  - There are several reasons beyond the ITC (e.g. optimizing queue request strategy) that support hybridization

FERC Order No. 2023 in July 2023 ("Improvements to Generator Interconnection Procedures and Agreements")

- Requires transmission providers to allow more than one generating facility—or storage resource—to co-locate on a shared site behind a single point of interconnection and share a single interconnection request
- Allows interconnection customers to add a resource to an existing interconnection request under certain circumstances, without that addition being deemed a "material modification" that would push the modified application to the "back of the queue"
- Overall, this policy creates some efficiencies to choosing hybridization within interconnection queues

Presentation 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.

Operational Hybrid Plants: Online as of the end of 2023

Methods and data sources

- Form ***EIA-860 2023 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 from front-of-the-meter resources
  - 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 (e.g. oil/gas plants, SEGS, Ivanpah, Solana, Martin solar thermal power plants)

Numerous configurations of hybrid/co-located power plants were operational as of the end of 2023, though the PV+storage configuration dominates

469 plants, 49 GW of generating capacity, 9.9 GW / 29 GWh storage capacity / energy

Operating at end of 2023	# 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	288	14,453	0	0	7,768	24,237	54%	3.1
Wind+Storage	19	2,981	0	0	528	598	18%	1.1
Wind+PV	8	590	268	0	0	0	0%	n/a
Wind+PV+Storage	5	526	76	0	69	139	11%	2.0
Fossil+PV	39	8,633	280	0	0	0	0%	n/a
Fossil+Storage	28	6,650	0	0	1,410	3,842	21%	2.7
Fossil+PV+Storage	7	2,827	34	0	19	38	1%	2.0
Fossil+Hydro	26	490	78	0	0	0	0%	n/a
Fossil+Wind+PV	3	116	6	2	0	0	0%	n/a
Fossil+Wind	9	59	26	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	7	214	45	0	0	0	0%	n/a
Geothermal+PV+CSP	1	47	22	2	0	0	0%	n/a

Sources: EIA 860 2023 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

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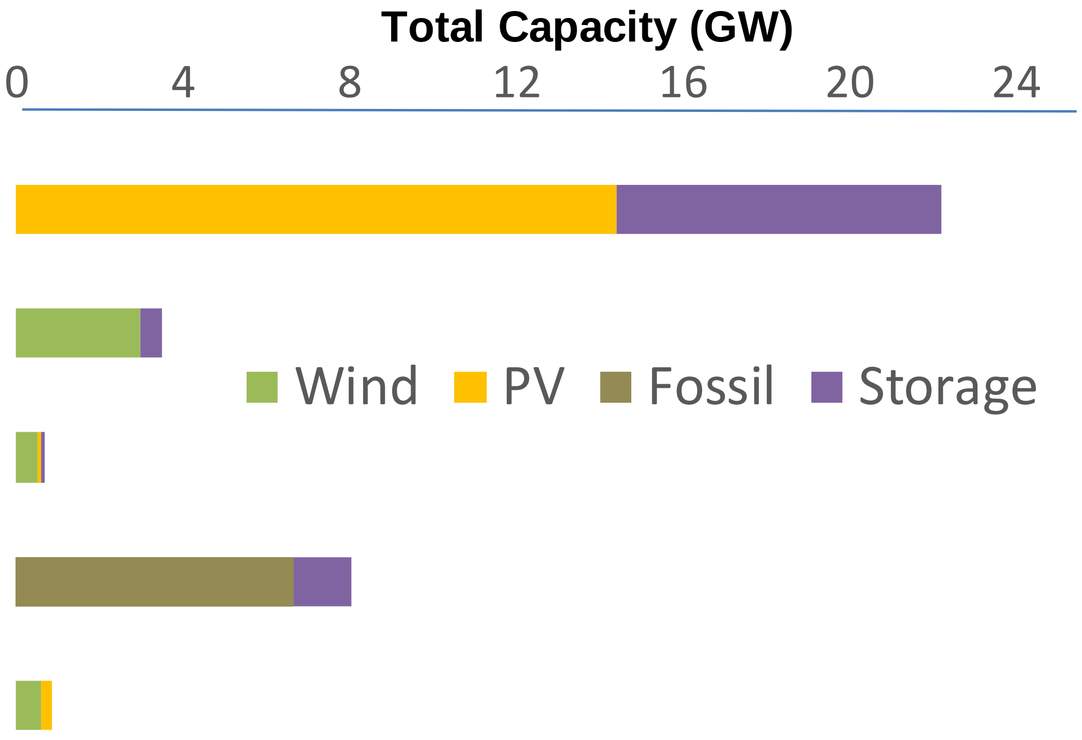
PV+Storage hybrids are the most popular (288), and have by far the most storage capacity (7.8 GW) and energy (24.2 GWh) than other hybrids

Cumulative Statistics Year End 2023



	# Plants	Weighted Average Storage Ratio	Total Storage Energy (MWh)	Weighted Average Duration (hrs)
PV+Storage	288	54%	24,237	3.1
Wind+Storage	19	18%	598	1.1
Wind+PV+Storage	5	11%	139	2.0
Fossil+Storage	28	21%	3,842	2.7
Wind+PV	8	n/a	n/a	n/a

Notes: Not included in the figure are 121 other hybrid / co-located plants with other configurations; details on those plants are provided in the table on slide 9. ***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 2023 Early Release, Berkeley Lab

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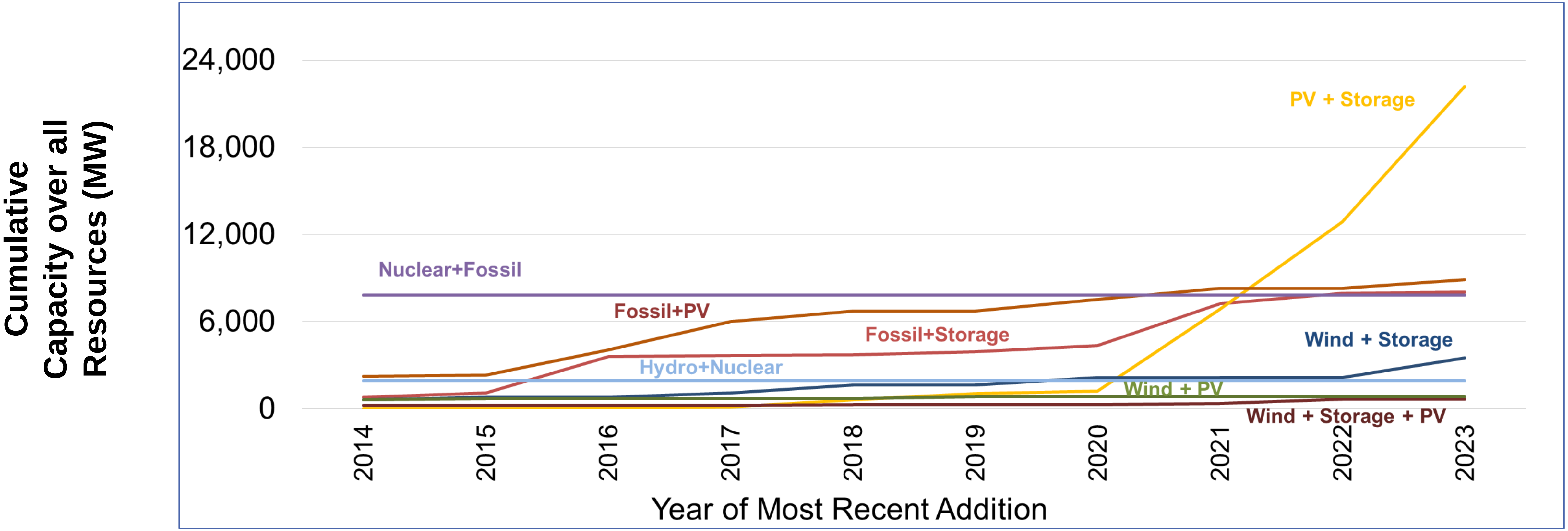
Growth of operational hybrid projects over last 3 years concentrated in the PV+Storage, Wind+Storage, and Fossil+Storage types

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 2023 Early Release, Berkeley Lab

Operational hybrid plants are scattered across the United States

PV Hybrid Plants

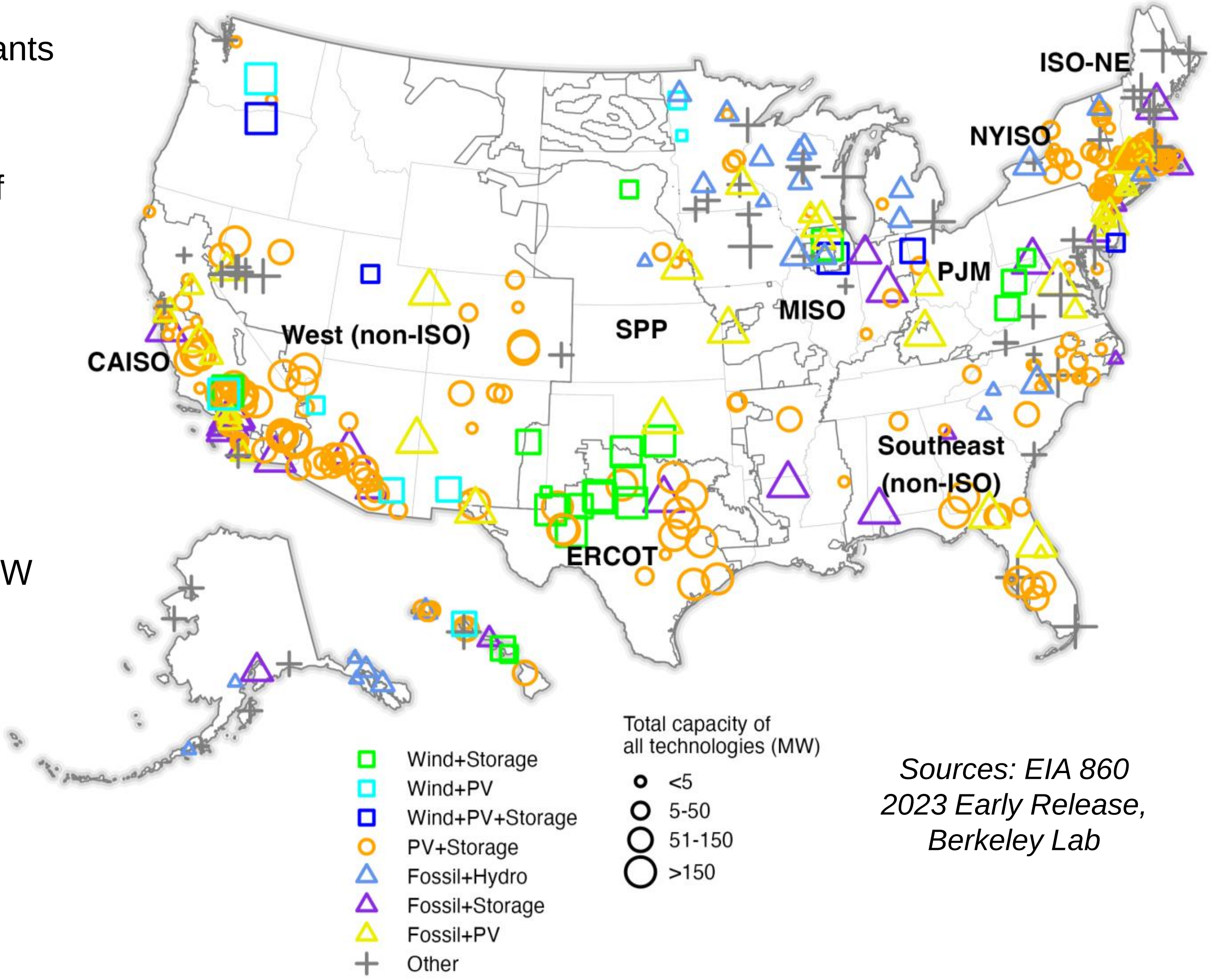
- Massachusetts contains the most (89) PV hybrid plants, though plants all include <7 MW of PV
- With 72 total plants (15 new in 2023), California has the second highest number of PV hybrid plants across the United States, 30 of which have installed PV capacities ≥100 MW
- Arizona had the most (16) new solar hybrids come online in 2023

Wind Hybrid Plants

- Wind hybrids are relatively sparse across U.S. compared to solar
- Only three new wind hybrids installed in 2023 (all in Texas)
- Texas contains 8 of the 17 wind hybrids with wind capacity ≥100 MW

Fossil Hybrid Plants

- California has almost half of all Fossil+Storage hybrids across the country (9), the next closest state only has 2 installations
- Fossil+PV is relatively spread out across the county with small amounts of PV added to larger fossil units



Sources: EIA 860 2023 Early Release, Berkeley Lab

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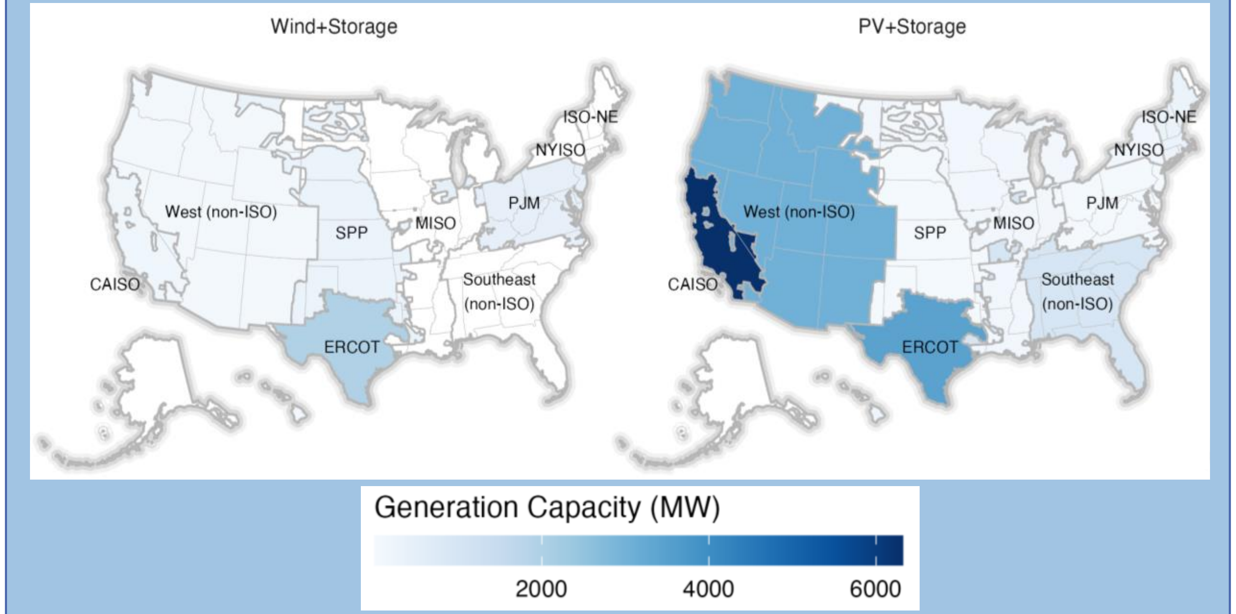
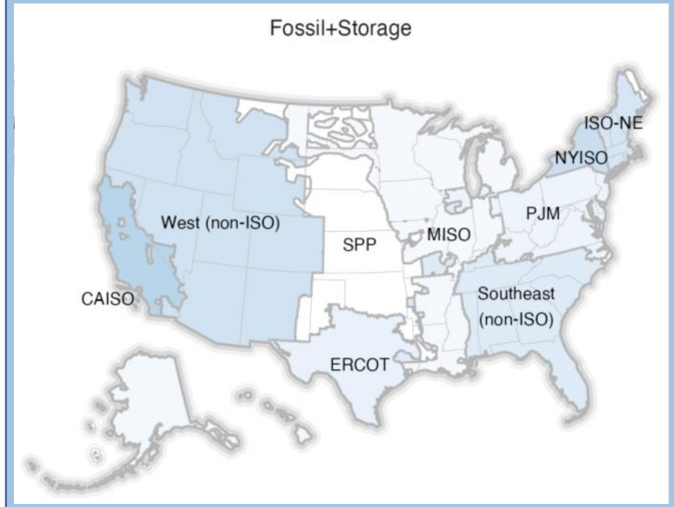
CAISO dominates for regional development across multiple hybrid types, ERCOT and the non-ISO West often are a close second

