

Hybrid Power Plants

Status of Operating and Proposed Plants, 2022 Edition



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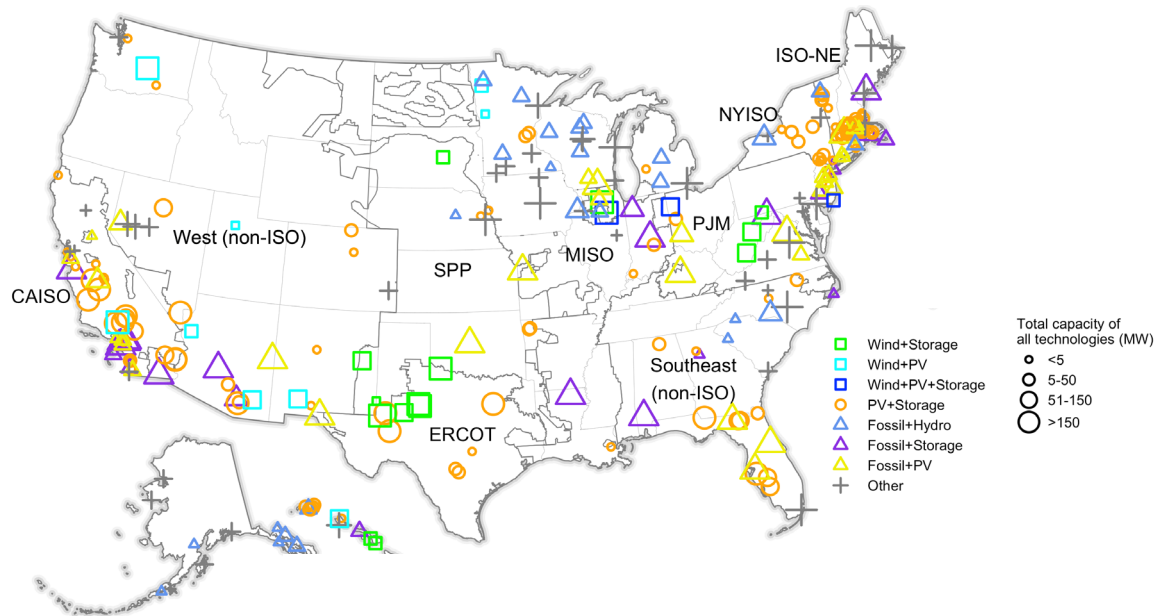
Funded by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Wind Energy Technologies Office and Solar Energy Technologies Office, under Contract No. DE-AC02-05CH11231.

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

High-Level Findings: 2021 Was a Big Year for Hybrids in the US

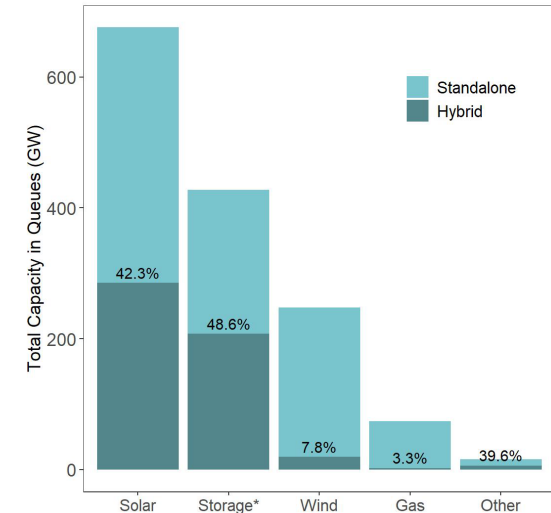
Hybrid / co-located plants exist in many configurations and are distributed broadly across the U.S.

- PV+Storage dominates in terms of number of plants (140), storage capacity (2.2 GW), and storage energy (7 GWh)
- There is now more battery capacity operating within PV+Battery hybrids than on a standalone basis
- Storage:generator ratios are higher and storage durations are longer for PV+Storage plants than for other types of generator+storage hybrids



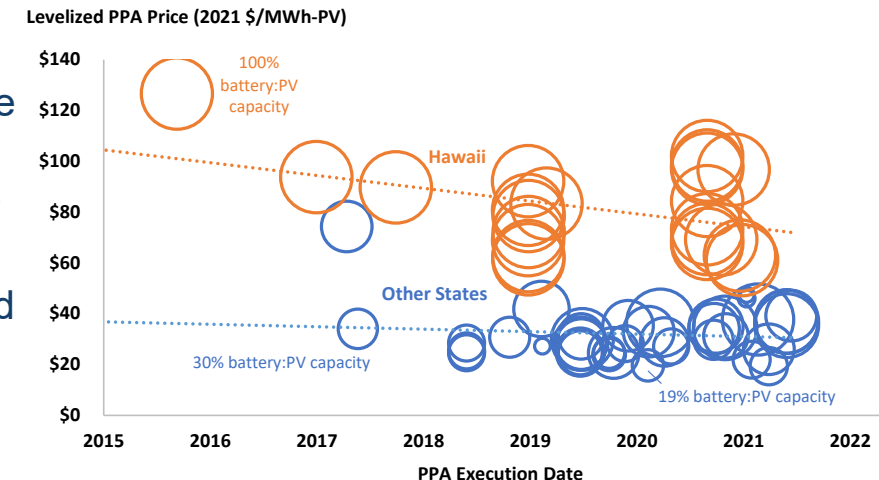
Hybrids comprise a large and growing share of proposed plants

- 42% (285 GW) of all solar and 8% (19 GW) of all wind in interconnection queues are proposed as hybrids (up from 34% and 6% in 2020)
- PV+storage dominates the hybrid development pipeline (at >90%)
- Proposed plants are concentrated in the West and CAISO



Prices from a sample of 67 PV+Storage PPAs in 10 states totaling 8.0 GW_{AC} of PV and 4.5 GW_{AC} / 18 GWh of batteries suggest that:

- Levelized PPA prices have declined over time
- But “levelized storage adders” for PV+Battery plants on the mainland have recently increased



Operational Hybrid Plants:

Online as of the end of 2021

Hybrid PPA Terms:

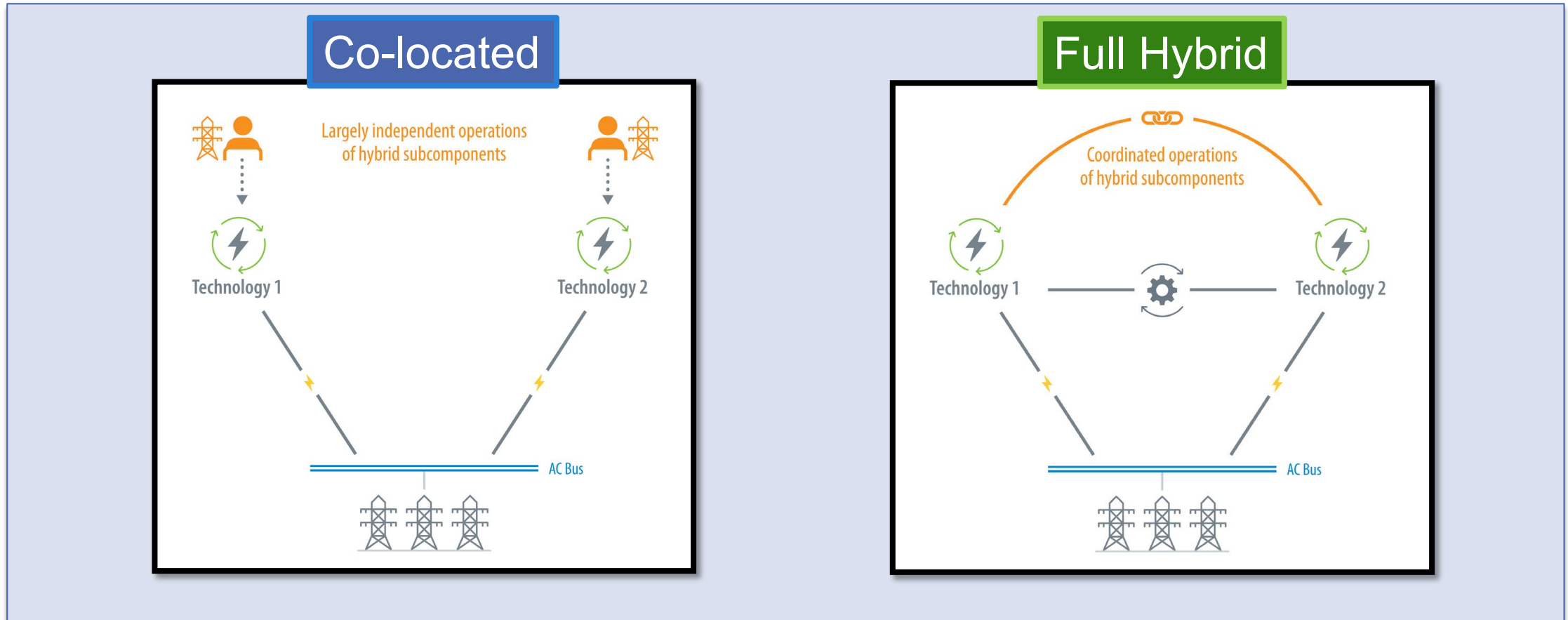
Among a sample of PV+battery plants with public PPAs

Hybrid Pipeline:

Hybrid plants in interconnection queues at the end of 2021

Presentation Scope

Scope includes **co-located** plants that pair two or more generators and/or that pair generation with storage 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.



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Operational Hybrid Plants: Online as of the end of 2021



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Methods and Data Sources

- Form **EIA-860 2021 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 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 2021

298 plants, 35.9 GW of generating capacity, 3.2 GW / 8.1 GWh storage capacity / energy

Operating at end of 2021	# plants	Gen 1* (Total MW)	Gen 2* (Total MW)	Gen 3* (Total MW)	Storage Capacity (Total MW)	Storage Energy (Total MWh)	Average Storage:Generator Ratio	Average Duration (hrs)
PV+Storage	140	4,175	0	0	2,196	7,015	53%	3.2
Wind+Storage	14	1,425	0	0	198	122	14%	0.6
Wind+PV	9	594	269	0	0	0	0%	n/a
Wind+PV+Storage	3	323	25	0	38	18	11%	0.5
Fossil+PV	34	10,127	223	0	0	0	0%	n/a
Fossil+Storage	24	6,067	0	0	727	867	12%	1.2
Fossil+PV+Storage	6	1,027	14	0	8	12	1%	1.6
Fossil+Hydro	26	490	78	0	0	0	0%	n/a
Fossil+Wind+PV	4	286	47	4	0	0	0%	n/a
Fossil+Wind	9	57	26	0	0	0	0%	n/a
Nuclear+Fossil	4	6,480	1,355	0	0	0	0%	n/a
Biomass+Hydro	9	327	54	0	0	0	0%	n/a
Biomass+PV	4	102	9	0	0	0	0%	n/a
Hydro+Storage	5	209	0	0	32	31	15%	1.0
Geothermal+PV	2	85	18	0	0	0	0%	n/a
Geothermal+PV+CSP	1	47	22	2	0	0	0%	n/a

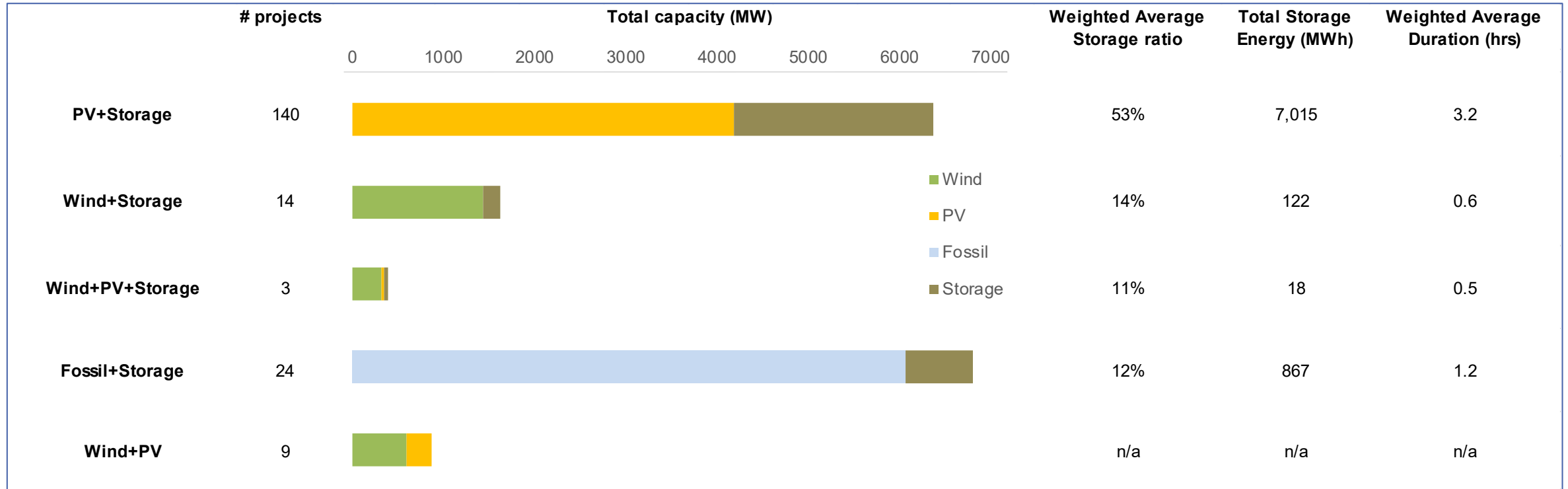
Sources: EIA 860
2021 Early
Release, Berkeley
Lab

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 hybrids are most numerous (140), and have by far the most storage capacity (2.2 GW) and energy (7 GWh) than other hybrids

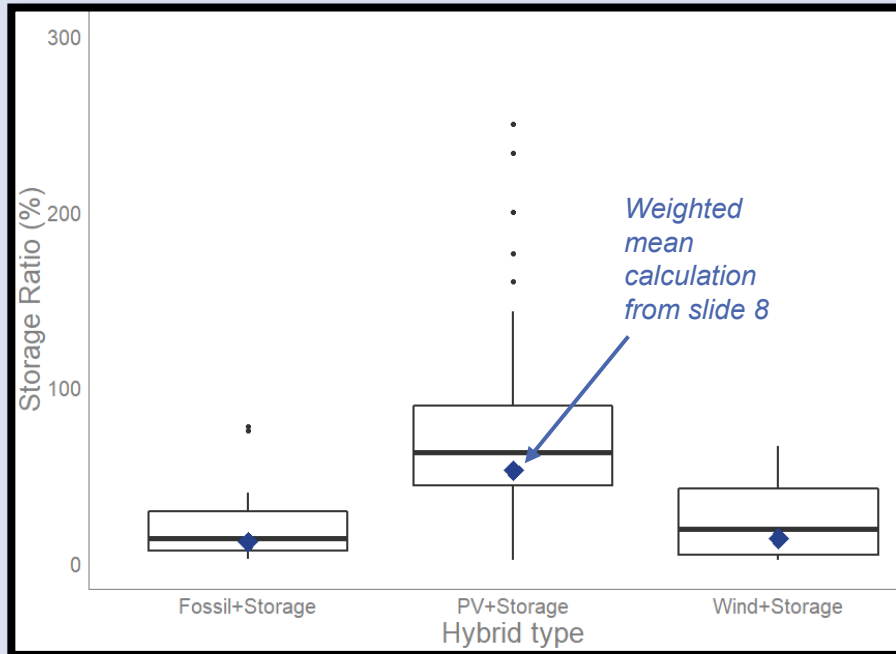


Notes: Not included in the figure are 108 other hybrid / co-located plants with other configurations; details on those plants are provided in the table on slide 7. **Storage ratio** is defined as total storage capacity divided by total generation capacity within a hybrid type. **Duration** is defined as total MWh of storage divided by total MW of storage within a hybrid type.

Sources: EIA 860 2021 Early Release, Berkeley Lab

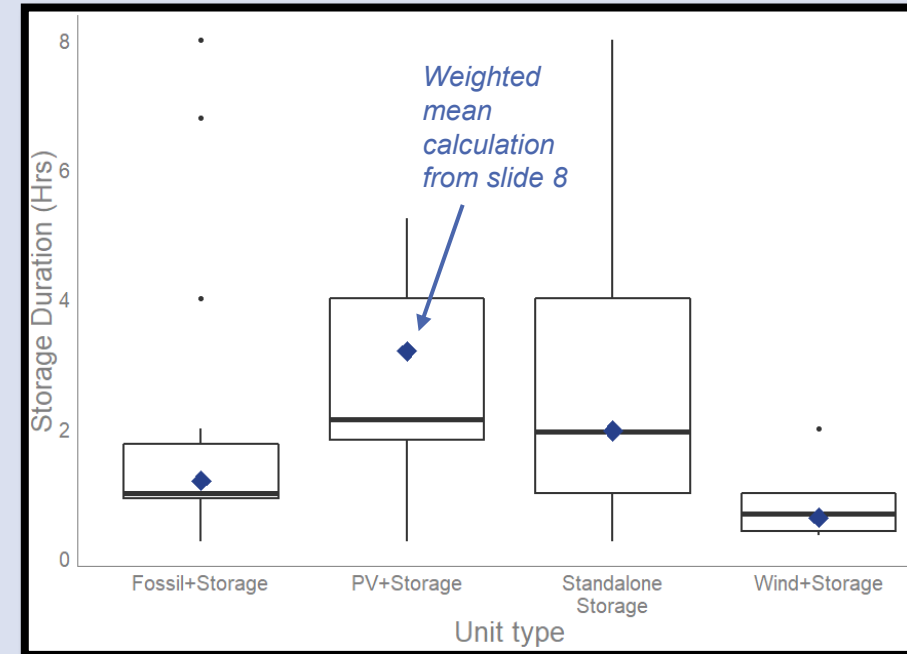
PV+Storage hybrids have higher storage-to-generator ratios and longer durations

PV+Storage median storage-to-generation ratio is highest at 64%



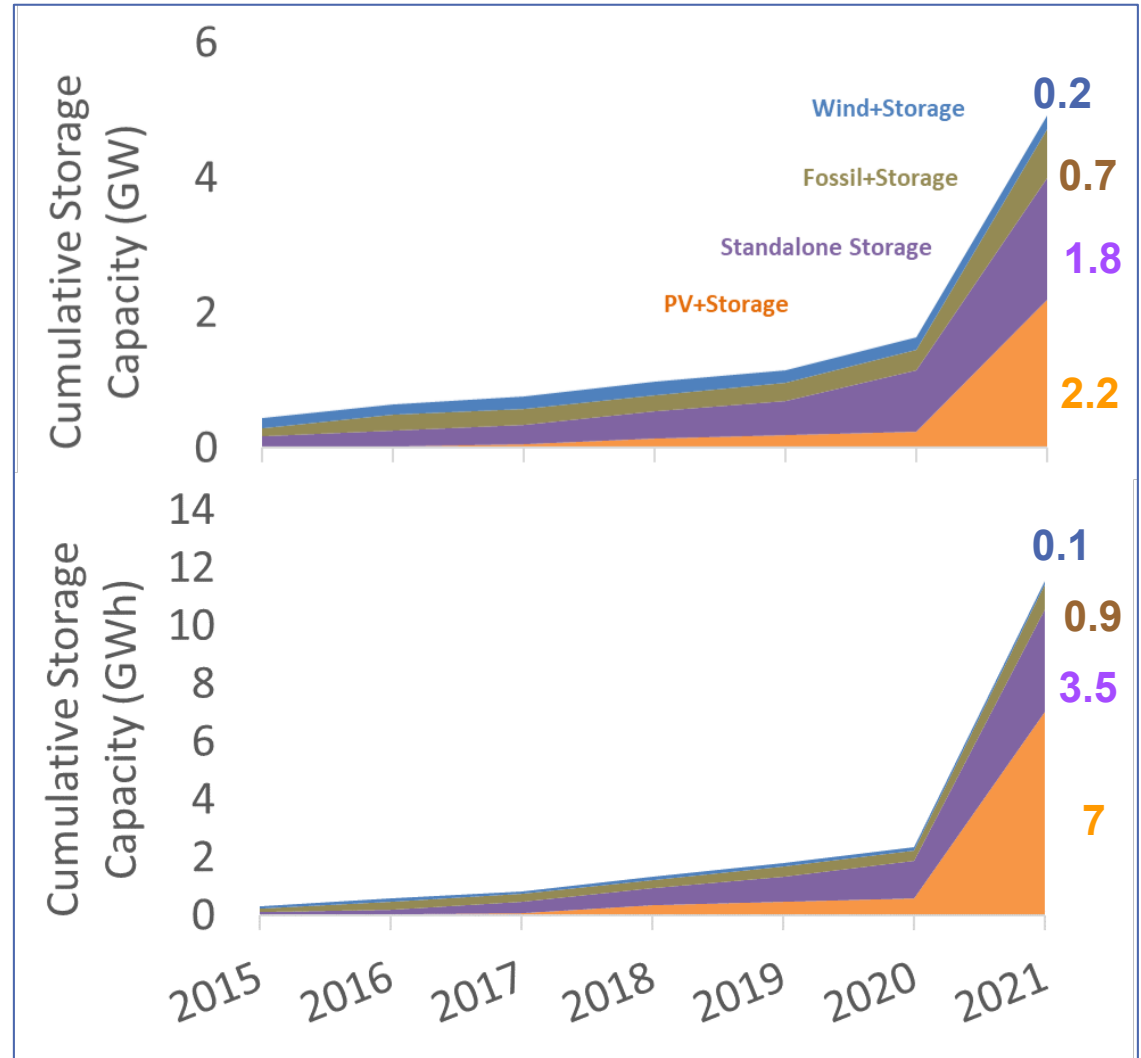
Note: Figure drops 2 PV+Storage outlier plants with storage ratios > 500%