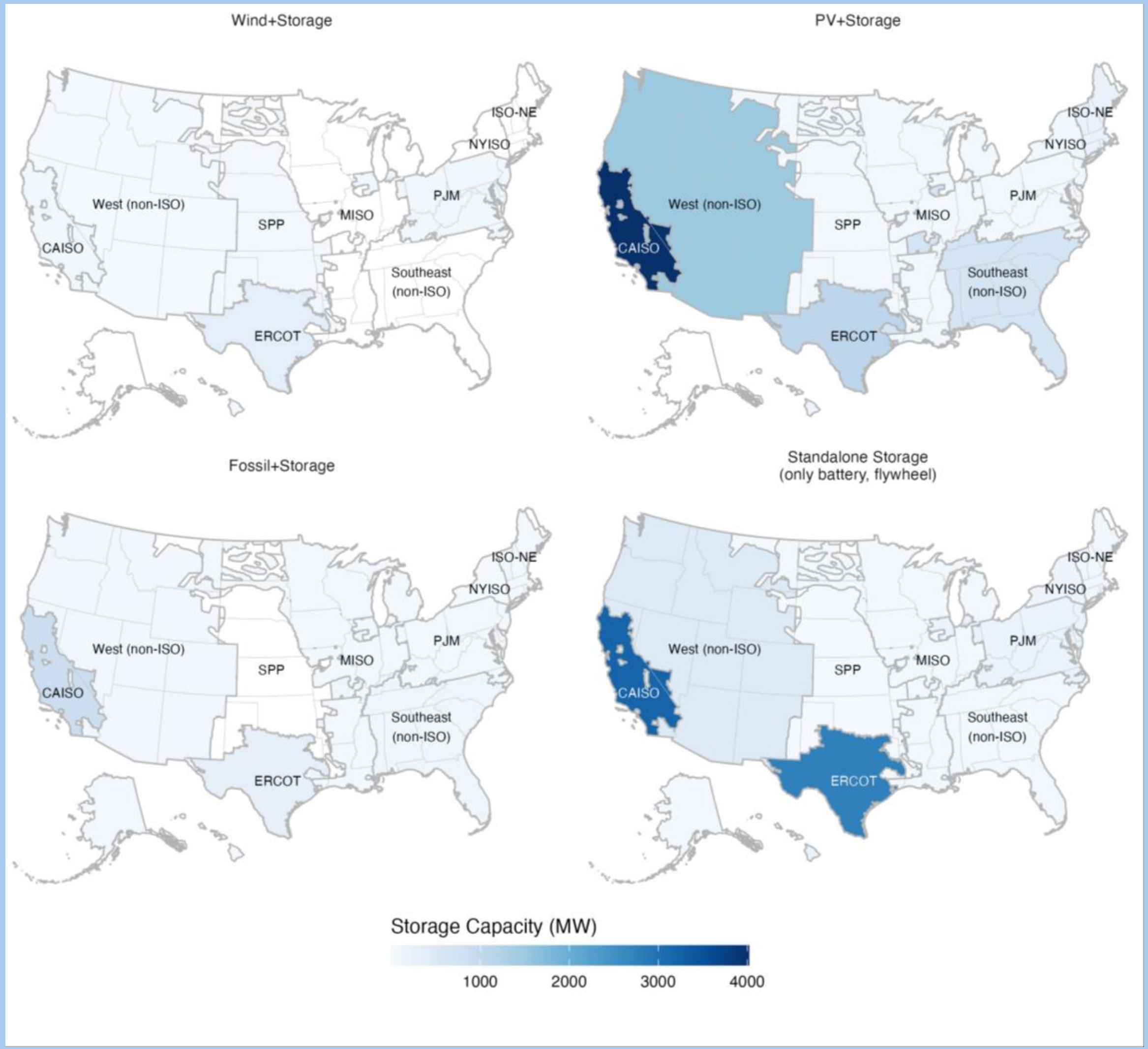
Aggregate Generator Capacity by Hybrid Type and ISO





Across all four plant types depicted in the right figure, CAISO (8.1 GW) has roughly equal amounts of storage capacity as all other regions combined (8.7 GW) but **almost double** the storage energy (28 GWh vs. 18 GWh)

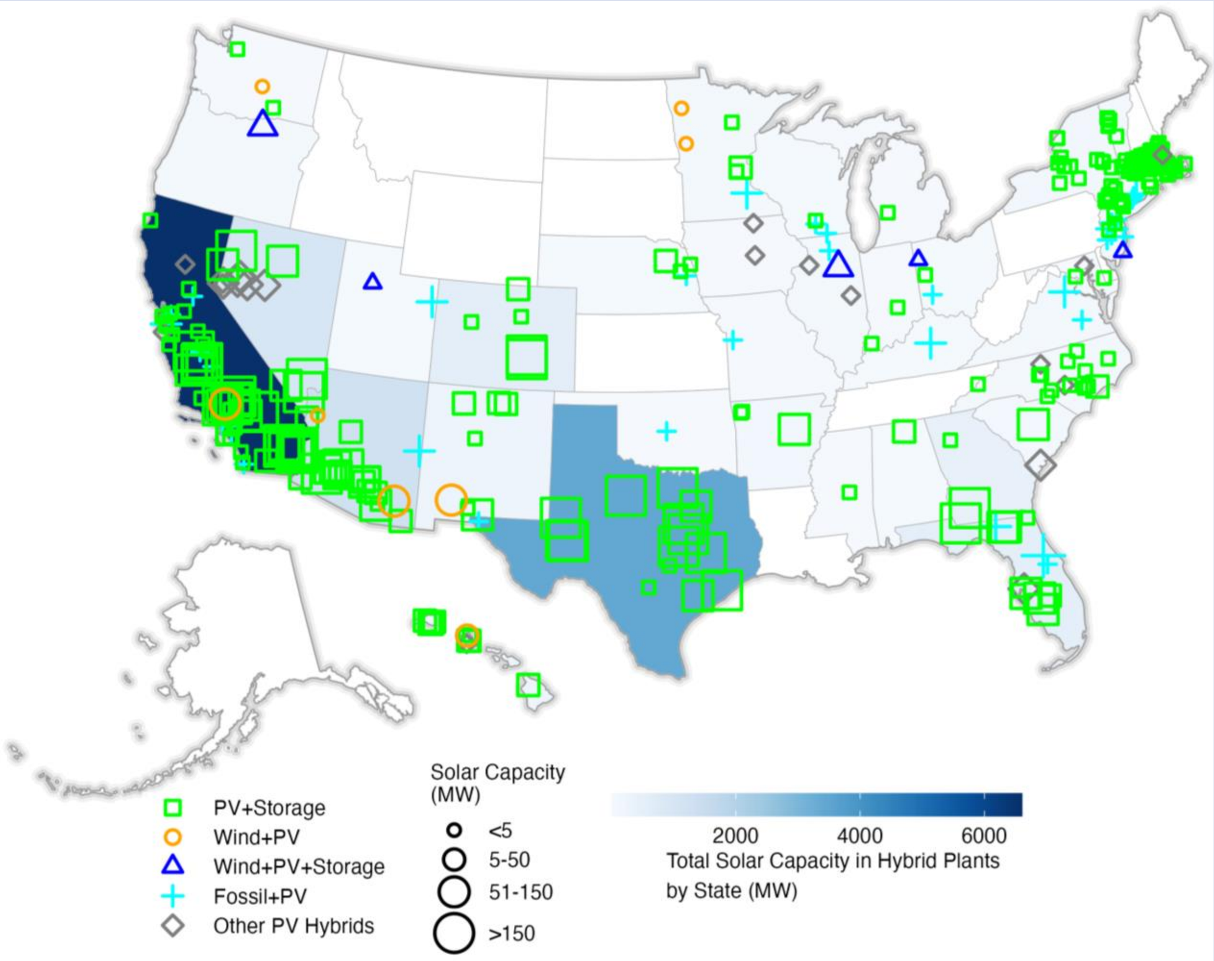
Aggregate Storage Capacity by Plant Type and ISO



Sources: EIA 860 2023 Early Release, Berkeley Lab

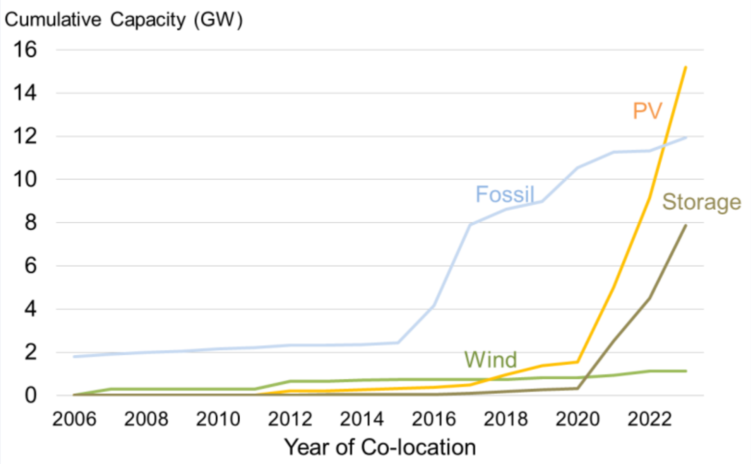
PV+storage plants can be found throughout much of the country, though the largest such plants are in California and the West, as well as Texas and Florida

Online PV Hybrid / Co-located Plants



Growth in PV Hybrid Capacity over Time

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

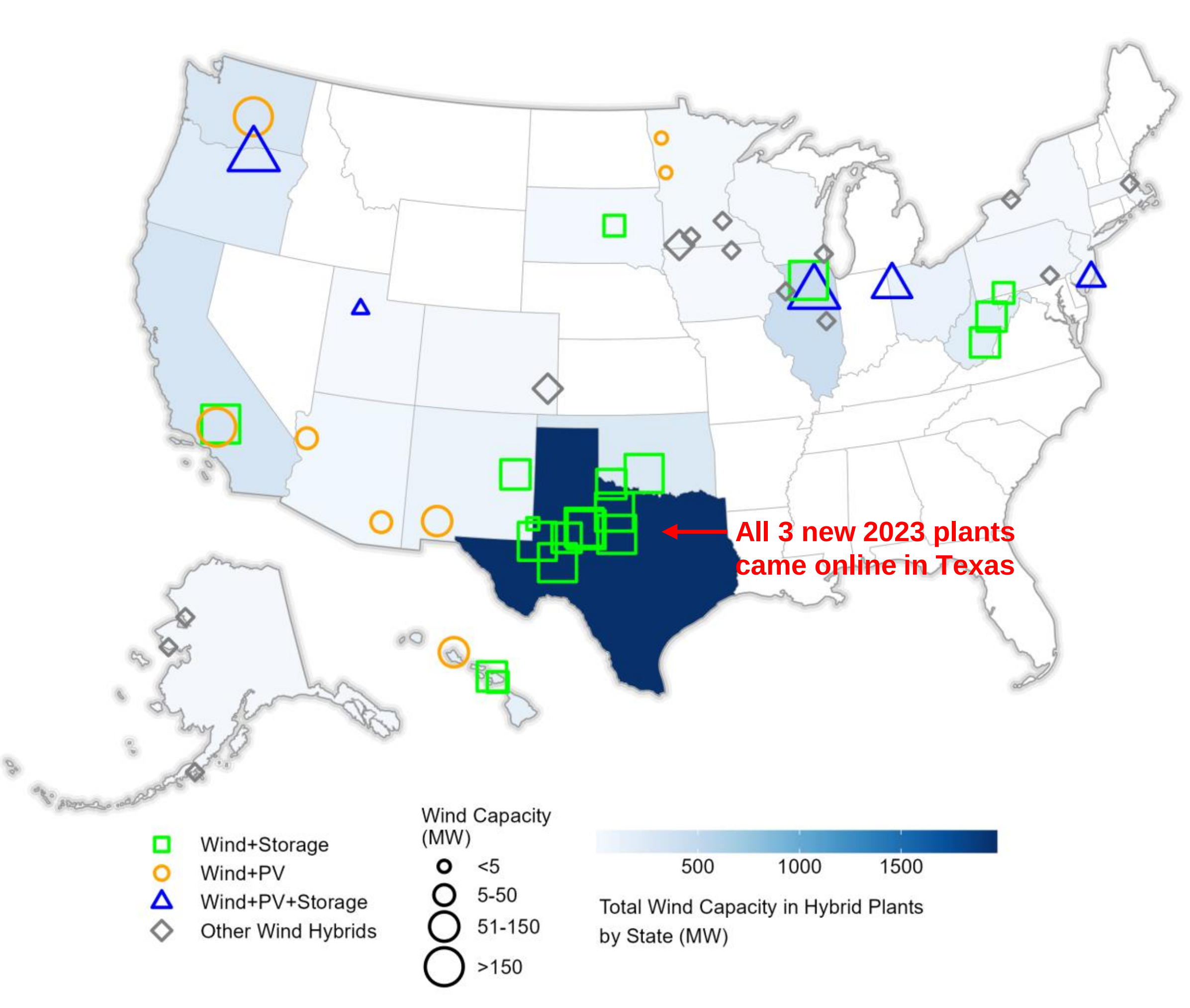


Note: Fossil+PV typically involves minor amounts of PV added to existing (and often much larger) fossil units at the point of interconnection; thus, the fossil category has a large presence in the figure.

Sources: EIA 860 2023 Early Release, Berkeley Lab

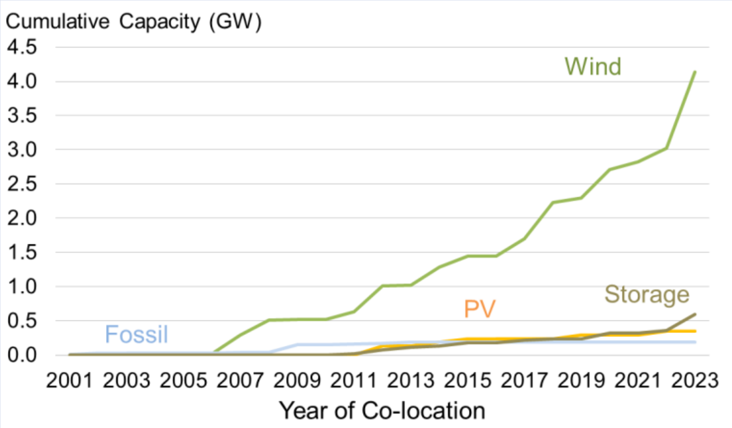
All new hybrid wind plants were installed in Texas in 2023

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

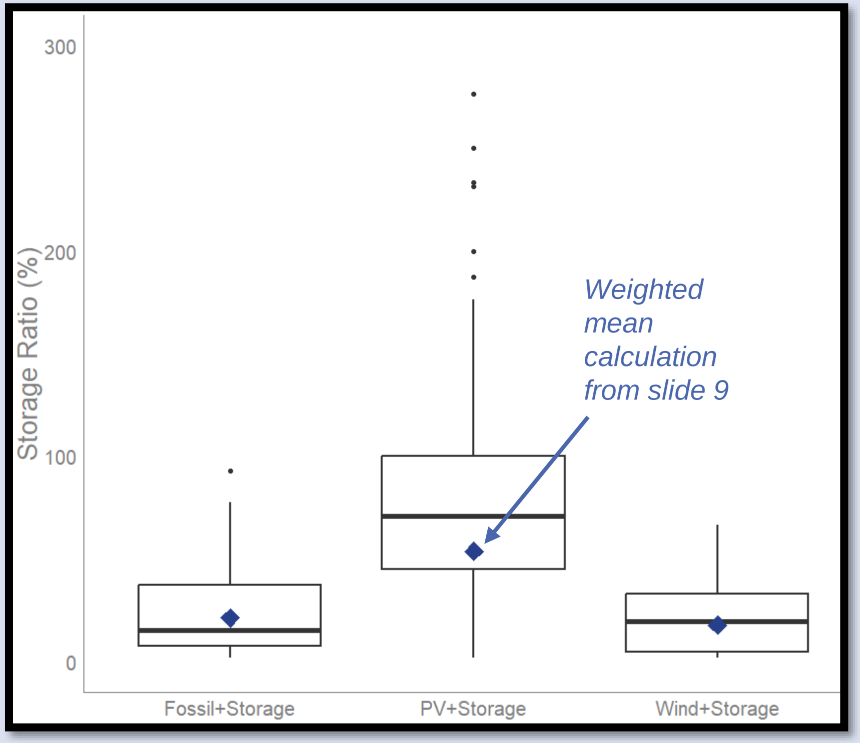


Note: Duration of storage for wind hybrids tends to be limited (typically ~1 hr)