PV+Storage median storage duration is highest at 2.1 hours



PV+Storage plants have more battery capacity and energy than standalone batteries

- Through 2021, PV+Storage plants include **more storage capacity** (by 400 MW) than standalone storage plants...
- ...and twice as much storage energy as (i.e., 3,500 MWh more than) standalone storage plants
 - ▣ In fact, PV+Storage has more storage energy than all other hybrid and standalone categories combined
- There was a large jump in battery capacity for both PV+Storage and Standalone Storage in 2021

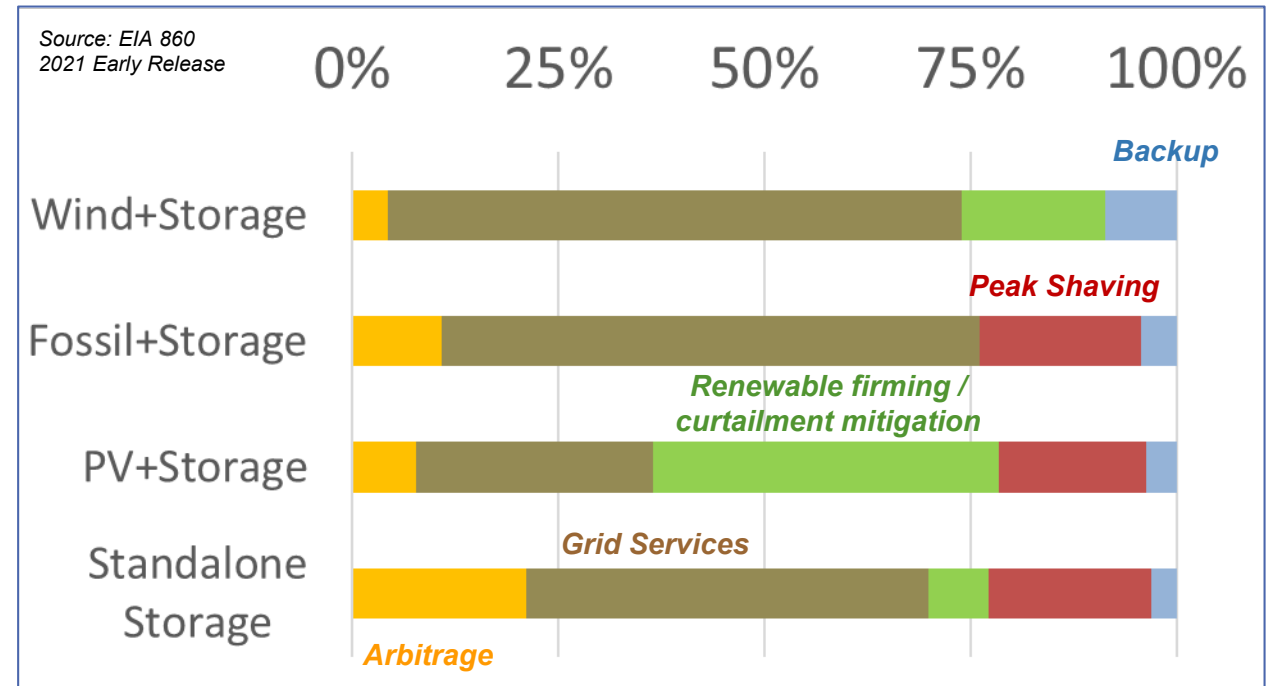


Note: These comparisons do not include pumped storage capacity or thermal storage from CSP plants. Rather, they only incorporate installed battery storage capacities, and limited amounts of flywheel and compressed air energy storage

Breakdown of self-reported use cases for battery storage is somewhat similar whether a standalone battery or a hybrid, though there are a few key differences

- Operators self-report use cases to EIA; individual plants can indicate multiple use cases
- Grid services are the most commonly reported use case, though renewable firming and curtailment mitigation is particularly important in PV+Storage hybrids
 - ▣ Wind+Storage has primarily targeted ancillary service markets
 - ▣ PV+Storage more often used to firm the PV capacity for resource adequacy purposes
- Backup power and arbitrage are least popular use cases reported by operators

Breakdown of battery use case among popular hybrid configurations and standalone storage



Grid services category includes the following: frequency regulation, load following, ramping/spinning reserve, load management, and voltage/reactive power support

Operational hybrid plants are scattered across the United States

PV Hybrids / Co-Located Plants

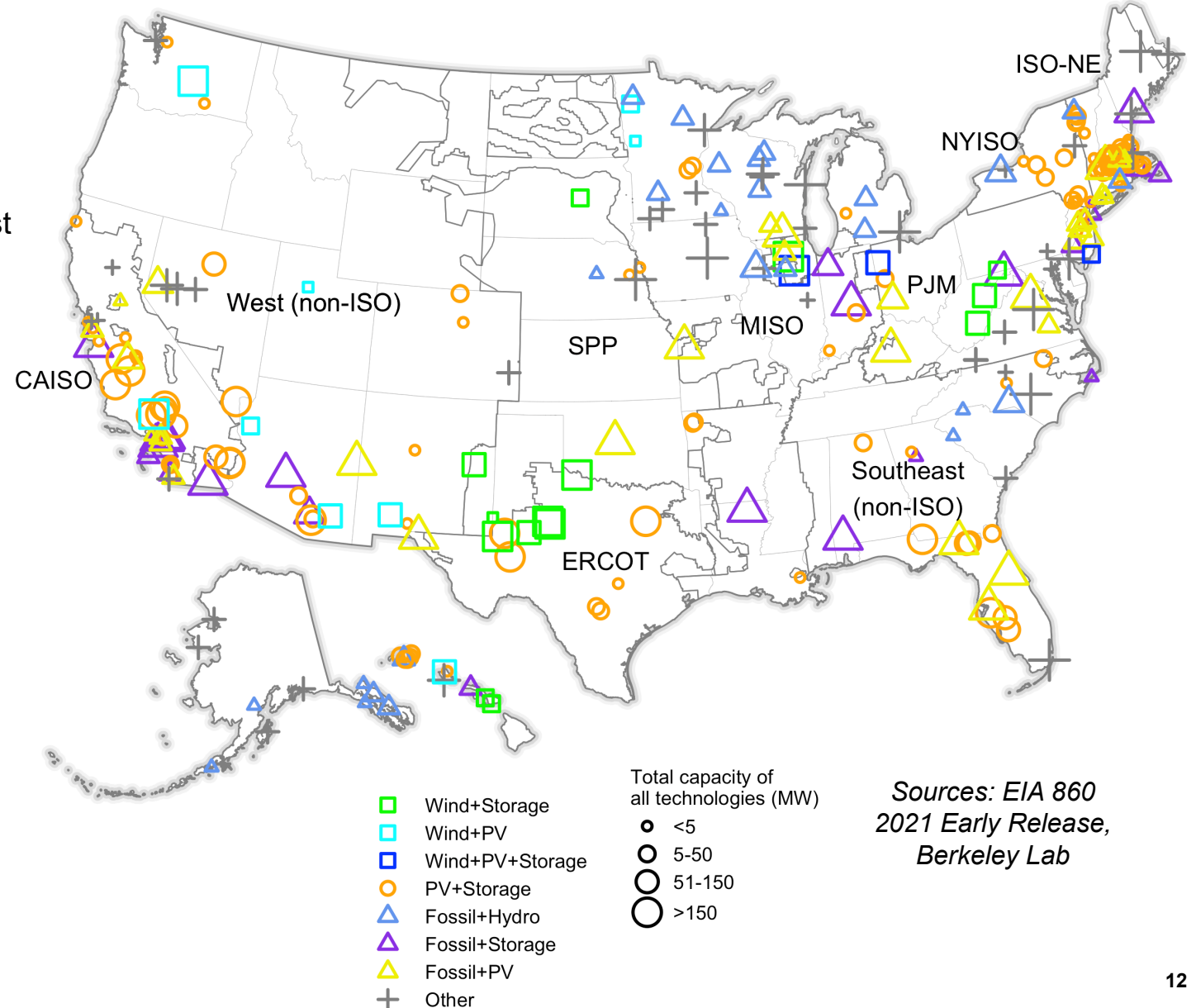
- Massachusetts contains the largest number of PV hybrid plants (54 plants total, 49 of which are PV+Storage), though plants all include <7 MW of PV
- With 37 total plants, California has the second highest number of PV hybrid plants across the United States, 12 of which have installed PV capacities >100 MW

Wind Hybrids / Co-Located Plants

- Wind hybrids are relatively sparse across United States
- Texas contains 5 of the 10 largest wind hybrids by wind capacity

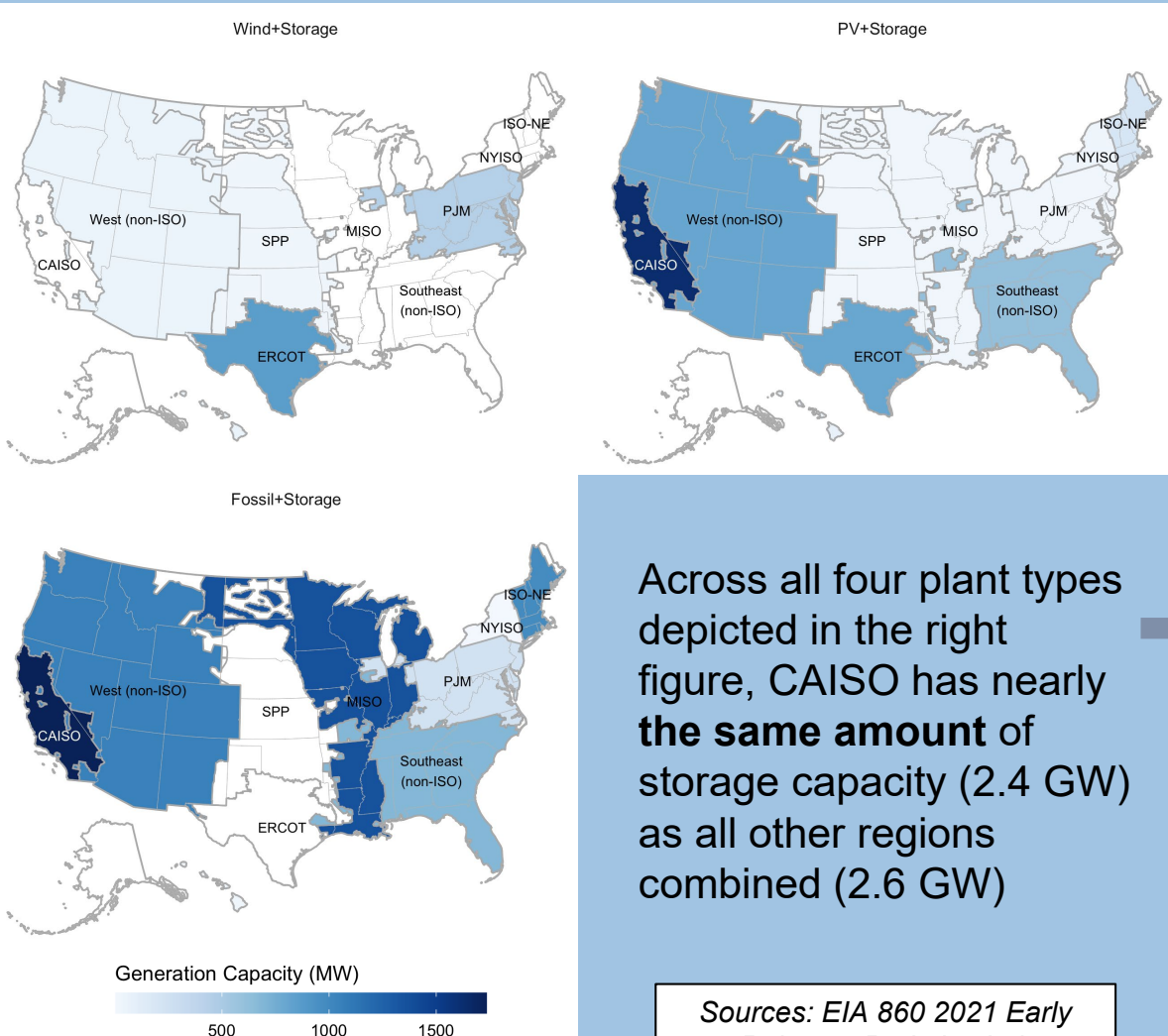
Fossil Hybrids / Co-Located Plants

- 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 country with small amounts of PV added to larger fossil units



Regional development trends differ depending on the plant type, though CAISO dominates across multiple types

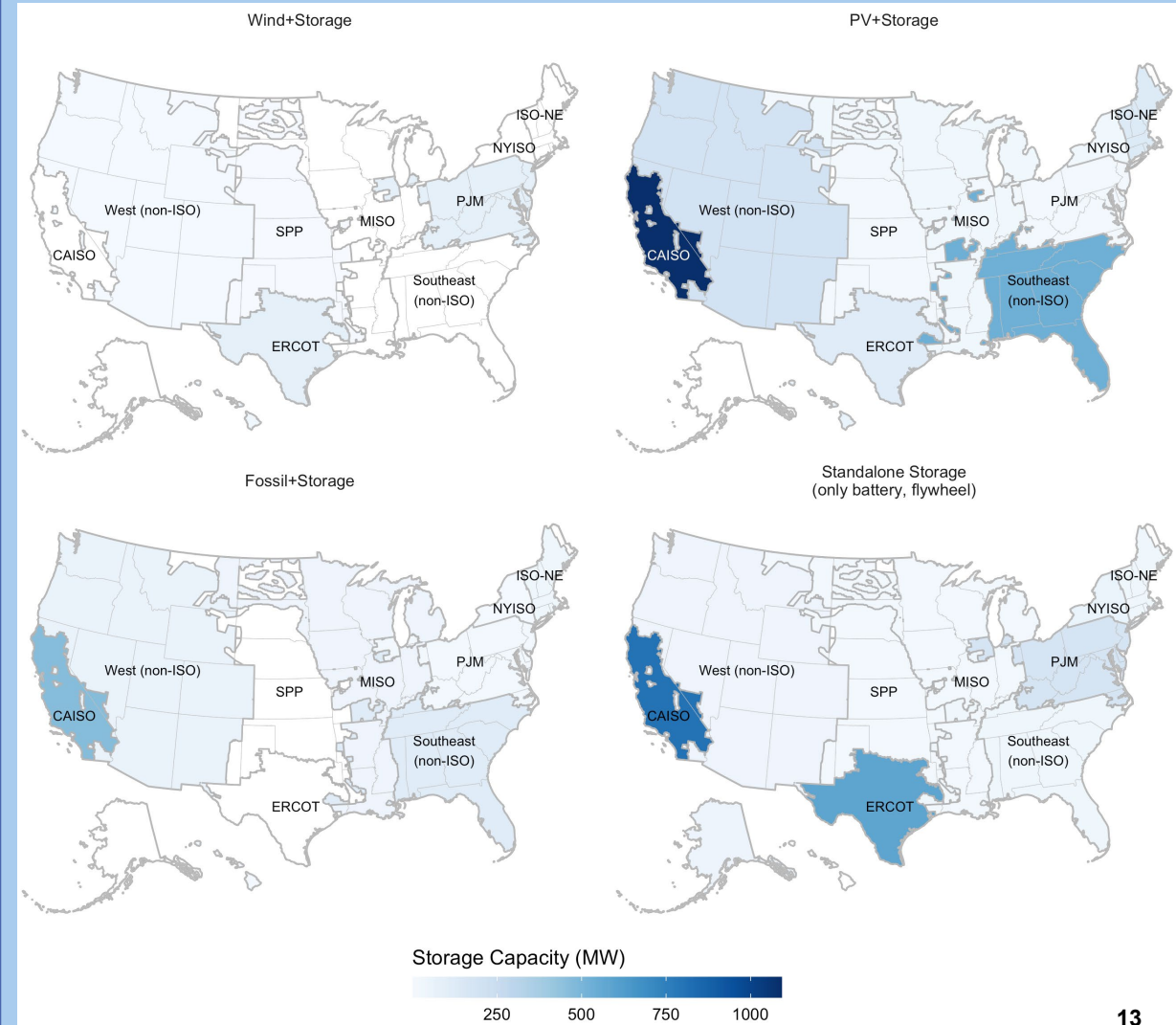
Aggregate Generator Capacity by Hybrid Type and ISO



Across all four plant types depicted in the right figure, CAISO has nearly **the same amount** of storage capacity (2.4 GW) as all other regions combined (2.6 GW)

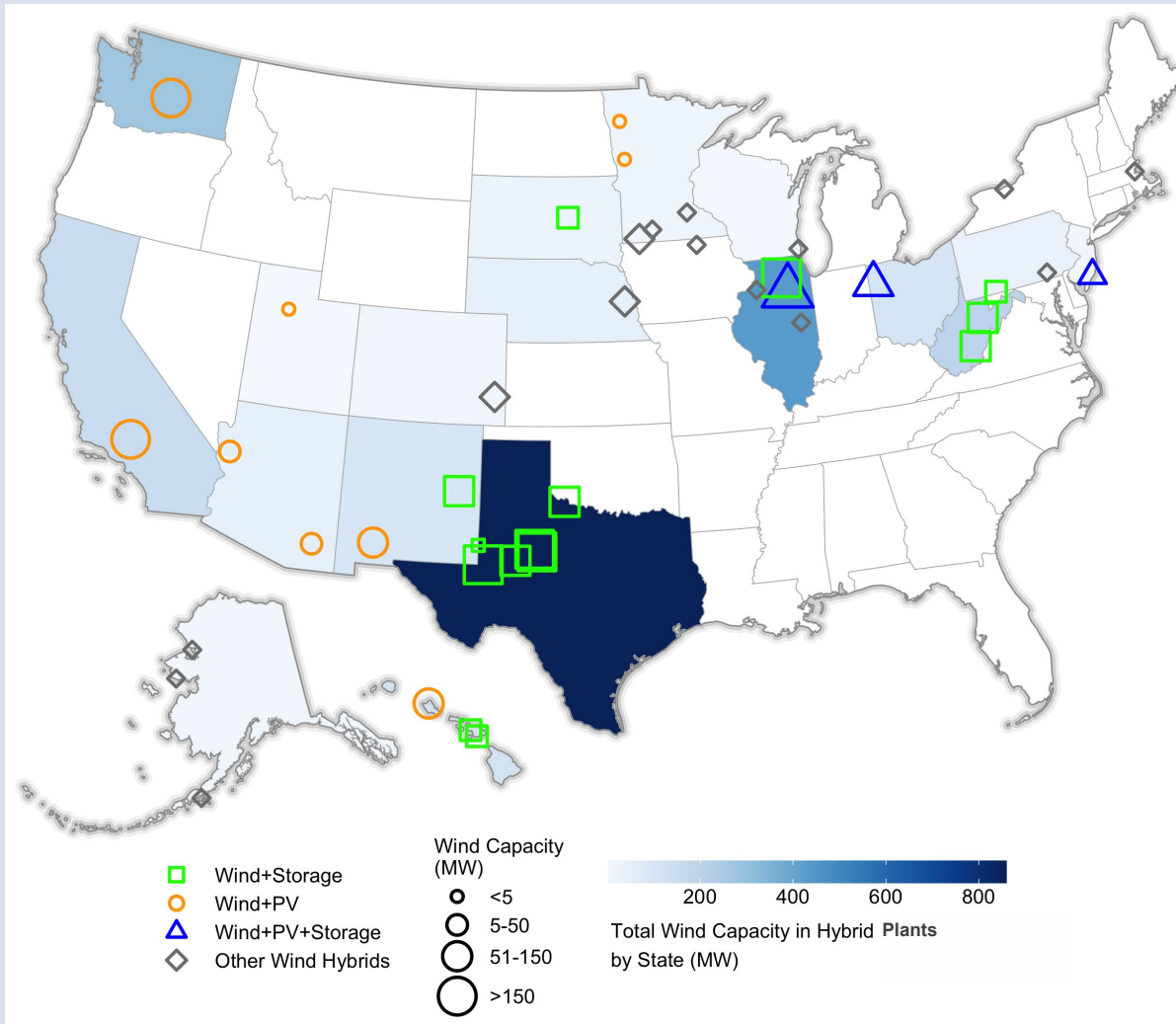
Sources: EIA 860 2021 Early Release, Berkeley Lab