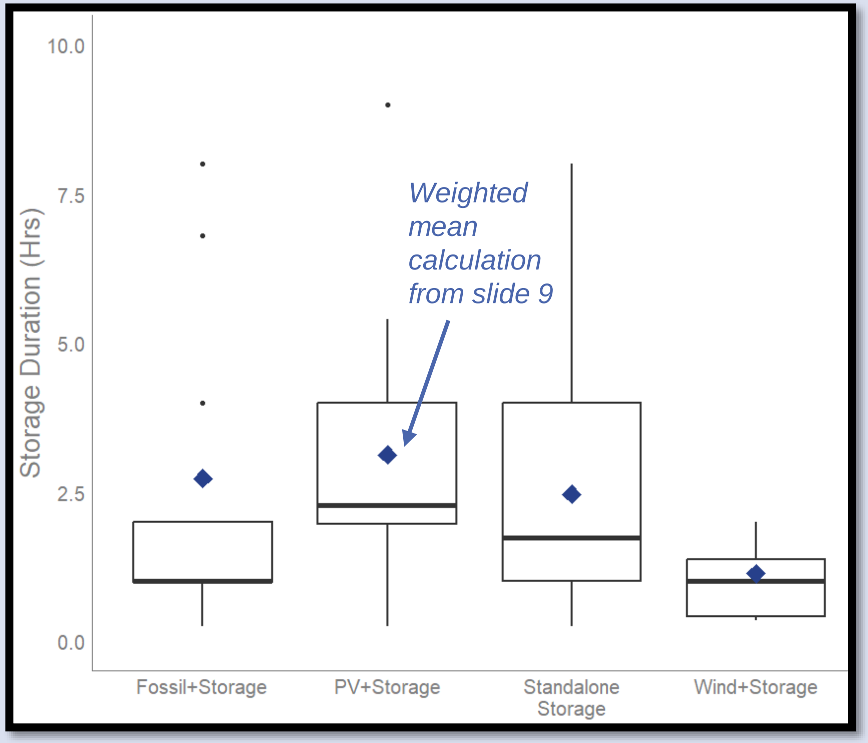
Sources: EIA 860 2023 Early Release, Berkeley Lab

PV+Storage hybrids have higher storage-to-generator ratios and longer durations

PV+Storage median storage-to-generation ratio is highest at 71%



PV+Storage median storage duration is highest at 2.3 hours



Note: Figure drops 2 PV+Storage outlier plants with storage ratios > 500%

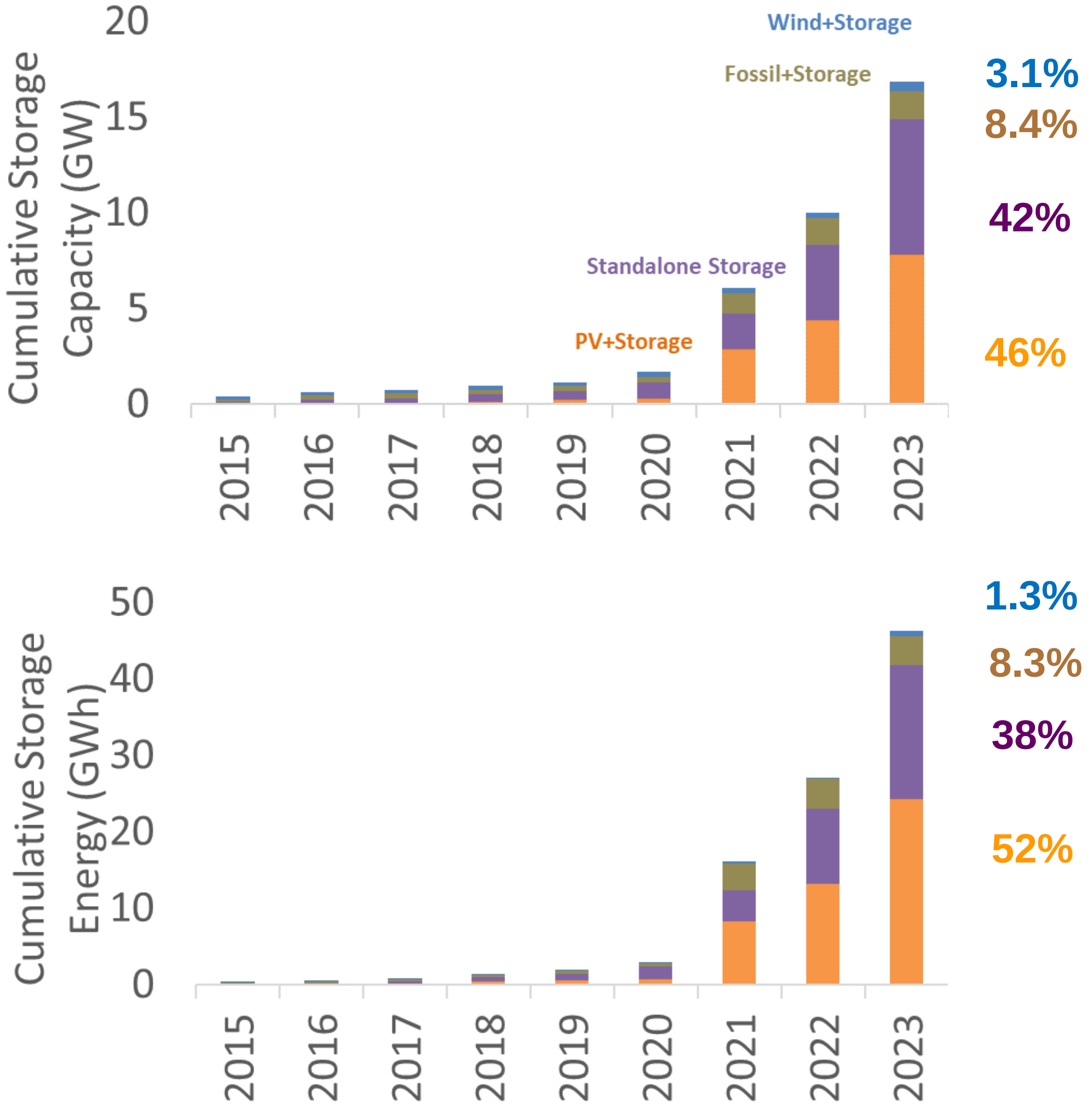
Sources: EIA 860 2023 Early Release, Berkeley Lab

PV+Storage plants have more battery capacity and more energy than standalone batteries in the U.S.

- Through 2023, PV+Storage plants represent roughly 46% of all installed ***battery storage* capacity*** in the U.S. compared to 42% for standalone storage

- …and roughly ***52% of all storage energy*** compared to only 38% for standalone storage

- Battery storage capacity has been ***increasing by 1.5 to 3x*** each year over the last 3 years

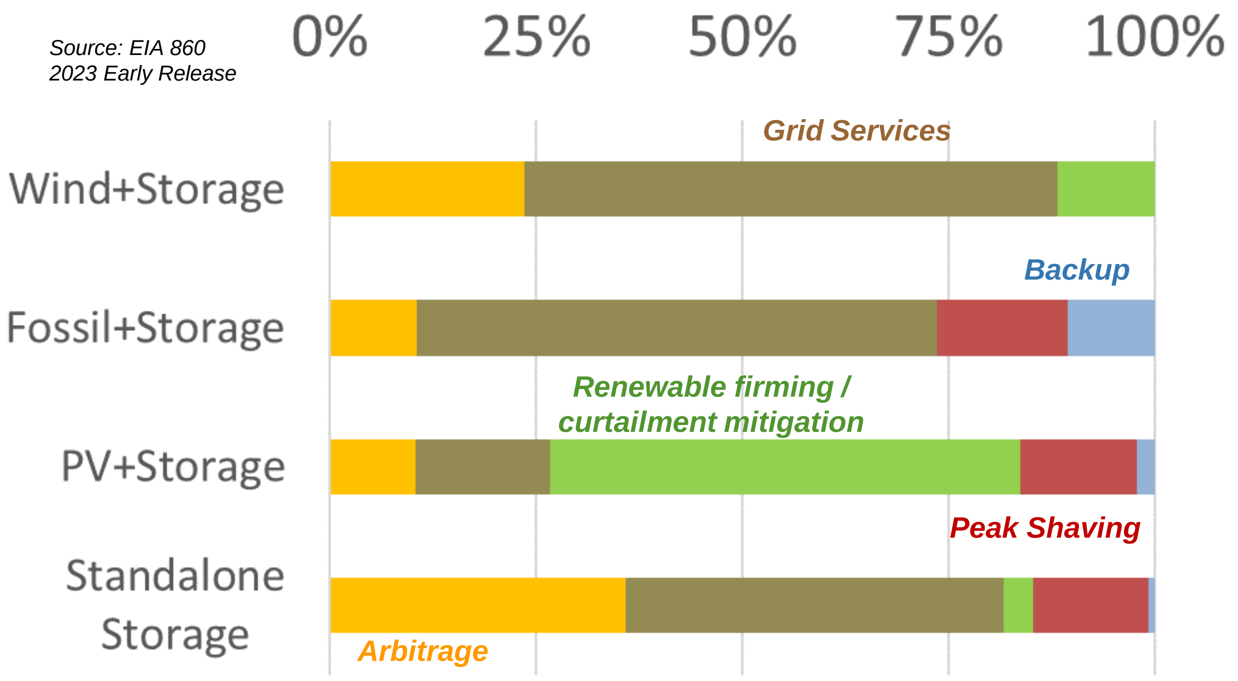


These comparisons do not include pumped storage capacity or thermal storage from CSP plants. Rather, they only incorporate installed battery storage capacities, and limited amounts of flywheel and compressed air energy storage. Furthermore, they largely do not consider behind-the-meter storage, given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

Breakdown of self-reported use cases for battery storage is different for PV+storage plants compared to standalone batteries and other hybrids in 2023

- 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 are ***most reported primary use case*** for all but PV+Storage plants
- Renewable firming and curtailment mitigation is particularly important in PV+Storage hybrids, suggesting need to firm the PV capacity for resource adequacy purposes
- Backup power and peak shaving are ***least popular*** use cases reported by operators

Breakdown of primary battery use-case among popular hybrid configurations and standalone storage in 2023 (% of projects)



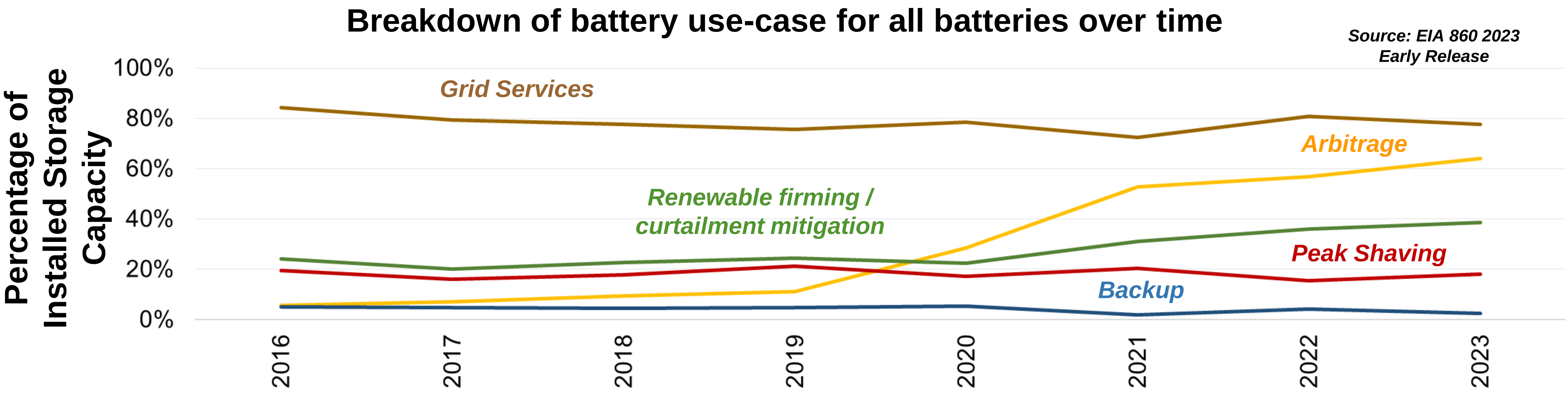
Note: Grid services category includes the following: frequency regulation, load following, ramping/spinning reserve, load management, and voltage/reactive power support. Additional details about all categories can be found in the EIA 860 Instruction form on page 18.

*Though we focus on primary use case on this slide, the results are similar even when aggregating for all selected use cases for each plant

Arbitrage and renewable firming use-cases continue to increase overtime as a percentage of installed storage capacity

- Battery operators have selected grid services, peak shaving, and backup use-cases at a ***relatively constant rate*** over the last 7 years.

- Over the ***last 3 years***, however, more operators are selecting the arbitrage and renewable firming/curtailment mitigation use-cases. Additional use-case stacking suggests operators view batteries as having increasing applications



Notes:
Percentages can add up to more than 100% because respondents 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

Capacity market rules for hybrids are evolving across ISOs, with ongoing FERC proceedings to mediate their appropriate capacity values

These rules aim to maintain reliability as the grid shifts towards more variable sources, but interpretations of hybrid power plants' capacity value can vary widely and have implications for ultimate market value and thus developmental prospects of hybrids in each region

CAISO	PJM	SPP	ISONE	NYISO	MISO
• 2023 hybrids were valued using a method similar to ELCC and sum-of-parts* • CAISO is switching to a "***slice-of-day***" framework that values each plant according to its performance in every hour on the highest peak-load day of each month. Implementation is expected to begin in 2025	• 2023 hybrids were valued using a *class-average* ELCC methodology • FERC approved PJM's request to transition to ***marginal ELCC*** method in 2024, which will value each generation resource according to its marginal contributions to resource adequacy	• SPP has been seeking approval to switch to a ***class-average ELCC*** methodology for wind, solar, and hybrid resources • FERC recently ***reversed its approval*** of SPP's proposal citing discrimination to variable resources. Proceedings for an amended proposal are ongoing	• Capacity accreditation is currently based on ***median net output*** during summer and winter peak hours, with annual capacity credits procured three years in advance • Reforms are underway to switch to ***prompt*** (just before the commitment period) ***auctions*** and a ***seasonal*** capacity market framework	• In 2023, hybrid resources in NYISO were valued using class-average ELCC and sum-of-parts methodologies • Starting in 2024, hybrid resources will be assessed based on the ***marginal ELCC*** of the ***combined hybrid resource***, following FERC's approval in 2022	• Hybrids are valued based on output during ***top eight peak load hours*** • MISO switched from an annual accreditation construct to a ***seasonal construct*** in 2023, where capacity value is now determined based on output during each season's peak load hours

Effective Load Carrying Capacity (ELCC**) quantifies how much additional load a generator can support on the grid while maintaining reliability. **Class-average ELCC** assigns a uniform capacity value to all generators of the same type, while **marginal ELCC** measures the incremental reliability contribution of each resource individually. **Sum-of-parts** methodology values each component of the hybrid power plant separately (e.g., battery and PV), then sums them to determine the overall capacity value.*

Note: ERCOT does not have a capacity market.

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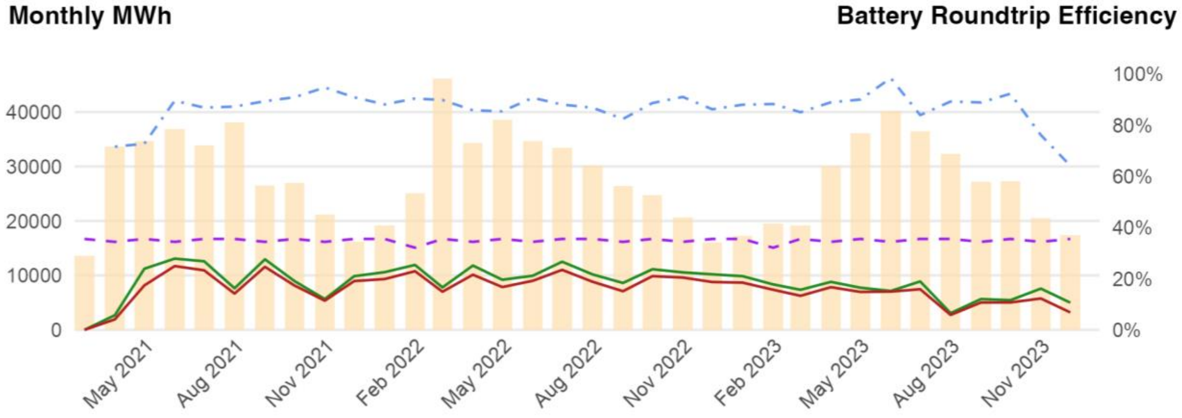
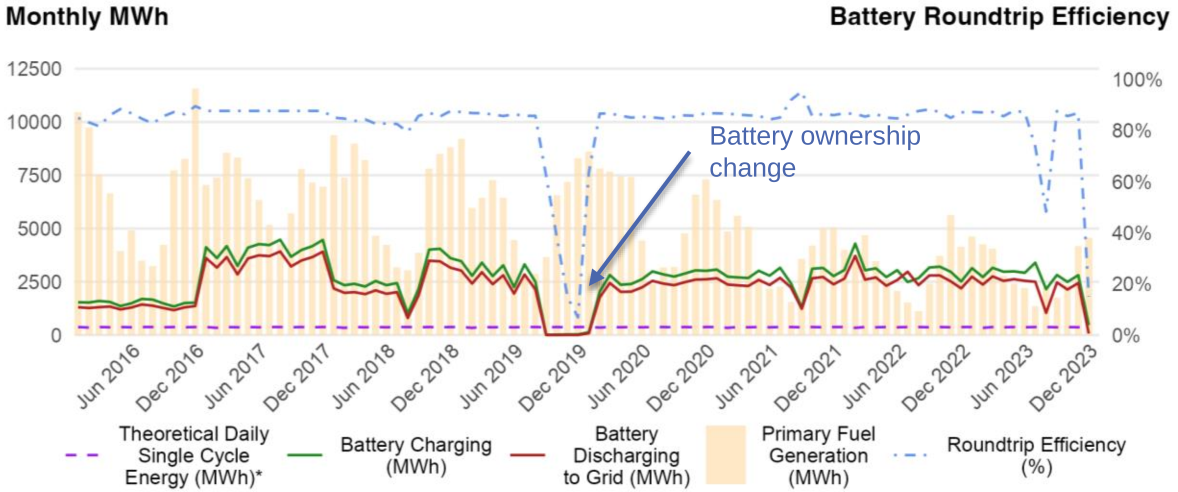
Case studies of battery charge and discharge patterns show a wide range of use-cases for battery-hybrid systems

Blythe Solar II *(located in CAISO)*



Meyersdale Windpower *(located in PJM)*



**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.*

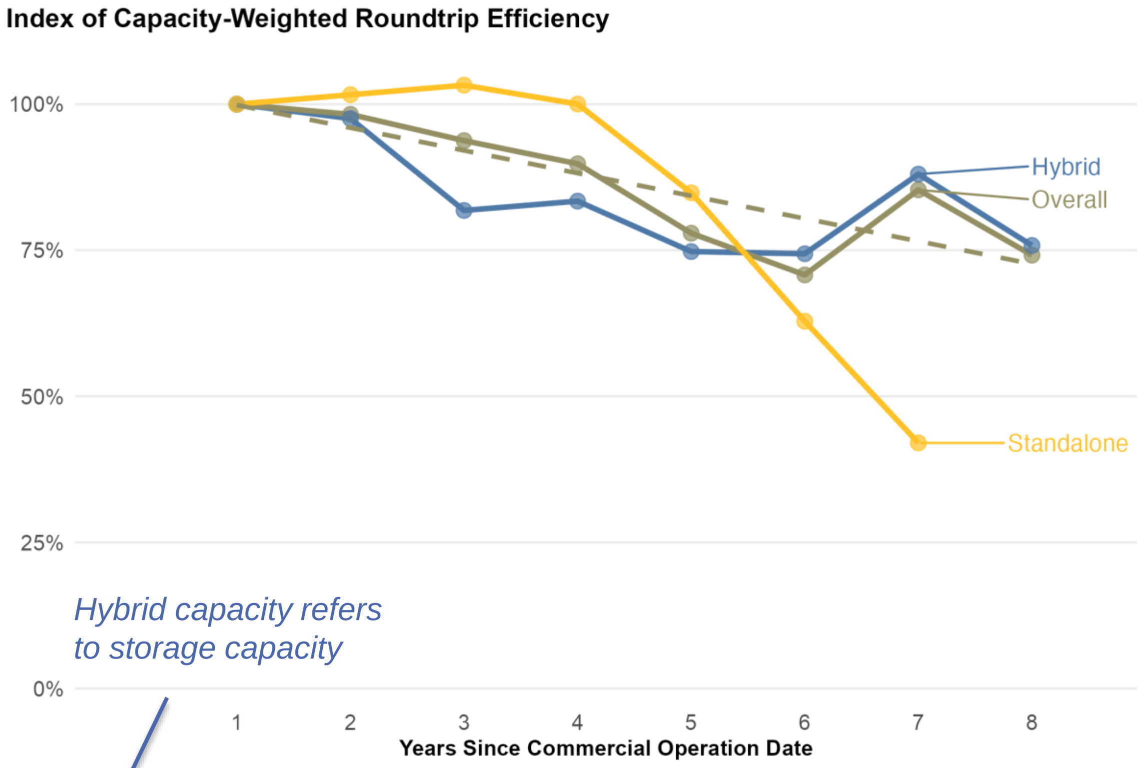
Data Sources and Methods

- Form EIA 923 now 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

- Blythe Solar II is a 131.2 MW AC PV facility completed in 2016, with a 115 MW/538.6 MWh battery added in 2021 (top graph)
  - Battery cycles ***less than once per day*** on average, suggesting energy arbitrage application, which aligns with CAISO wholesale pricing patterns and solar shifting
  - EIA, however, reports the primary function as frequency regulation, with a secondary function of arbitrage
- Meyersdale is a 30 MW wind facility completed in 2003, with an 18 MW/12.1 MWh battery added in 2015 (bottom graph)
  - Battery cycles an average of ***6 times per day*** and sometimes up to 12
  - EIA reports the primary (***and only***) function of the battery is frequency regulation, which aligns with cycling multiple times per day
- Both batteries on these hybrids do not show extensive degradation in efficiency over time and both usually, though not always, charge less in a month than the monthly renewable energy production

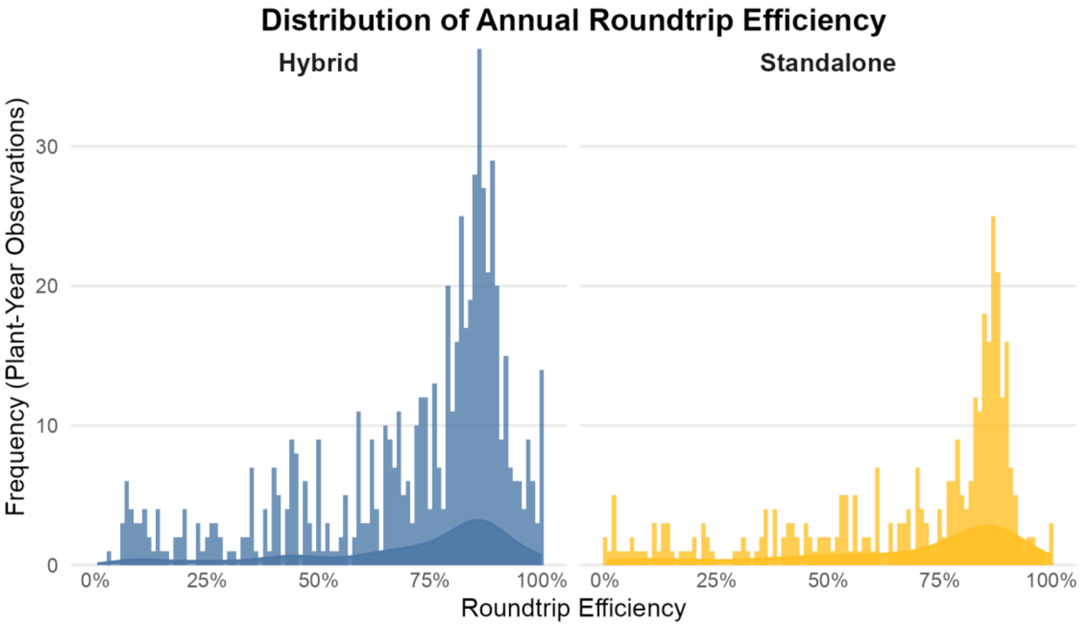
Battery roundtrip efficiency generally declines with project age, though there is significant variability across projects and a relatively small sample of older projects



Hybrid capacity refers to storage capacity

	1	2	3	4	5	6	7	8
Hybrid Projects:	196	116	69	49	41	25	18	9
Hybrid Capacity (MW):	5,304	3,378	565	491	440	378	329	96
Standalone Projects:	83	55	43	35	18	10	3	
Standalone Capacity (MW):	3,609	1,451	606	300	218	127	6	

Significant drop in sample size over time, indicating a relatively limited set of batteries with longitudinal operations data



- Battery roundtrip efficiency often ***declines with age***, though some projects maintain high efficiency in the early years post-COD, as shown on the previous slide
  - Battery storage deployment in US is relatively nascent, so interpret results after year 2-3 post-COD with caution
- Most batteries operate in the ***75% - 95% efficiency*** range, but a sizable portion operate ***below 50% efficiency*** in some years

Notes: Only plants with a COD of 2015 or later are included in left graph, as charge and discharge data are unavailable for earlier years. All plants, regardless of COD, are included in right graph. We exclude observations from the first calendar year of the plant's operation. Batteries that do not report operational data to EIA 923 are excluded.

AC versus DC coupling for PV+Storage plants

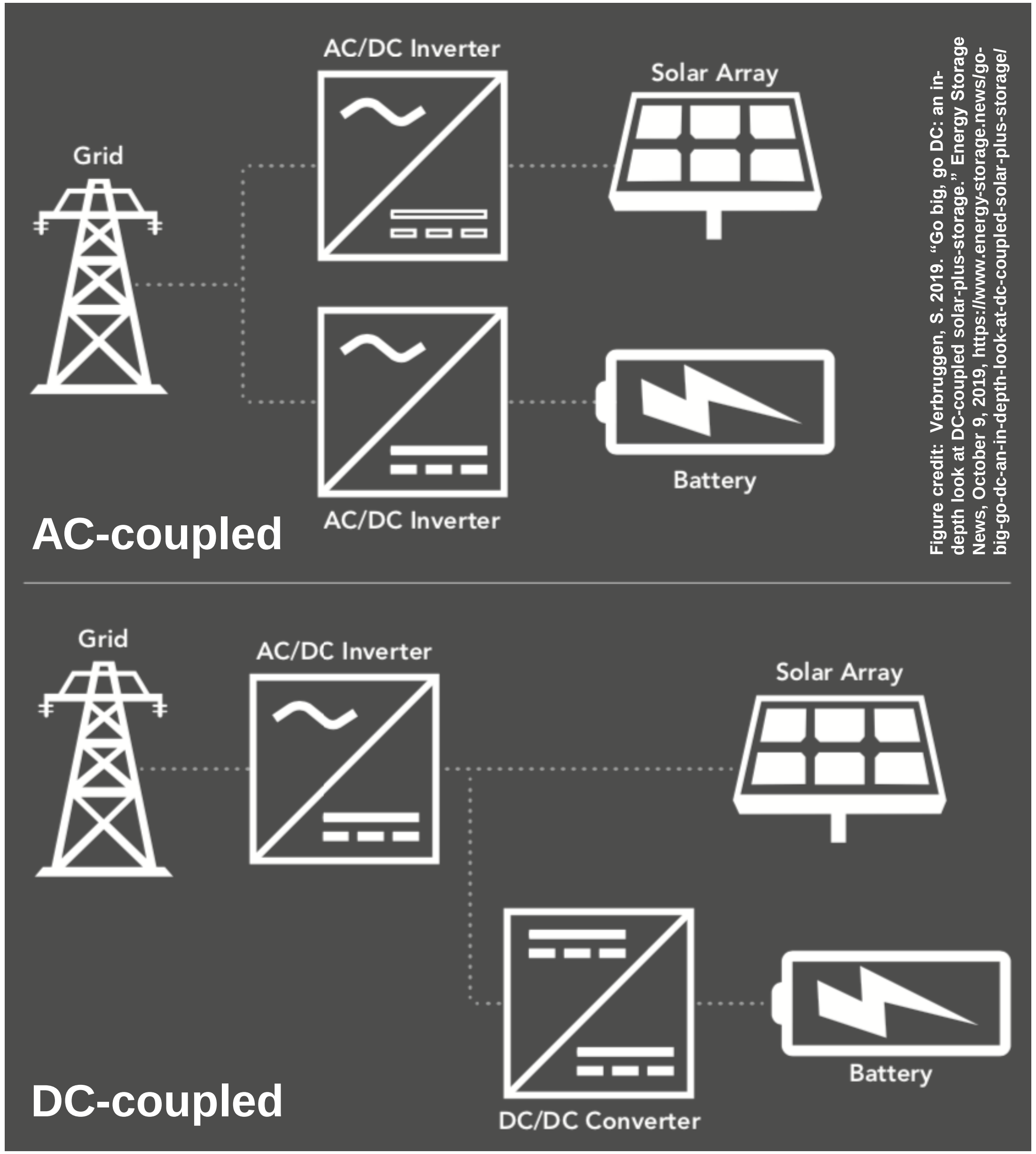
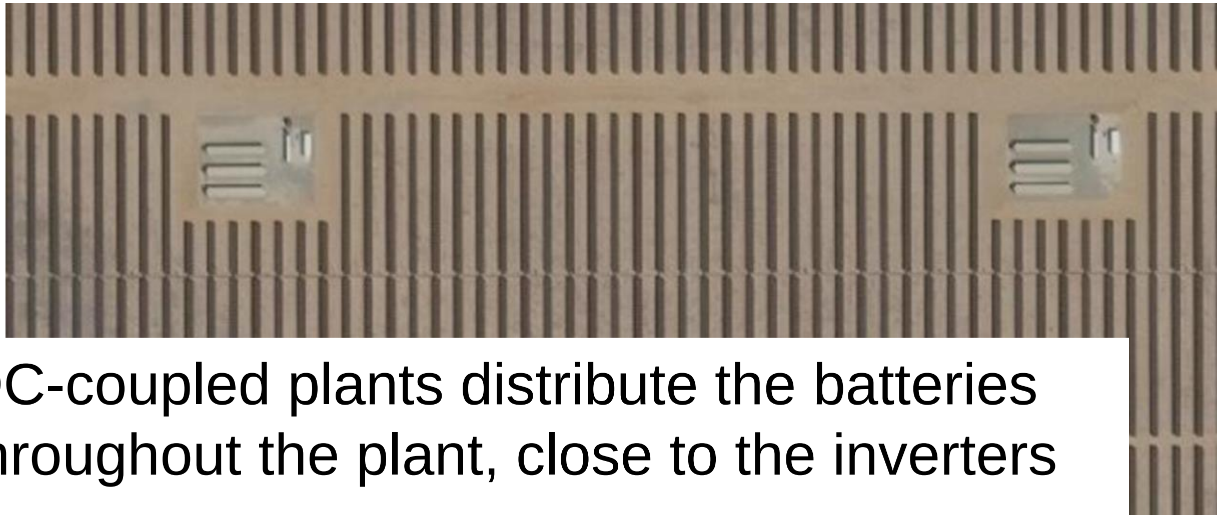


Figure credit: Verbruggen, S. 2019. "Go big, go DC: an in-depth look at DC-coupled solar-plus-storage." Energy Storage News, October 9, 2019, https://www.energy-storage.news/go-big-go-dc-an-in-depth-look-at-dc-coupled-solar-plus-storage/

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

Large PV+Storage hybrids are usually greenfield projects, AC-coupled, and have a separate dispatch schedule

The 100-plant sub-sample of PV+Storage plants with PV capacity >5 MW_{AC} accounts for nearly 90% of the total PV capacity, storage capacity, and storage energy of the 288 PV+Storage plants that were operational at the end of 2023. This represents ***significant growth in large PV hybrid installations*** since the end of 2022, when there were just 53 operational PV+Storage plants with PV capacity >5 MW_{AC}.