Aggregate Storage Capacity by Plant Type and ISO



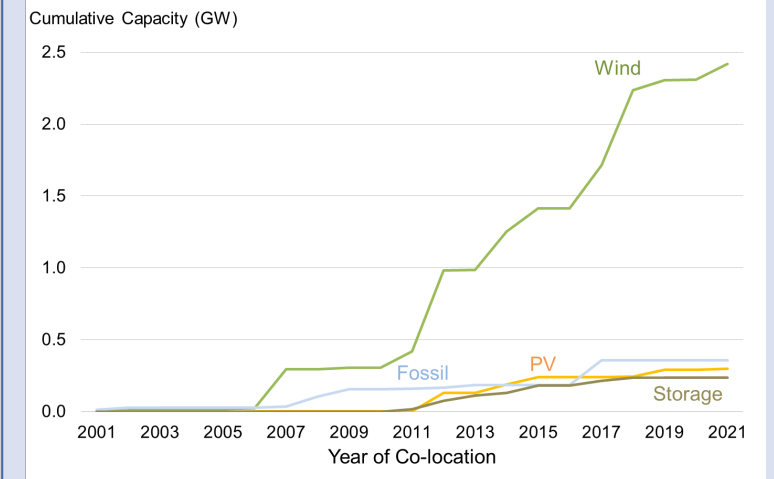
Hybrid wind plants that pair wind with storage and other resources saw limited growth in 2021

Online Wind Hybrid / Co-located Plants



Growth in Wind Hybrid / Co-located Capacity over Time

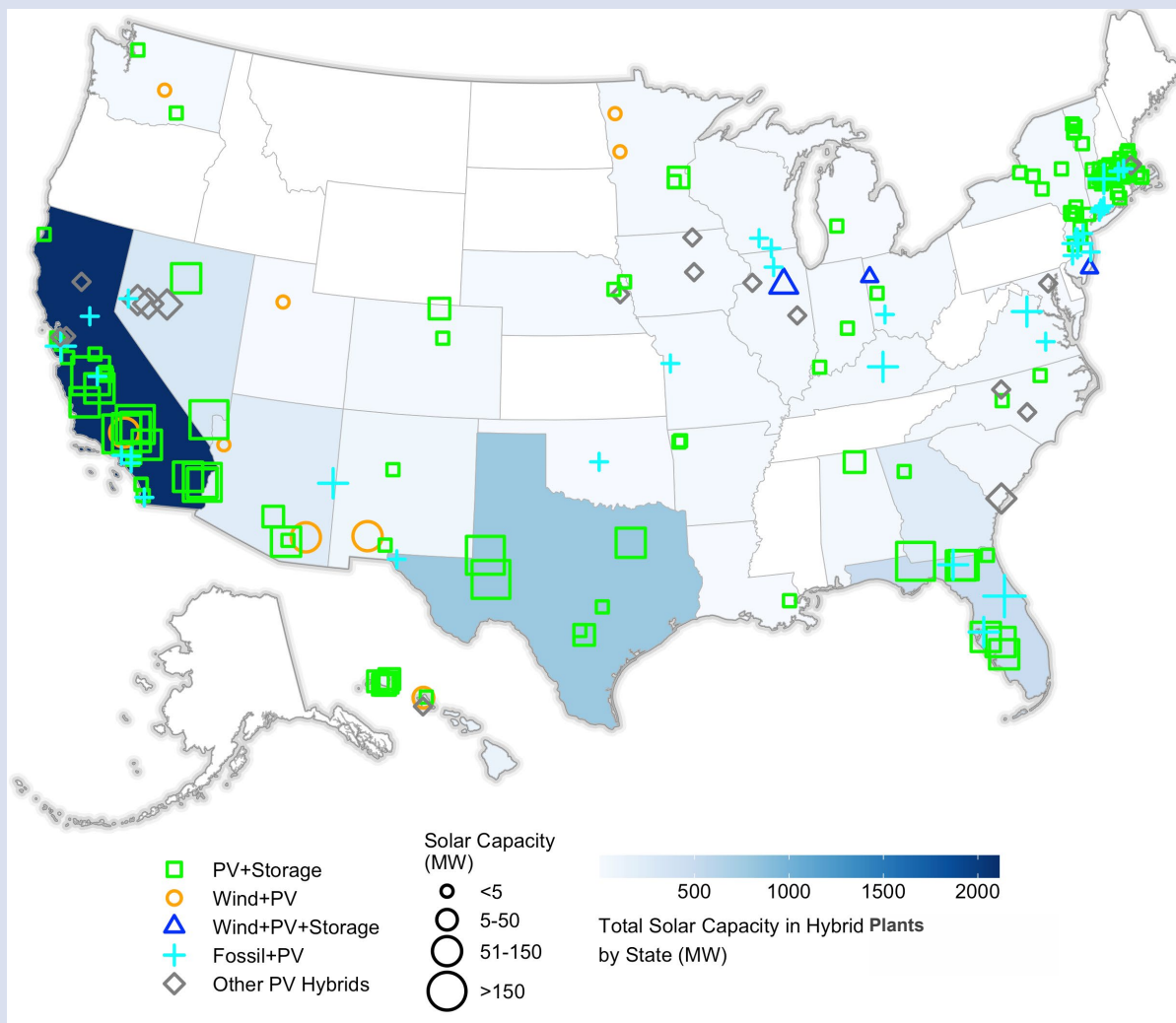
depicts amount of wind and other types of generation and storage being paired with wind, over time



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

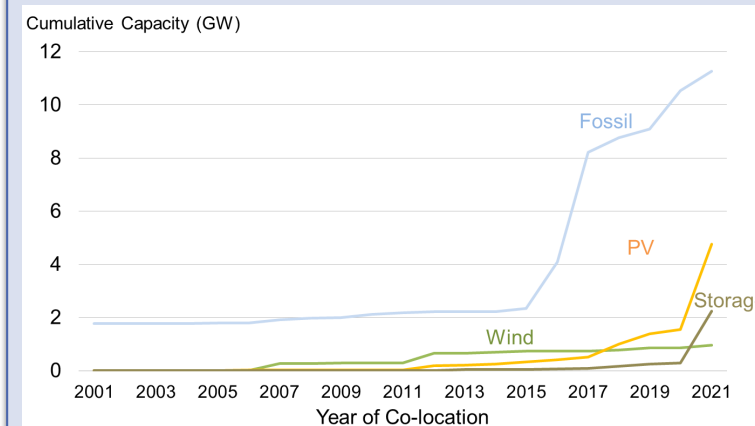
PV+Storage dominates the various PV+ hybrid configurations in terms of number of plants, PV capacity, storage energy, and year-over-year growth

Online PV Hybrid / Co-located Plants



Growth in PV Hybrid / Co-located 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 dominates this figure.

AC vs. DC coupling among the 35 operating PV+Storage plants with PV capacity >5 MW_{AC}

- This 35-plant sub-sample accounts for ~90% of the total PV capacity, storage capacity, and storage energy of the 140 PV+Storage plants that were operational at the end of 2021
- 27 are AC-coupled and 8 are DC-coupled
 - But 16 of these 35 plants are battery retrofits, which favors AC coupling (i.e., centralized batteries)
 - All but 1 of these 16 retrofits are AC-coupled
 - The lone DC-coupled retrofit has a very small battery (a 5% battery:PV capacity ratio), which makes it easier to retrofit as DC-coupled
 - Focusing on just the 19 greenfield plants (i.e., excluding retrofits), 12 are AC-coupled and 7 are DC-coupled
 - A somewhat more-balanced mix
 - 5 of the 7 DC-coupled plants came online in 2021 (compared to 6 of the 12 AC-coupled plants)—potentially a sign of growing comfort with DC-coupling?
 - DC-coupled plants have only slightly higher DC:AC ratios on the PV portion—average of 1.35 vs. 1.31 for AC-coupled

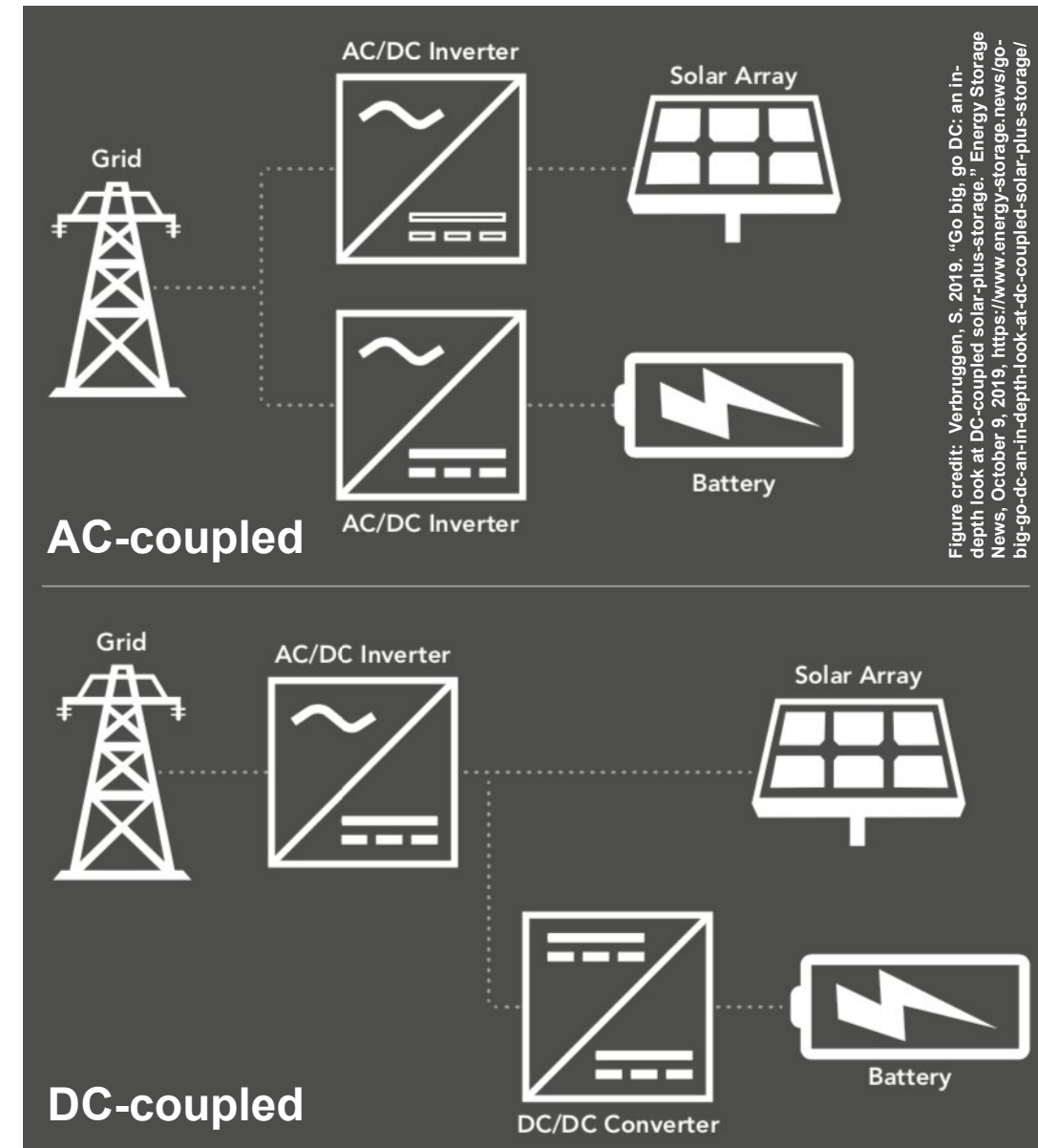


Figure credit: Verbruggen, S. 2019. "Go big, go DC: an in-depth look at DC-coupled solar-plus-storage." Energy Storage News, October 9, 2019, <https://www.energy-storage.news/go-big-go-dc-an-in-depth-look-at-dc-coupled-solar-plus-storage/>

A large contingent of batteries retrofitted to existing PV plants came online in 2021

State	Plant Name	Coupling	PV					Battery				
			COD Year	Capacity MW _{AC}	CapEx \$/W _{AC}	PPA Price \$/MWh	PPA Term Years	COD Year	Capacity MW _{AC} /MWh (Hours)	CapEx \$/kW (\$/kWh)	ESA Price \$/kW-mo	ESA Term Years
CA	McCoy	AC	2016	250	NA	~95	20	2021	230 / 920 (4.0)	NA	9.73	15
CA	Blythe Solar II	AC	2016	125	NA	~57	20	2021	115 / 460 (4.0)	NA	9.73	15
CA	Blythe Solar III	AC	2020	125	NA	~53	20	2021	115 / 460 (4.0)	NA	9.73	15
CA	Blythe Solar 110	AC	2016	110	NA	NA	NA	2021	63 / 252 (4.0)	NA	7.48	15
CA	RE Mustang	AC	2016	100	NA	~62	20	2021	75 / 300 (4.0)	NA	??	??
CA	RE Tranquility	AC	2016	200	NA	~48	18	2021	72 / 288 (4.0)	NA	??	20
CA	CA Flats 130	AC	2017	130	NA	~72	25	2021	60 / 240 (4.0)	NA	4.75+9.50	10 & 15
CA	RE Garland	AC	2016	180	NA	~56	15	2021	88 / 352 (4.0)	NA	9.13	20
FL	Babcock	AC	2016	74.5	1.75	NA	NA	2018	10 / 40 (4.0)	1554 (389)	NA	NA
FL	Citrus	DC	2016	74.5	1.80	NA	NA	2018	4 / 16 (4.0)	1687 (422)	NA	NA
FL	Manatee	AC	2016	74.5	1.78	NA	NA	2021	409 / 900 (2.2)	588 (267)	NA	NA
FL	Sunshine Gateway	AC	2019	74.5	1.29	NA	NA	2021	30 / 75 (2.5)	708 (283)	NA	NA
FL	Echo River	AC	2020	74.5	1.34	NA	NA	2021	30 / 75 (2.5)	661 (264)	NA	NA
			Total:	1,592.5				1,301 / 4,378 (3.4)				

COD=commercial operation date; PPA=power purchase agreement; ESA=energy storage agreement. Cost/price data are in nominal dollars, and PPA/ESA prices are levelized over the contract term.

- Battery retrofits are able to capture the solar ITC (as extrapolated from IRS PLR 201809003), and so have been popular
- All CA and most FL retrofits are AC-coupled, which makes sense in a retrofit situation (one DC-coupled has a very small battery, easing retrofit)
- Based on CAISO Resource IDs, none of the CA retrofits are operating as “true” hybrids—all are co-located (makes sense for retrofits)
- Battery ESA terms are often shorter than original PV PPA terms, but time has elapsed on PV so they are now pretty well synched
- Just a few developers have been engaged in this retrofit practice: FPL/NextEra, Southern Power, Capital Dynamics/Arevon, and Goldman Sachs
- No PPAs/ESAs in Florida since plants are utility-owned
- Often shorter battery durations in Florida

Case Study: Slate PV+Storage plant in California

300 MW_{AC} of PV and 140.25 MW / 561 MWh (4-hour) of AC-coupled storage

- Developer:
Recurrent Energy /
Canadian Solar
- Owner:
Goldman Sachs
Renewable Power

Five Offtakers	PV		Battery		Storage Ratio Battery:PV MW
	Capacity MW _{AC}	Price \$/MWh	Capacity MW _{AC} / MWh	Price \$/MW-month	
San Francisco Bay Area Rapid Transit	50.5	30.92 flat (20 years)	NA	NA	NA
Silicon Valley Clean Energy	93	27.51 flat (17 years)	46.5 / 186	5340 flat (17 years)	50%
Central Coast Community Energy	67.5	27.51 flat (17 years)	33.75 / 135	5340 flat (17 years)	50%
Power and Water Resources Pooling Authority	26	26.81 flat (20 years)	10 / 40	6700 flat (20 years)	38%
Stanford University	63	21.98 flat (25 years)	50 / 200	6100 flat (25 years)	79%
Total:	300		140.25 / 561		47%

- SF BART buying only PV (all others buy both)
- Phased COD, from 11/2021 through 4/2022
- Single-axis tracking, DC:AC ratio of 1.30, expecting an AC capacity factor of ~32%
- Appears to be operating as a “true” hybrid rather than merely co-located (i.e., just one CAISO Resource ID)
- Buyers control the battery dispatch
- Anchor tenants SVCE/CCCE originally executed PPA in October 2018, but upsized both the PV and battery capacity (at the same price) in February 2020 when other offtakers joined



Case study of a novel use case: 15 MW_{DC} of PV and 10 MW / 40 MWh of DC-coupled storage serving as a “non-wires alternative” in upstate New York

- Winner of a 2018 National Grid RFP seeking non-wires alternatives to alleviate congestion at the Pine Grove substation (<https://nyrevconnect.com/wp-content/uploads/2019/01/National-Grid-NWA-RFP-Pine-Grove.pdf>)
- Technical requirements per RFP:
 - ▣ 10 MW of load relief; max 49 MWh/day for up to 12 hours (noon-midnight); up to 44 calls per year with 24 hours load notice and 5-minute response time; up to 19 consecutive days called
- Cost hurdle: The estimated net present value of deferring the traditional solution (i.e., a T&D upgrade) for 10 years was ~\$13.8 million
- When not called upon to relieve congestion, the plant will participate in NYISO’s wholesale electricity market



Image: Convergent Energy + Power

Case Study: Wheatridge Wind+PV+Storage plant in Oregon

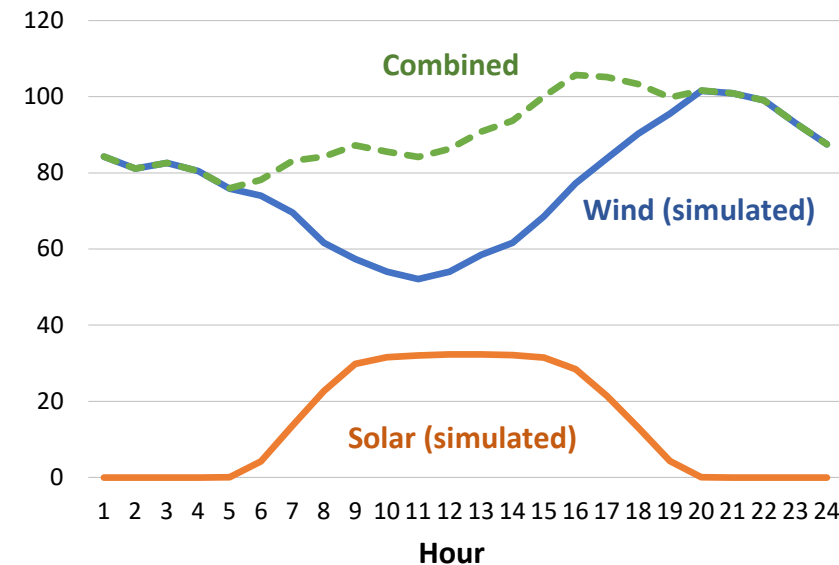
200 MW_{AC} of wind + 50 MW_{AC} of PV + 30 MW / 120 MWh (4-hour) of DC-coupled storage

- Wheatridge is one of the largest Wind+PV+Storage plants operating in the US
- Owned by NextEra and sells to Portland General Electric under two separate PPAs: wind and solar+storage