1) 25 of these 100 plants are ***battery retrofits*** (10 retrofits in 2023, up from 4 in 2022)
2) 83 of these plants are ***AC-coupled*** and 17 are ***DC-coupled***
   - Battery retrofits favor AC coupling (i.e., centralized battery yards): 21 of the 25 retrofits are AC-coupled
   - Of the 75 greenfield plants, 62 are AC-coupled and 13 are DC-coupled
     - 31 out of 62 greenfield AC-coupled plants and 4 out of 13 greenfield DC-coupled plants came online in 2023
     - The typical ***DC-coupled project has a higher DC:AC ratio*** compared to the typical AC-coupled project, with median values of 1.40 for DC-coupled plants and 1.32 for AC-coupled plants
       - However, when looking at capacity-weighted means, the DC:AC ratios are similar: 1.30 for DC-coupled plants and 1.33 for AC-coupled plants, which is opposite the expected direction, indicating some large DC-coupled systems have lower DC:AC ratios
3) 38 of these 100 plants are in CAISO, and 8 of these 38 CAISO plants operate as "***true hybrids***" (i.e., PV+Storage is scheduled as a single unit) while the other 30 are "***co-located hybrids***" (i.e., the PV and Storage are scheduled as two separate units)

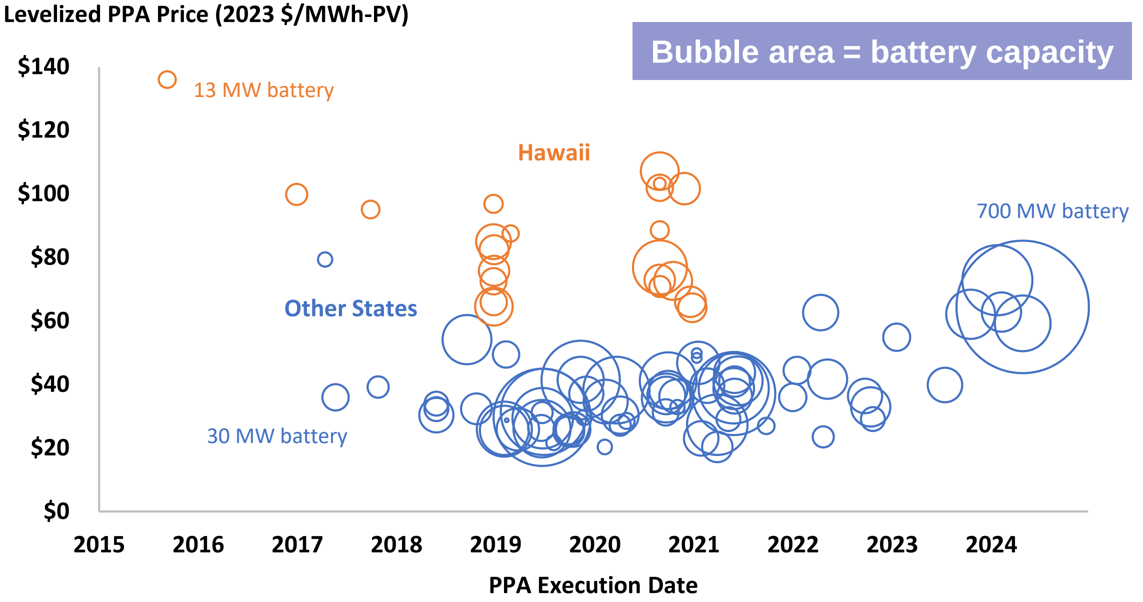
Hybrid PPA Terms:
Among a sample of PV+battery plants with public PPAs

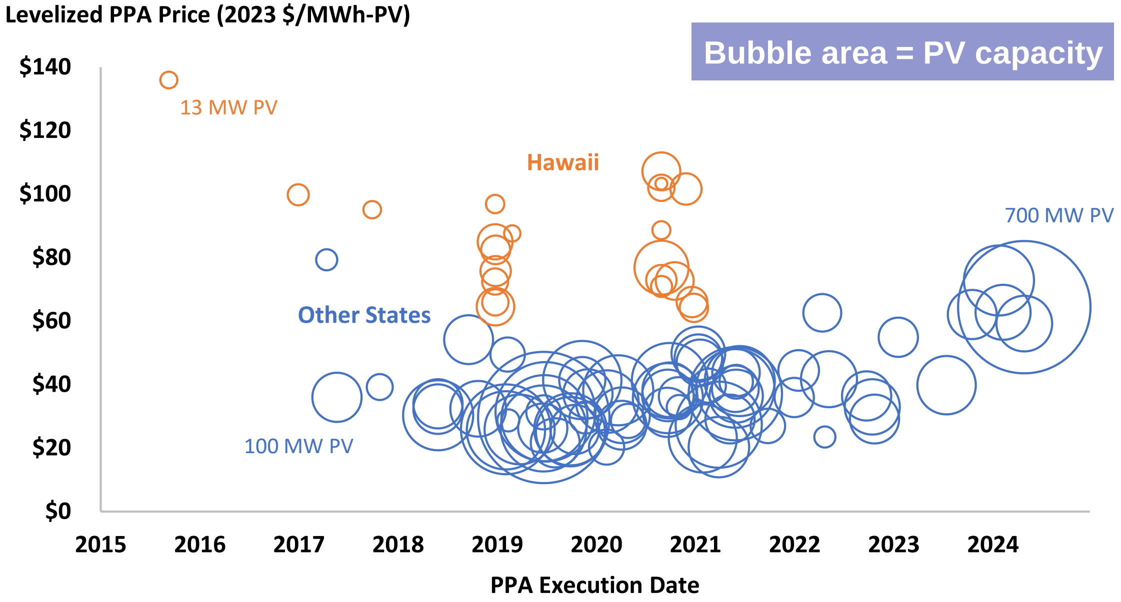
We have PPA prices from a sample of 105 PPAs in 10 states totaling 13.0 GW_{AC} of PV and 7.8 GW_{AC} / 30.9 GWh of batteries

State	# of Plants	Total Capacity (MW_{AC}) PV	Battery	Average Battery:PV Capacity	Battery Storage Avg Duration	Total MWh
AZ	7	631	508	81%	3.8	1,944
CA	36	4,323	2,530	59%	4.0	10,091
CO	3	595	226	38%	4.0	902
FL	1	50	12	24%	2.0	24
GA	2	409	80	20%	2.0	160
HI	23	803	797	99%	4.1	3,258
NM	13	2,000	955	48%	4.0	3,818
NV	17	3,922	2,651	68%	4.0	10,574
NY	2	213	10	5%	4.0	40
OR	1	50	30	60%	4.0	120
Total	**105**	**12,993**	**7,798**	**60%**	**4.0**	**30,931**

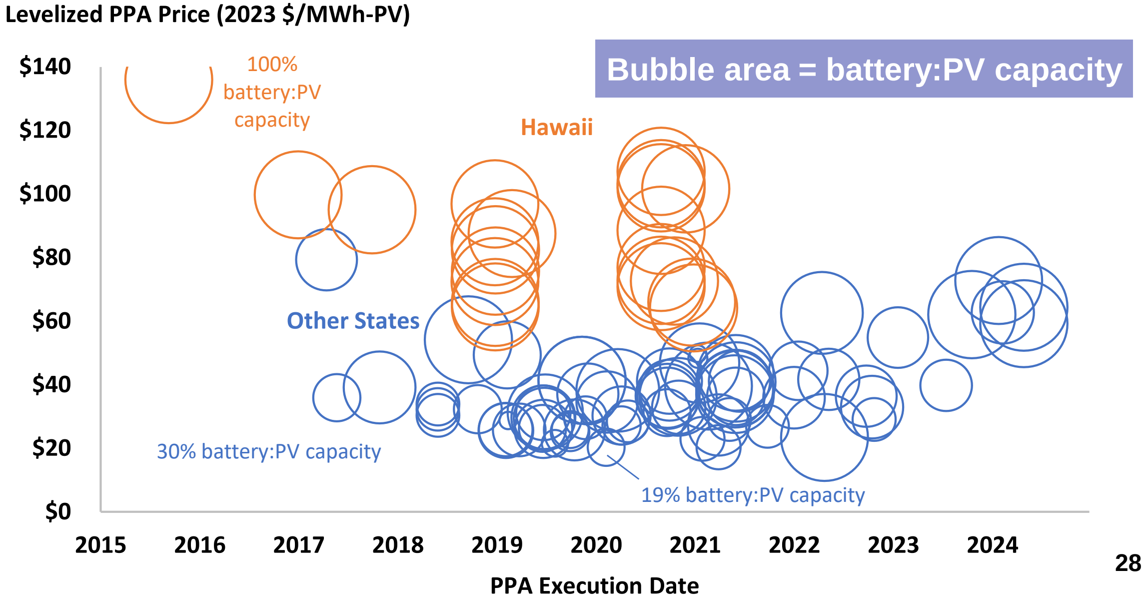
- Sample dominated by CA, NV, NM, and HI
- 68 of these 105 PPAs are for plants that are operational (other 37 still in development/construction)
- 11 of the operational plants are battery retrofits to pre-existing PV plants (9 in CA, 2 in NM)

PPA prices for PV+battery have risen since 2019/20 lows; Hawaii at a premium



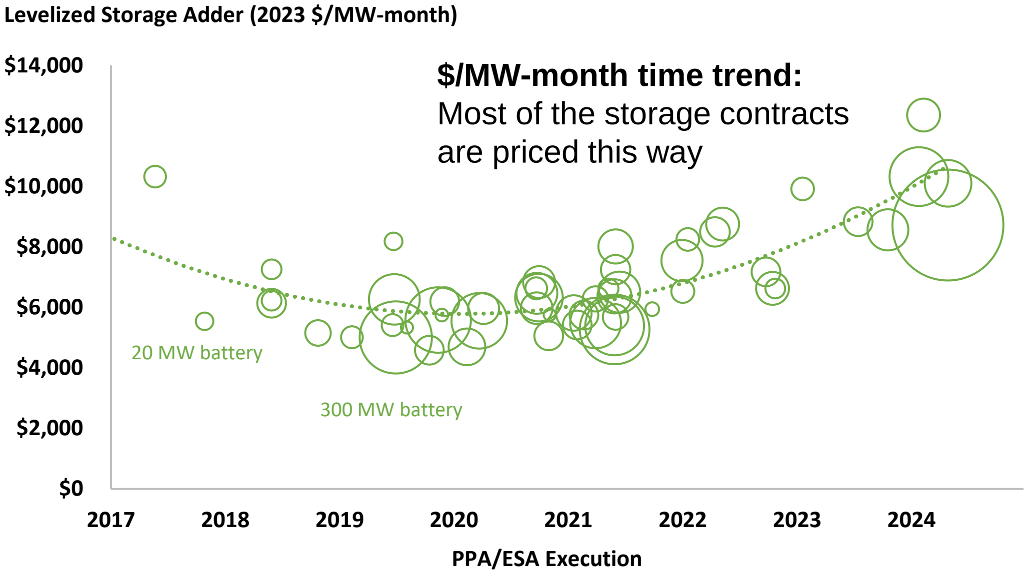


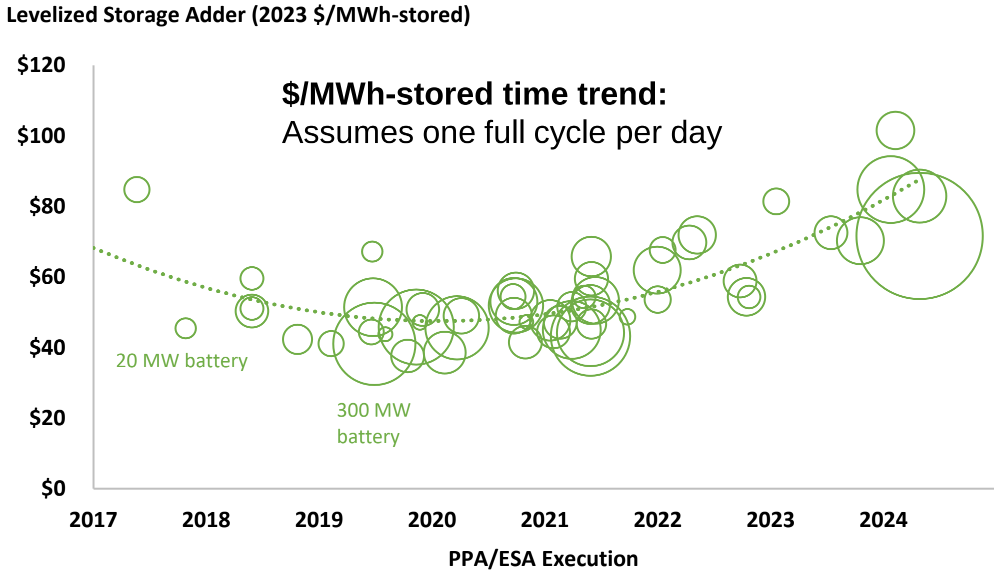
- All 3 graphs show same data from sub-sample of 93 plants (retrofits not included); the only difference is what the bubble size represents
  - ➢ Hawaii (orange): 22 plants, 0.8 GW_{AC} PV, 0.8 GW_{AC} battery
  - ➢ Other States (blue): 71 plants, 10.5 GW_{AC} PV, 5.8 GW_{AC} battery
- Upward price trend among more-recent PPAs on the mainland (third round of Hawaii PPAs expected soon)
- Battery:PV capacity ratio always at 100% in HI, but is often lower on the mainland (see bottom right graph)
- Storage duration ranges from 2-8 hours; 80 of the 93 plants have 4-hr duration (other 13 are 5x2 hr, 1x2.5, 1x3, 1x3.7, 4x5, & 1x8 hr)



PPAs that price the PV and storage separately enable us to calculate a “levelized storage adder,” shown here 4 different ways—all recently increasing