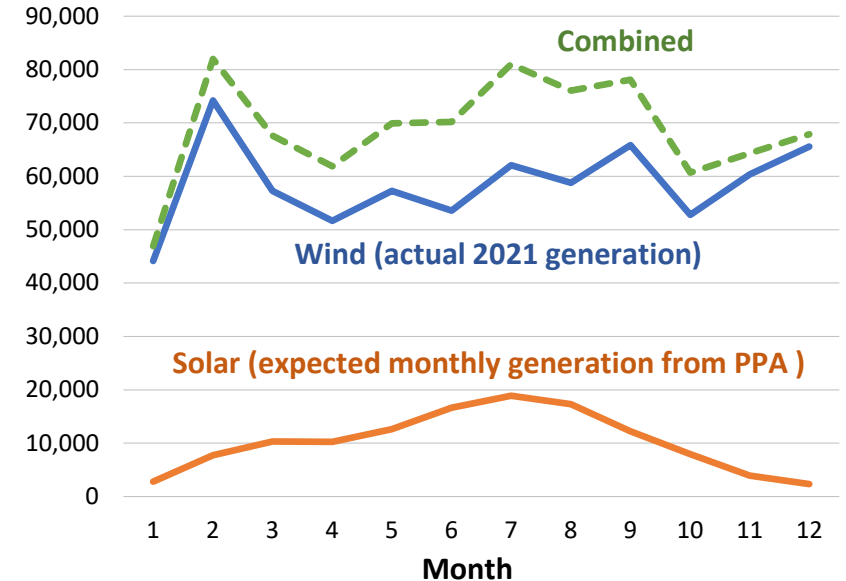
Wheatridge Hybrid	Wind	Solar	Battery
Capacity	200 MW _{AC}	50 MW _{AC}	30 MW (4-hour, DC-coupled)
COD	November 2020	March 2022	March 2022
Contract Term	30 years	30 years	20 years
Contract Price	\$35.29/MWh flat	\$39.80/MWh flat	\$5.83/kW-month flat
Capacity Factor (AC)	~40%	~28%	

- Complementary generation profiles (particularly diurnal)
- Profile graphs do not include battery charging or discharging

MWh (annual average diurnal generation)



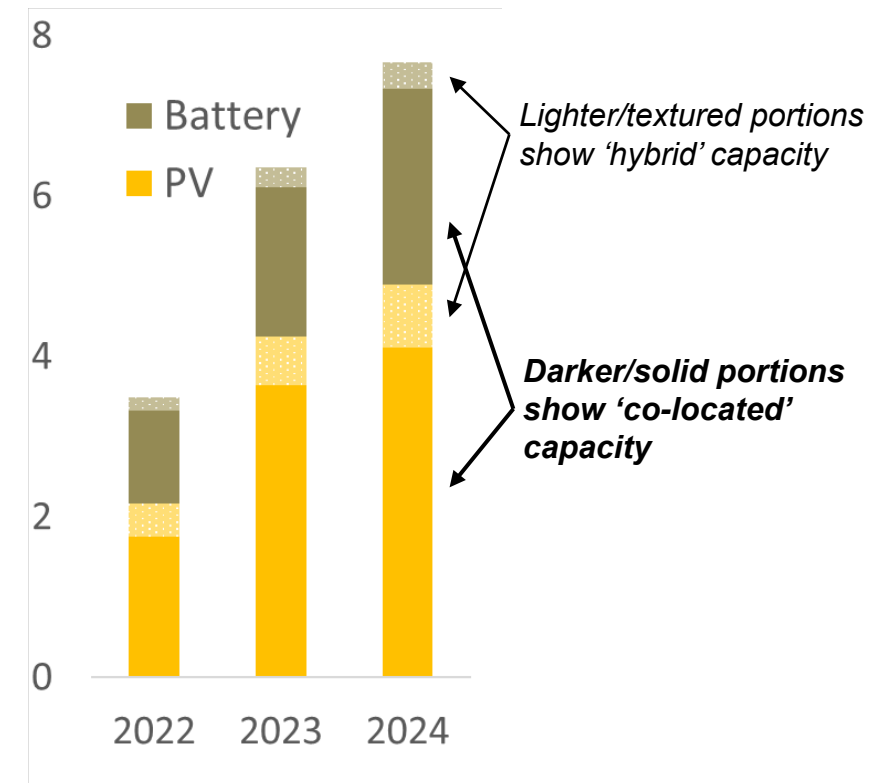
MWh (monthly generation)



CAISO data on online and near-term solar+storage pipeline suggests popularity of 'co-location' rather than 'hybrid' model

- **Co-located model** involves distinct modeling and dispatch instructions for individual resources behind shared interconnection
- **Hybrid model** involves single bidding approach for multiple resources behind shared interconnection (e.g., no separate renewable resource forecast and dispatch)
- Difficult to evaluate how this near-term projection compares with the significantly larger pipeline of plants in CAISO's interconnection queue
 - This near-term projection reported by CAISO is presumably **more certain** than the pipeline of plants in CAISO's interconnection queue
 - However, there are **>130 GW** active in the CAISO queue (see later section) compared to the **8 GW** of plants shown in graph to the right

Cumulative CAISO Solar+Storage capacity expected through 2024 (GW)



Source: CAISO. 2022. Final Flexible Capacity Needs Assessment for 2023

Note: For further reading on participation models, see section 5 of prior LBNL report: <https://emp.lbl.gov/publications/motivations-and-options-deploying>



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



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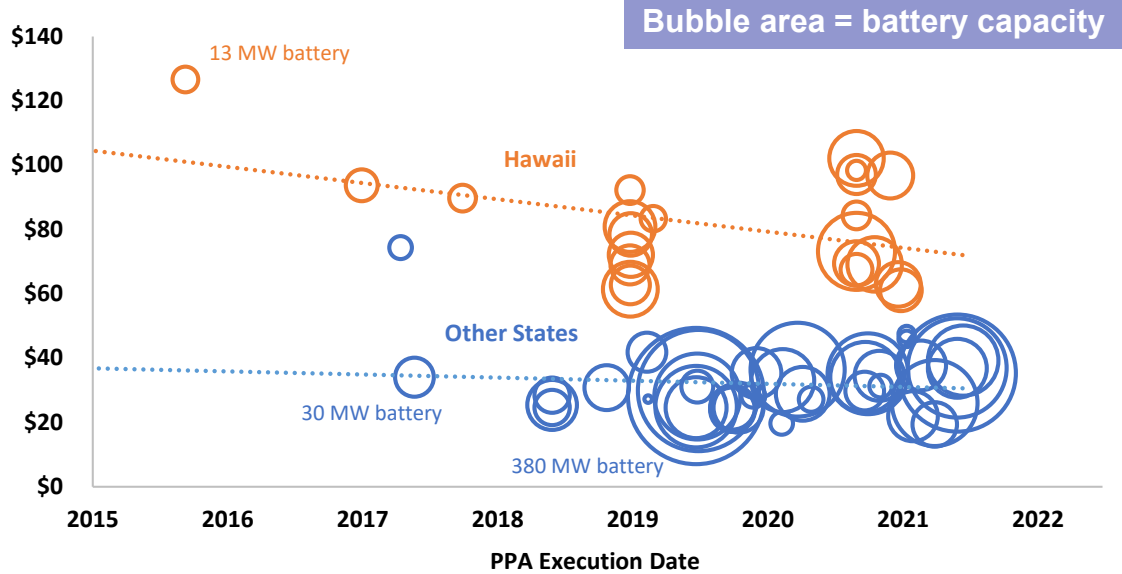
We have PPA prices from a sample of 67 PPAs in 10 states totaling 8.0 GW_{AC} of PV and 4.5 GW_{AC} / 18 GWh of batteries

State	Sample Count	Total Capacity (MW _{AC})		Average Battery:PV Capacity	Battery Storage	
		PV	Battery		Avg Duration	Total MWh
AZ	3	173	50	29%	4.0	200
CA	17	2,415	1,564	65%	4.0	6,257
CO	1	22	1	5%	2.0	2
FL	1	50	12	24%	2.0	24
GA	2	409	80	20%	2.0	160
HI	22	791	791	100%	4.1	3,253
NM	8	1,390	590	42%	4.0	2,360
NV	10	2,519	1,408	56%	4.0	5,603
NY	2	213	10	5%	4.0	40
OR	1	50	30	60%	4.0	120
Total	67	8,030	4,536	56%	4.0	18,019

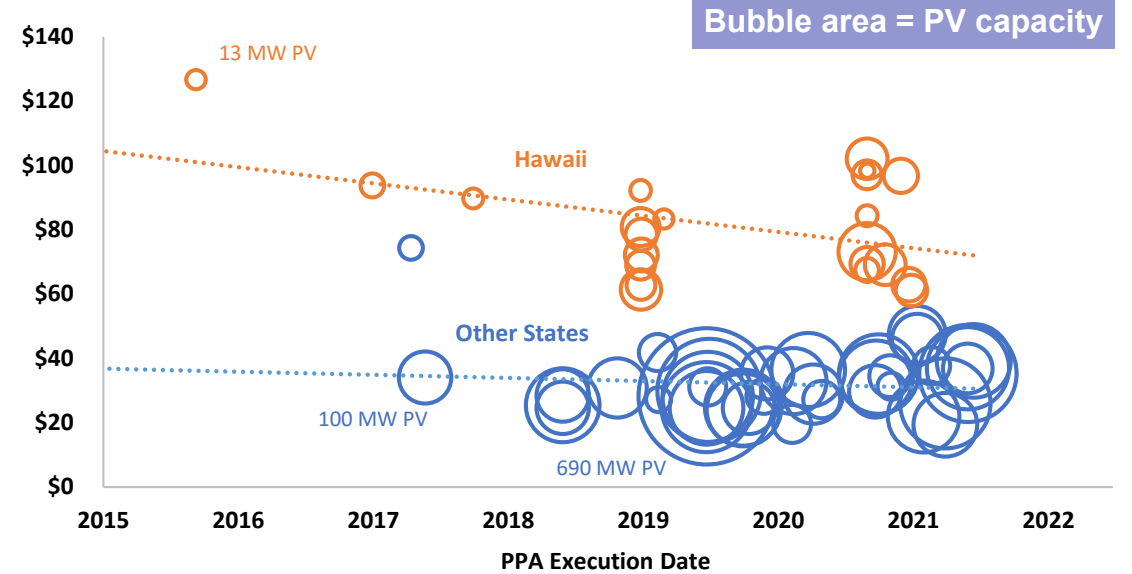
- Sample dominated by HI, CA, NV, and NM
- 23 of these 67 PPAs are for plants that are operational (other 44 still in development/construction)
- 6 of the operational plants are battery retrofits to pre-existing PV plants (all in CA, see earlier slide)