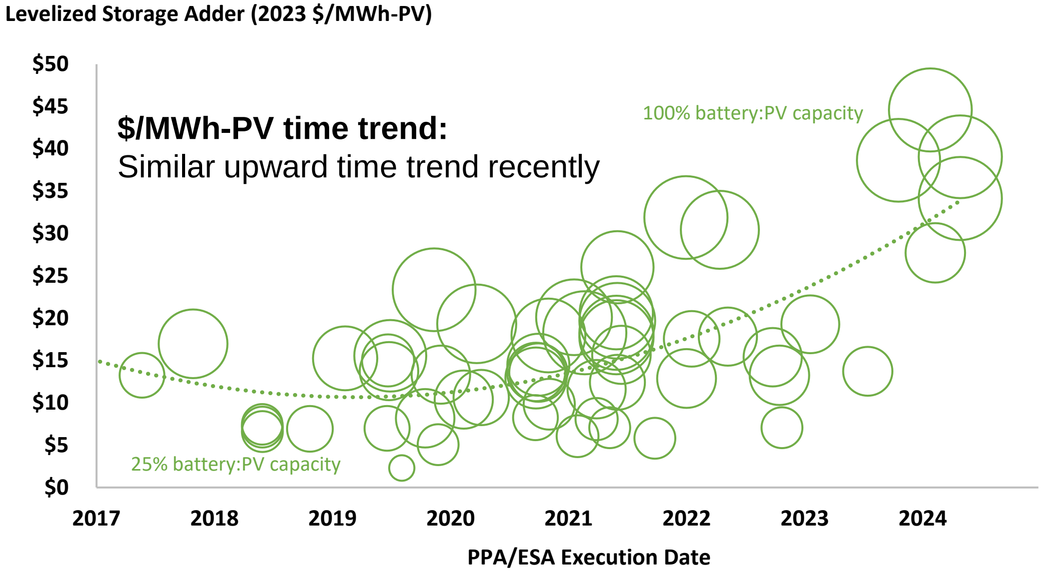
Graphs show adders from 55 PV hybrids in CA (26), NV (14), NM (11), AZ (3) and OR (1) totaling 4.8 GW_{AC} of batteries, all 4-hour duration

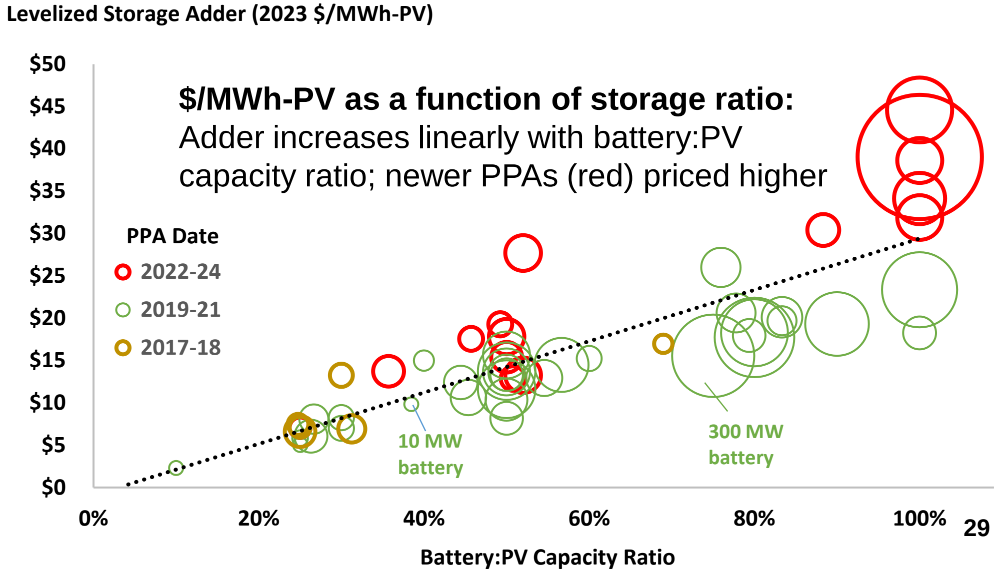




Greenfield plants only

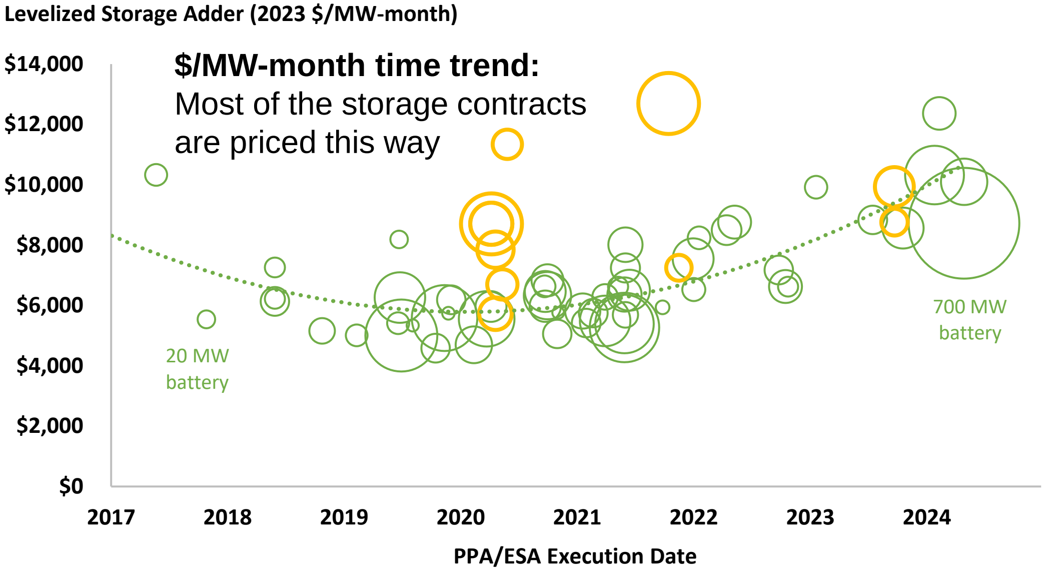
Bubble size corresponds to battery capacity except in bottom-left graph, where it corresponds to battery:PV capacity

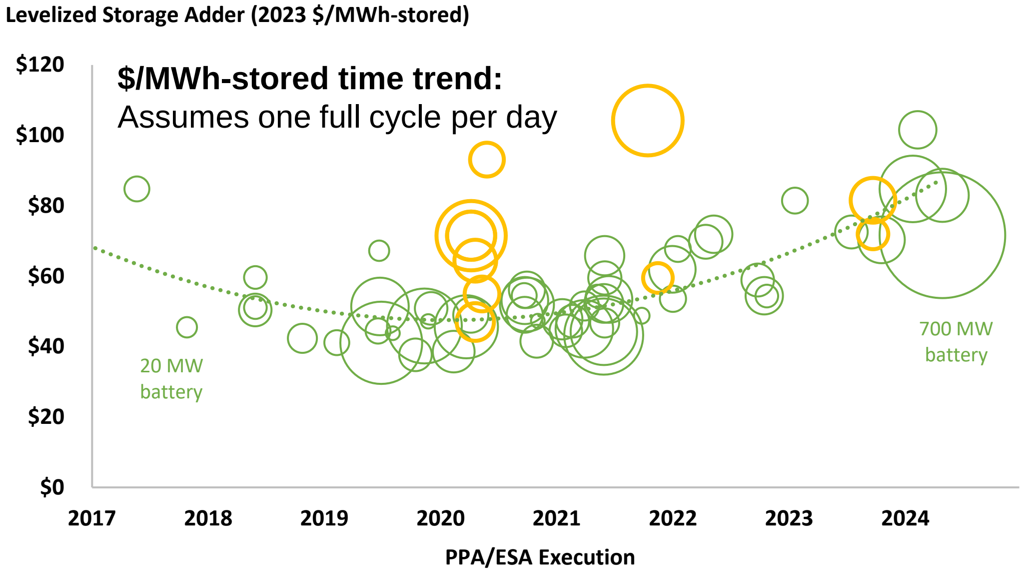




Retrofits tend to have higher "levelized storage adders" than greenfield projects; that's less true for the more recent (though limited) retrofit sample

Graphs show same data from last slide with an additional 11 retrofitted PV hybrids in CA (9) and NM (2) totaling 1.1 GW_{AC} of batteries

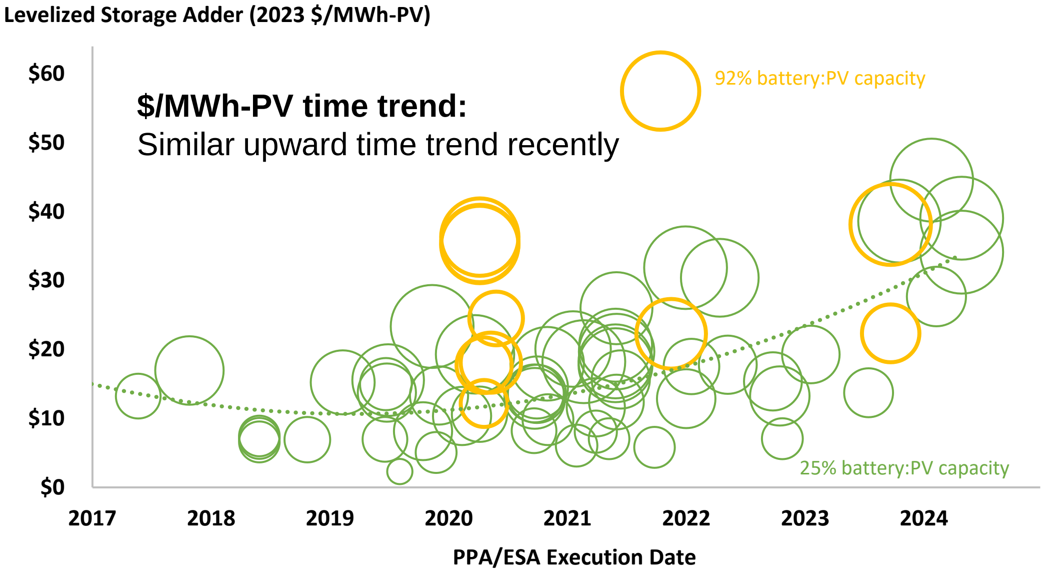


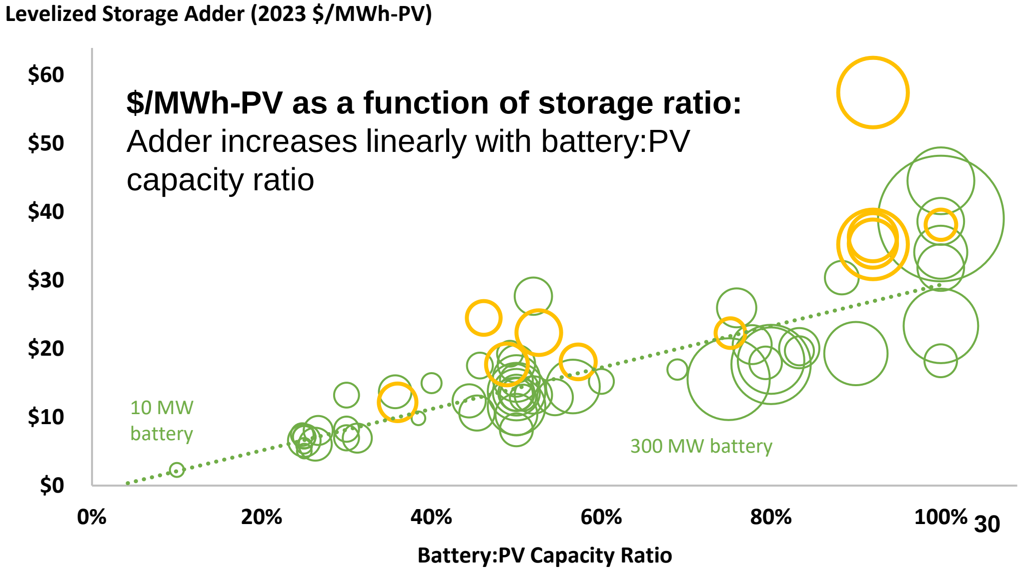


Green = greenfield

Gold = battery retrofit

Bubble size corresponds to battery capacity except in bottom-left graph, where it corresponds to battery:PV capacity

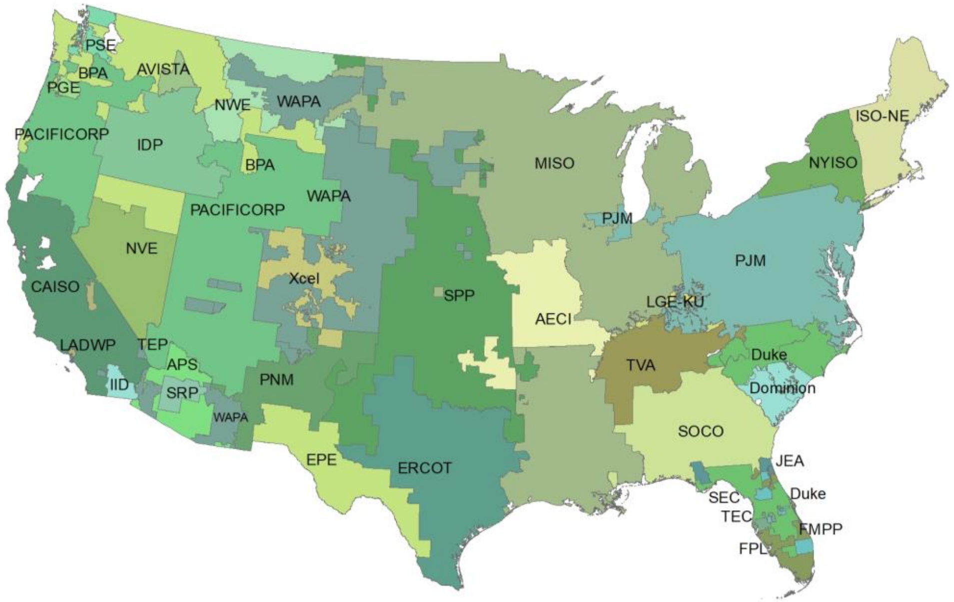




Hybrid Pipeline:
Hybrid plants in interconnection queues at the end of 2023

Methods and Data Sources

- Data collected from interconnection queues for 7 ISOs / RTOs and 44 non-ISO balancing areas, which collectively represent >95% 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 2023
  - Full sample includes 11,472 “active” plants, of which 2,734 (24%) are in a hybrid or co-located configuration
  - Hybrids represent 667 GW (42%) of active generation capacity in queues, and 528 GW (52%) 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 ~46% of proposed hybrid plants
  - For the remainder, storage capacity was estimated using known storage:generator ratios from other plants

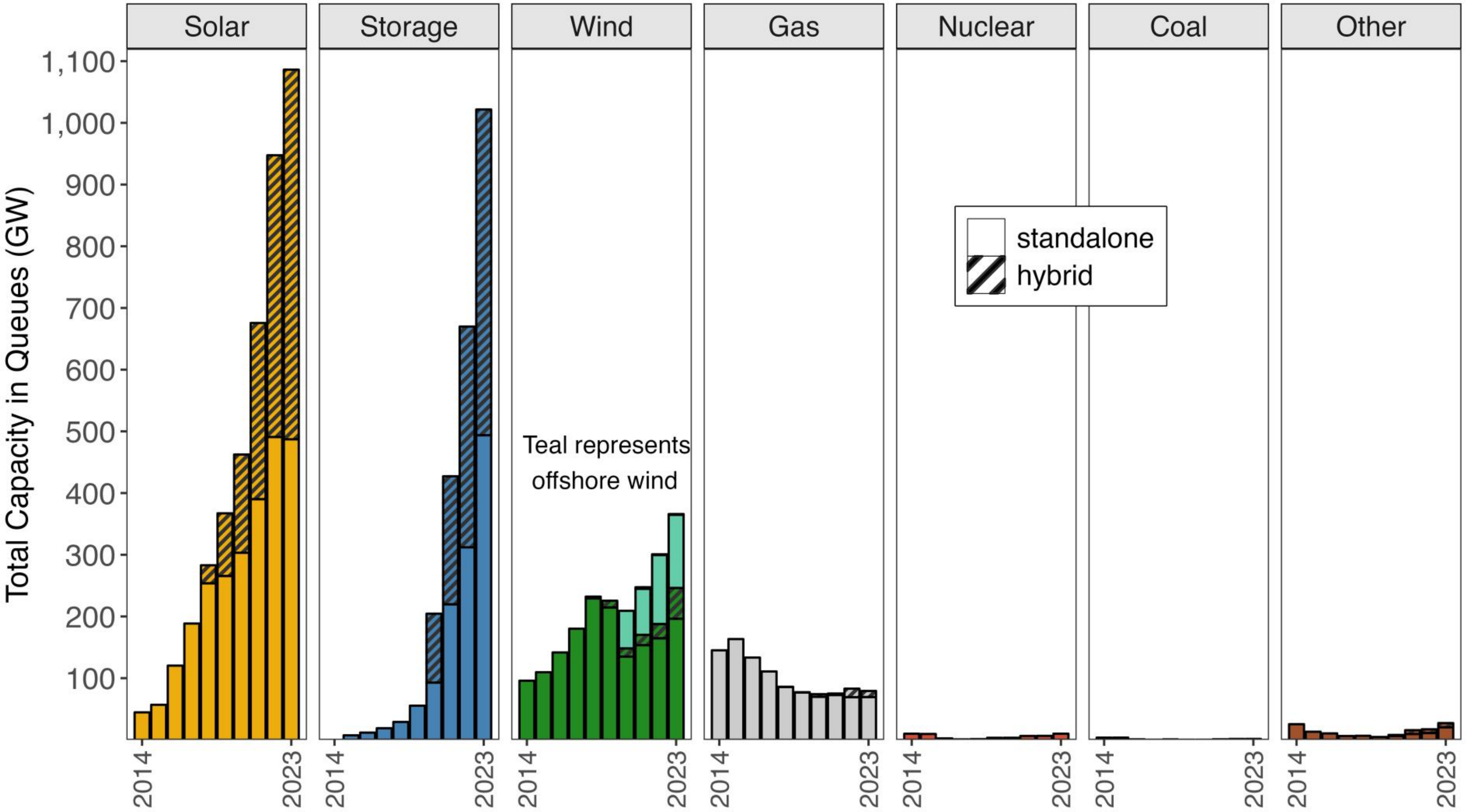


Coverage area of entities for which data was collected
Data source: Homeland Infrastructure Foundation-Level Data (HIFLD)
Note that service areas can overlap
No data collected for Hawaii or Alaska

For more information, see LBNL’s annual interconnection queue report 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.

Interconnection queues indicate that commercial interest in solar, storage, and wind has grown, including via hybridization; gas relatively stable in recent years



- "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.

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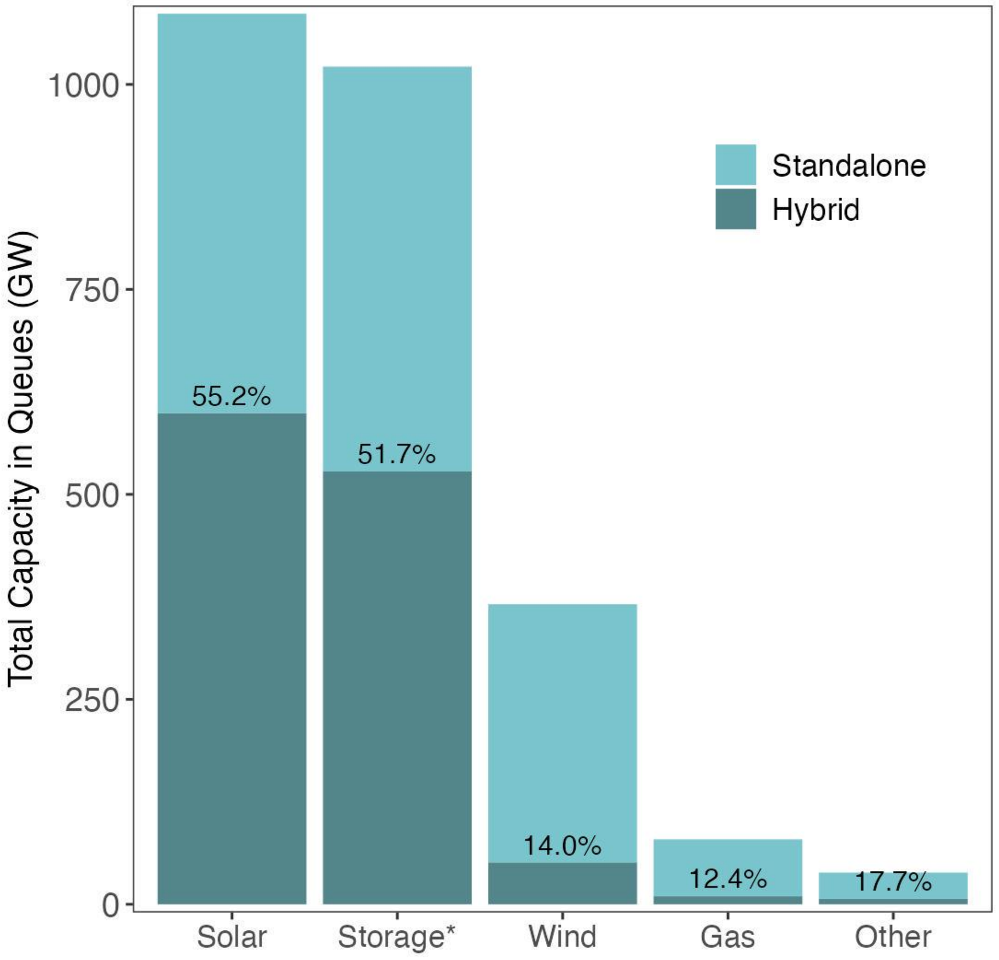
Numerous hybrid configurations exist in the queues, but Solar+Battery is dominant in both number of proposed plants and total capacity

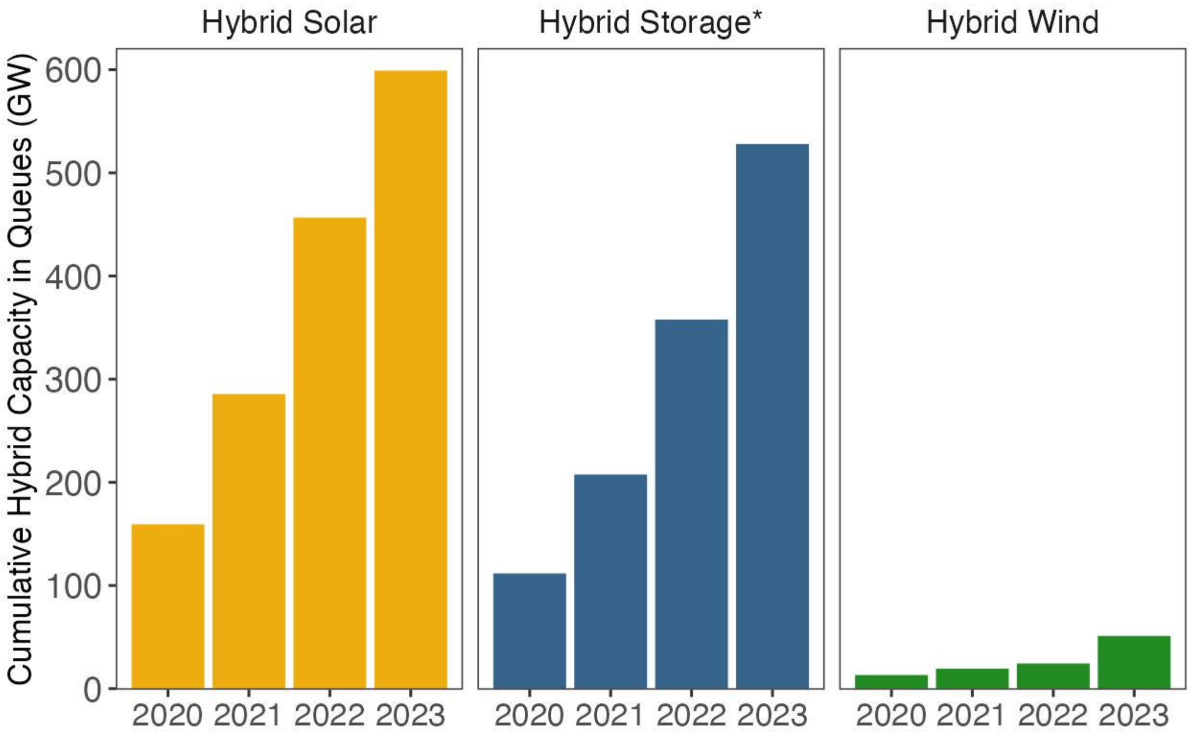
Hybrid Type	Number of Plants	Generator(s) Capacity (MW)
Solar+Battery	2,532	575,467
Wind+Battery	80	35,348
Solar+Wind+Battery	48	26,172
Unknown Hybrid	25	5,258
Gas+Battery	22	5,952
Solar+Wind	9	1,970
Gas+Solar+Battery	7	13,558
Other+Battery	6	1,410
Hydro+Other	1	165
Offshore Wind+Battery	1	1,190
Other+Solar	1	7
Solar+Gas	1	412
Solar+Hydro	1	7
Hybrid Total	**2,734**	**666,916**
Non-Hybrid Total	*8,738*	*1,399,594*

- Over 92% of all hybrid plants are Solar+Battery, representing 86% of all known hybrid generation capacity in the queues
- The next two largest configurations – Wind+Battery and Solar+Wind+Battery - account for only ~5% and ~4% of known hybrid capacity in the queues, respectively
- The 25 “Unknown” hybrids are plants from MISO for which details were unavailable
- There were 18% more hybrid plants – representing 33% more generating capacity – in the queues at the end of 2023 compared to 2022
- By comparison, storage capacity in hybrid configurations in the queues increased by 48% year-over-year (storage capacity in standalone configuration went up by 52%)

Capacity in hybrid plants is increasing: Hybrids comprise 55% of active solar capacity (599 GW), 52% of storage (528 GW), and 14% of wind (51 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.



- **Solar Hybrids** include: Solar+Storage (575 GW), Solar+Wind (2 GW), Solar+Wind+Storage (26 GW)
- **Wind Hybrids** include: Wind+Storage (35 GW), Wind+Solar (2 GW), Wind+Solar+Storage (26 GW)
- **Storage Hybrids** may be paired with any generator type; most are paired with solar
- **Gas Hybrids** include: Gas+Solar+Storage (14 GW) [not shown above]

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.

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

Region	% of Proposed Capacity Hybridizing in Each Region			
	Solar	Wind	Gas	Storage*
CAISO	98%	34%	88%	51%
ERCOT	49%	7%	4%	34%
ISO-NE	31%	0%	10%	8%
MISO	35%	13%	0%	63%
NYISO	24%	4%	0%	15%
PJM	24%	1%	0%	35%
SPP	22%	2%	3%	32%
Southeast (non-ISO)	34%	0%	0%	63%
West (non-ISO)	81%	30%	28%	69%
TOTAL	**55%**	**14%**	**12%**	**52%**

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

- **Solar** hybridization relative to total amount of solar in each queue is highest in CAISO (98%) and non-ISO West (81%), and is above 20% in all regions
- **Wind** hybridization relative to total amount of wind in each queue is highest in CAISO (34%), the non-ISO West (30%), and MISO (13%) and is less than 10% in all other regions

The percent of new queue requests electing a hybrid configuration has remained relatively constant over the last 3 years, except for solar proposals

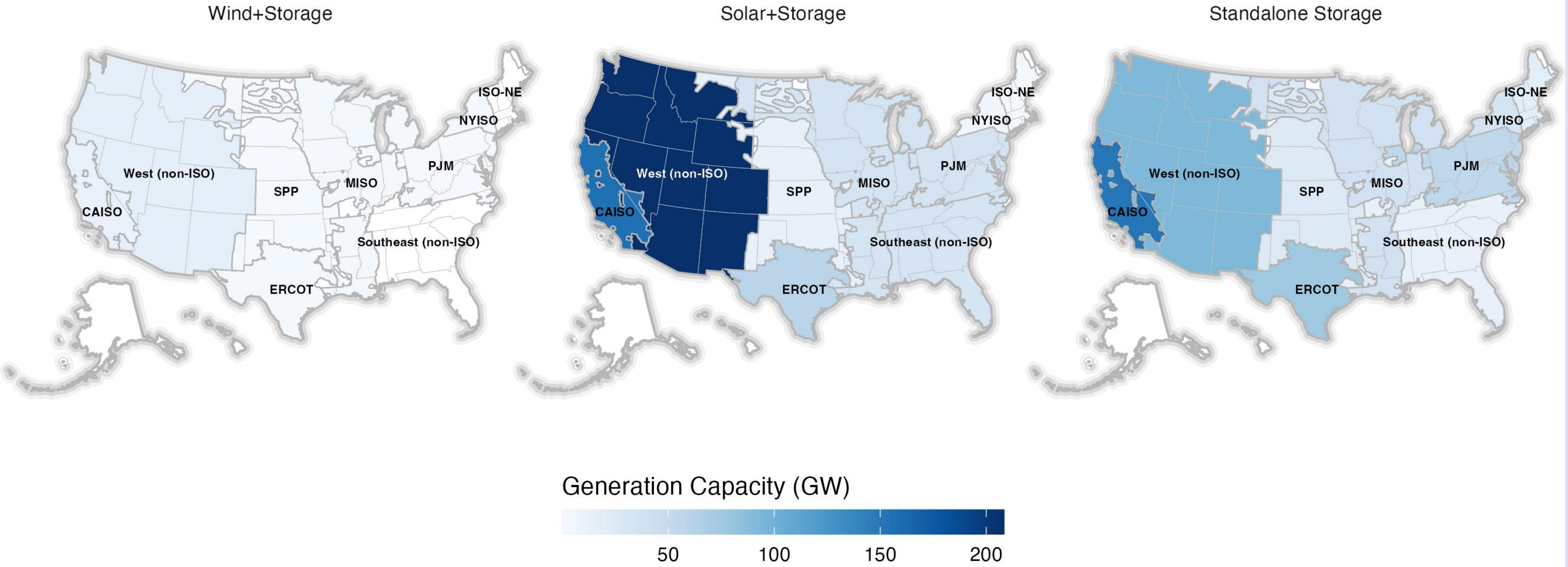
One might expect an increase in hybridization proposals overtime in regions with increasing solar saturation or with particularly clogged interconnection queues. A countervailing influence is that since the passage of the Inflation Reduction Act (IRA), storage need not be paired with solar or wind to receive the Investment Tax Credit (ITC).

Our U.S. wide results show flat or sometimes increasing (in the case of solar) proportions of hybridization requests in 2023, suggesting that the IRA has at least not yet severely dampened hybrid interest across the country

Region	% of Proposed Capacity Hybridizing in Each Region by Request Year											
	Solar			Storage			Wind			Gas		
	2021	2022	2023	2021	2022	2023	2021	2022	2023	2021	2022	2023
CAISO*	99%	n/a	98%	43%	n/a	51%	54%	n/a	29%	100%	n/a	100%
ERCOT	28%	53%	55%	18%	32%	23%	8%	0%	11%	10%	0%	0%
ISO-NE	38%	46%	12%	6%	8%	1%	0%	0%	0%	0%	0%	0%
MISO*	36%	39%	n/a	50%	50%	n/a	15%	17%	n/a	0%	0%	n/a
NYISO	13%	37%	47%	8%	0%	19%	11%	0%	40%	0%	0%	0%
PJM*	24%	41%	61%	18%	17%	22%	0%	2%	0%	0%	0%	0%
SPP*	n/a	12%	36%	n/a	24%	31%	n/a	0%	3%	n/a	0%	5%
Southeast (non-ISO)	63%	27%	33%	67%	70%	54%	0%	0%	0%	0%	0%	0%
West (non-ISO)	78%	87%	85%	69%	71%	68%	15%	31%	34%	0%	91%	2%
TOTAL	**52%**	**55%**	**75%**	**43%**	**55%**	**50%**	**16%**	**11%**	**24%**	**3%**	**43%**	**20%**

**CAISO paused their queue in 2022, 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 due to queue processing pauses/delays, such that data for PJM in that year should be interpreted with caution.*

Solar+Storage is dominant hybrid type in queues, with over 15x the proposed capacity of Wind+Storage; CAISO & West are of greatest interest, but other regions are growing



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

Note: Not all of this capacity will be built

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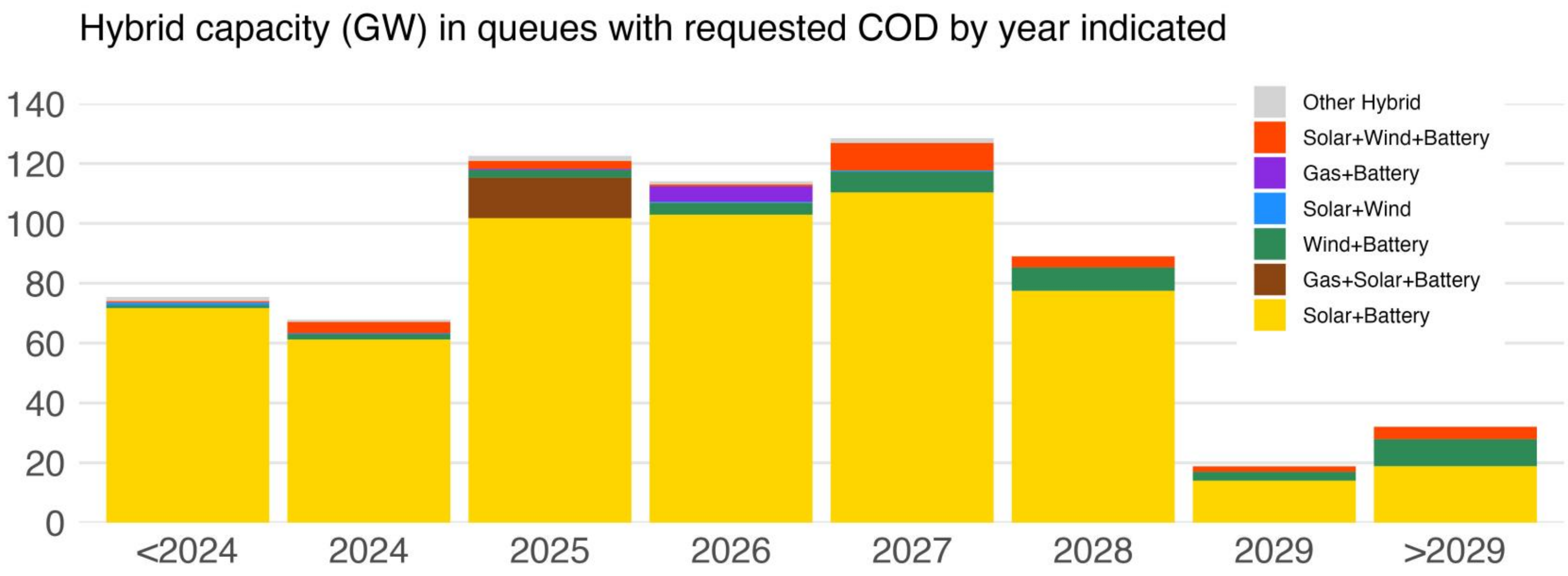
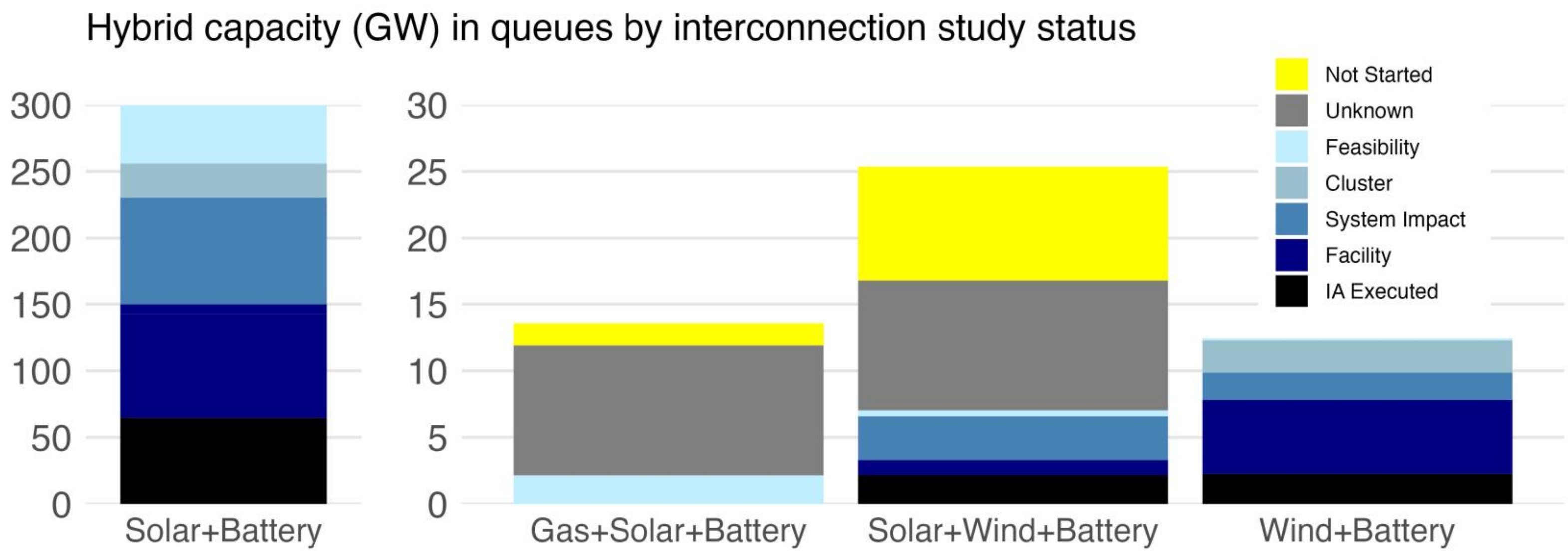
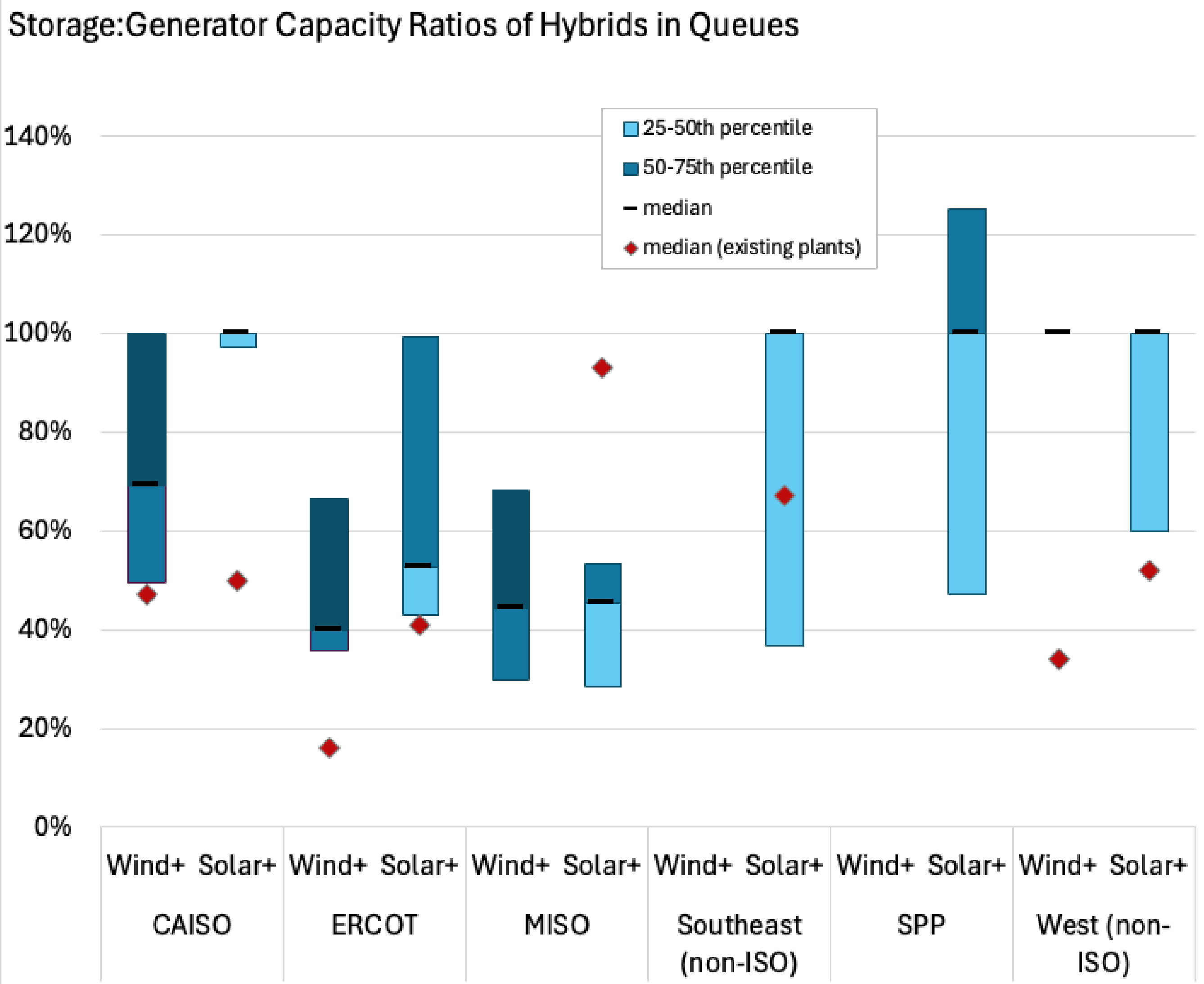
The majority (78%) of hybrid (generator) capacity in the queues has requested to come online by the end of 2027; 11% has an executed interconnection agreement (IA)





- Nearly all (95%) hybrid capacity in the queues is requesting to come online before 2029
- Solar+Battery dominates requested hybrid capacity additions through 2029
- Over 64 GW (11%) of Solar+ Battery have an executed IA, which is an order of magnitude more than IAs in other hybrid forms.
  - This compares to ~25 GW (5%) of standalone storage having an executed IA

In ERCOT and CAISO, proposed hybrid plants feature a higher storage contribution than existing hybrids; in these regions, median storage:generator ratio is higher for solar than wind 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, and slides 9-10)

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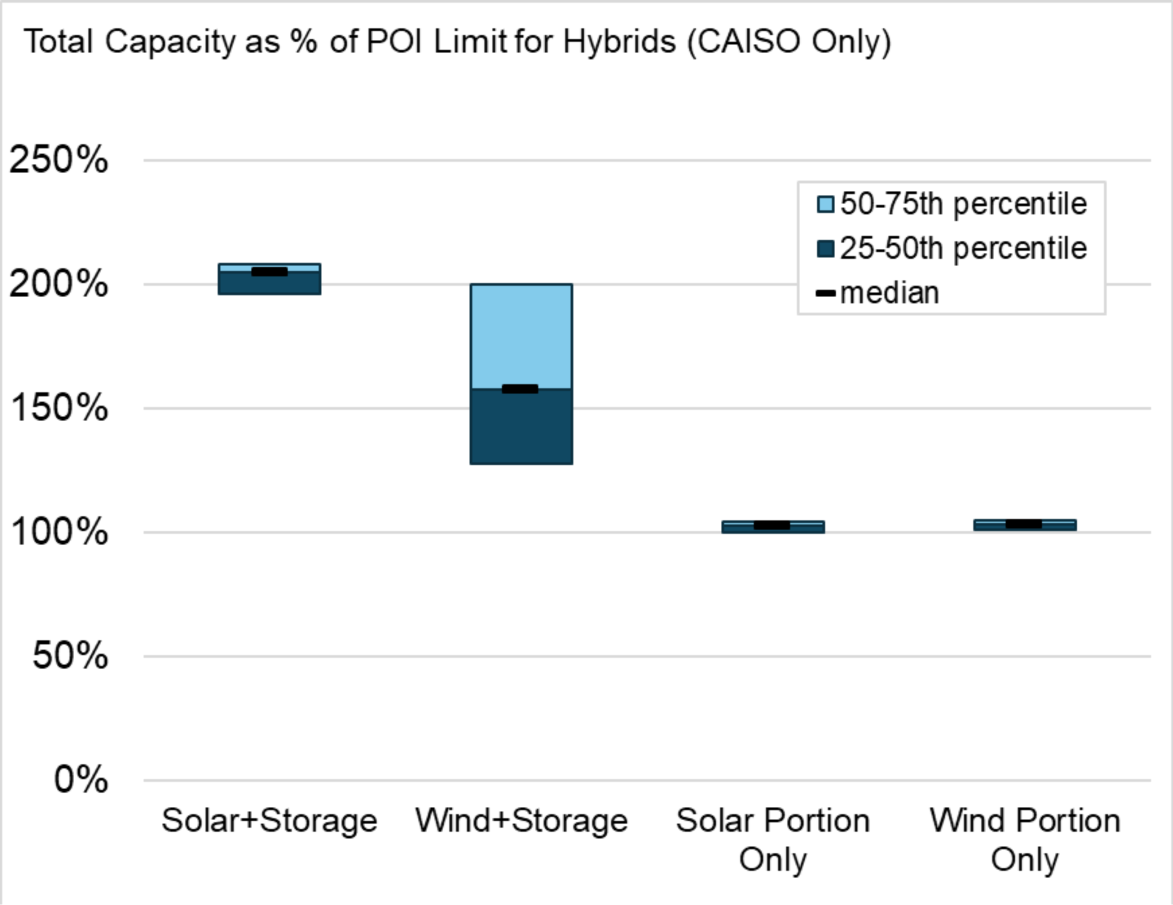
Solar+storage and wind+storage plants in CAISO base POI limits on generator capacity; wind and solar portion of hybrid projects in the queue data are equivalent to their POI limits



- Point of interconnection (POI) capacity limits were only provided in CAISO's queue
- For solar+storage plants, the median combined (solar+storage) capacity is more than double (205%) the POI limit
  - The median solar+storage capacity has hovered around 200% of the POI limit for queue requests since 2015
- For wind+storage plants, the wind capacity alone equals or exceeds the POI limit in 93% of plants, and the median total (wind+storage) capacity is 158% of the POI limit
- These values suggest that these plants (both wind and solar) expect to dispatch the battery only when the generator is operating at less than full output
- This has important implications for dispatch assumptions of hybrid plants in modelling

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Conclusions

Conclusions: 2023 was another big year for hybrids in the US

At the end of 2023, there were nearly 49 GW of operational hybrid plants, and roughly 667 GW in the queues. More batteries were operating as part of hybrid plants than on a standalone basis.

- In 2023, 80 new hybrid plants (+21% year-over-year) added 7.9 GW (+19%) of operational generating capacity and 3.6 GW / 11.6 GWh (+59% / +67%) of operational storage capacity. There were also 18% more hybrid plants in the queues at the end of 2023 compared to 2022 even though the IRA, passed in August 2022, made standalone storage eligible for the ITC, thereby removing some of the impetus to couple batteries with PV. The hybridization trend remains strong.
- There are many different hybrid configurations currently operating in the US, but PV+Storage dominates, with by far the most plants (288), storage capacity (7.8 GW), and storage energy (24 GWh). The vast majority of new hybrid plants added in 2023—66 out of 80—are PV+Storage.
- Similarly, PV+Storage accounts for >92% of the 2,734 hybrids totaling 667 GW of generation capacity in interconnection queues across the US. Nationally, 55% of all solar capacity in the queues is proposed in hybrid format; in CAISO and the non-ISO West, it's 98% and 81% respectively.
- On average, operational PV+Storage plants have significantly higher storage ratios (54%) and longer durations (3.1 hours) than other hybrid types. Proposed PV+Storage plants tend to have even higher storage ratios.
- Grid services are most reported primary use case for storage in all but PV+Storage hybrid plants, which rather focus on renewable firming and curtailment mitigation. Battery roundtrip efficiency declines with age, though some projects maintain high efficiency in early years post-COD
- At least in CAISO, the solar capacity of operational and proposed PV+Storage plants typically matches or exceeds the grid interconnection limit, which suggests that these plants expect to dispatch the battery only when the generator is operating at less than full output.
- Among a sample of PV+battery plants with public PPAs, PPA prices have increased since 2020. Levelized storage adders for PV+Battery plants on the mainland have recently increased to ~$10000/MW-month, ~$80/MWh-stored, and ~$35/MWh-PV (depending on the storage ratio).

Hybrid Power Plants

Status of Operating and Proposed Plants, 2024 Edition

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Image: Slate Hybrid in California
300 MW PV + 140.25 MW/561 MWh of AC-coupled storage
Photo credit: Goldman Sachs Renewable Power