PPA prices for PV+battery have declined over time; Hawaii priced at a premium

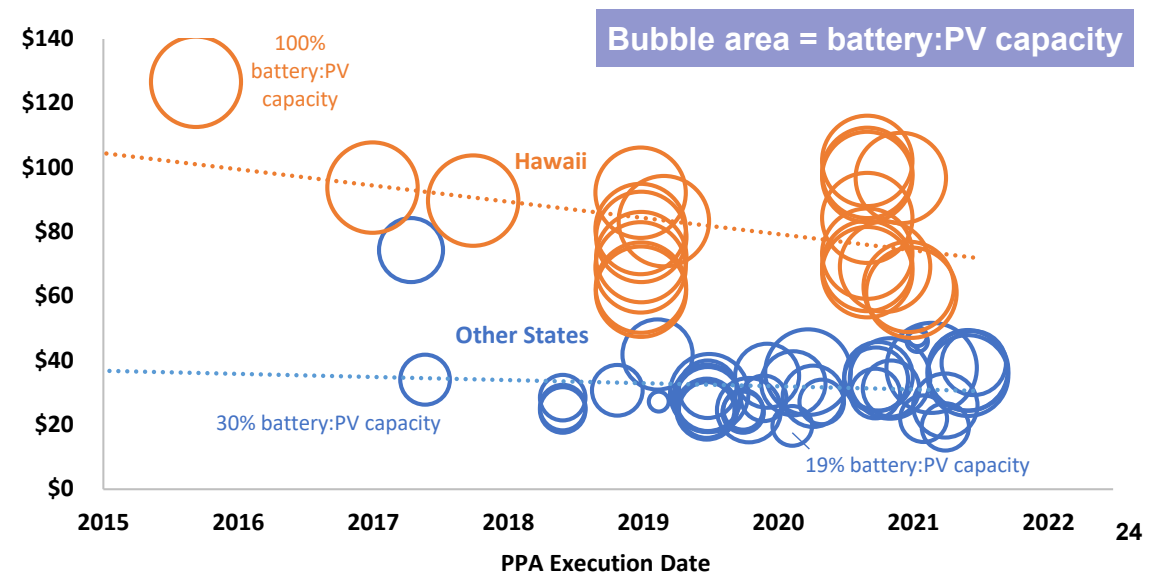
Levelized PPA Price (2021 \$/MWh-PV)



Levelized PPA Price (2021 \$/MWh-PV)



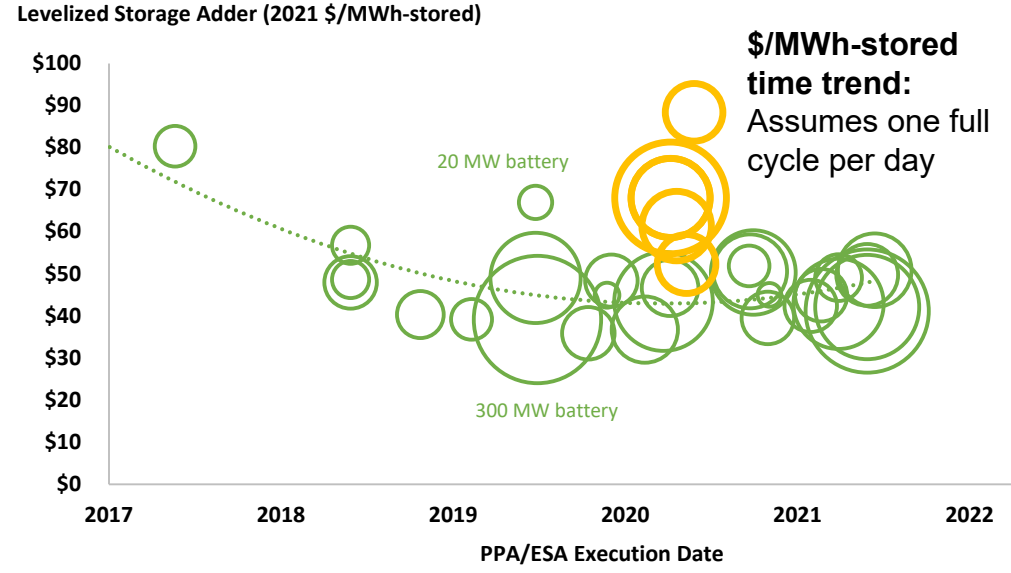
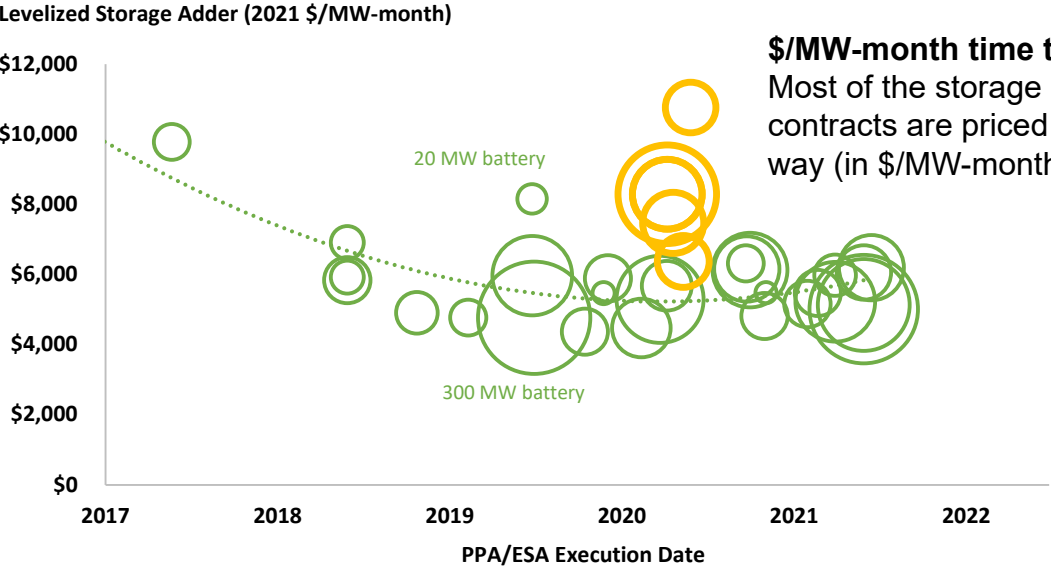
Levelized PPA Price (2021 \$/MWh-PV)



- All 3 graphs show same data from sub-sample of 61 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): 39 plants, 6.3 GW_{AC} PV, 3.1 GW_{AC} battery
- Downward trend over time, particularly in HI, but refinement is complicated by multi-dimensionality of these plants; other states are more heterogenous than HI in terms of solar resource
- Battery:PV capacity ratio always at 100% in HI; lower on the mainland (but increasing over time—see bottom right graph)
- Storage duration ranges from 2-8 hours; 50 of the 61 plants have 4-hour duration (other 11 are 5x2 hr, 1x3.7 hr, 4x5 hr, and 1x8 hr)

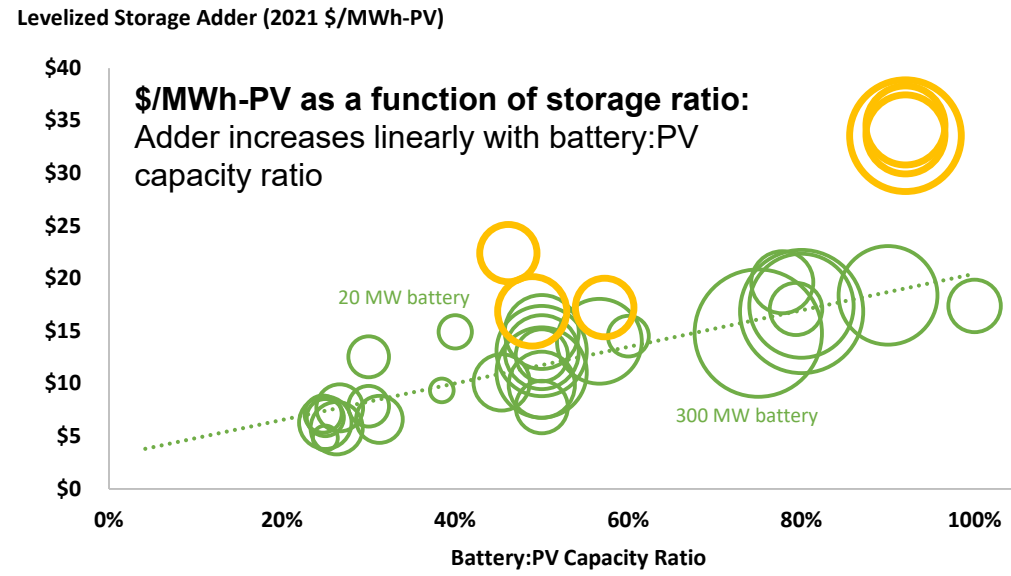
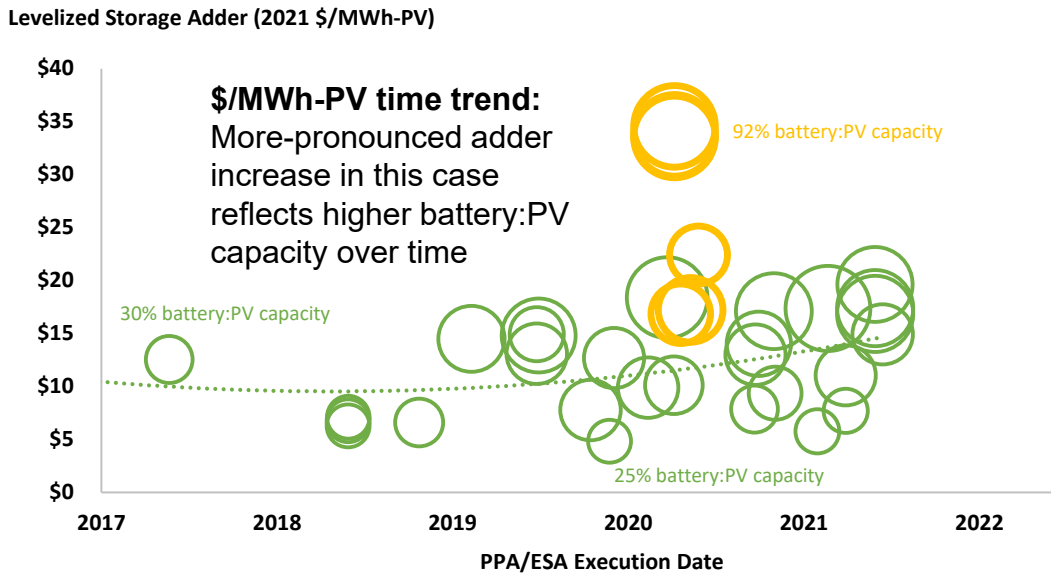
PPAs that price the PV and storage separately enable us to calculate a “levelized storage adder,” shown here 4 different ways—all recently increasing

Graphs show adders from 34 PV hybrids in CA (17), NM (8), NV (7), AZ (1) and OR (1) totaling >3 GW_{AC} of batteries, all with 4-hour duration



Green = greenfield
Gold = battery retrofit

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





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Hybrid Pipeline: Hybrid plants in interconnection queues at the end of 2021



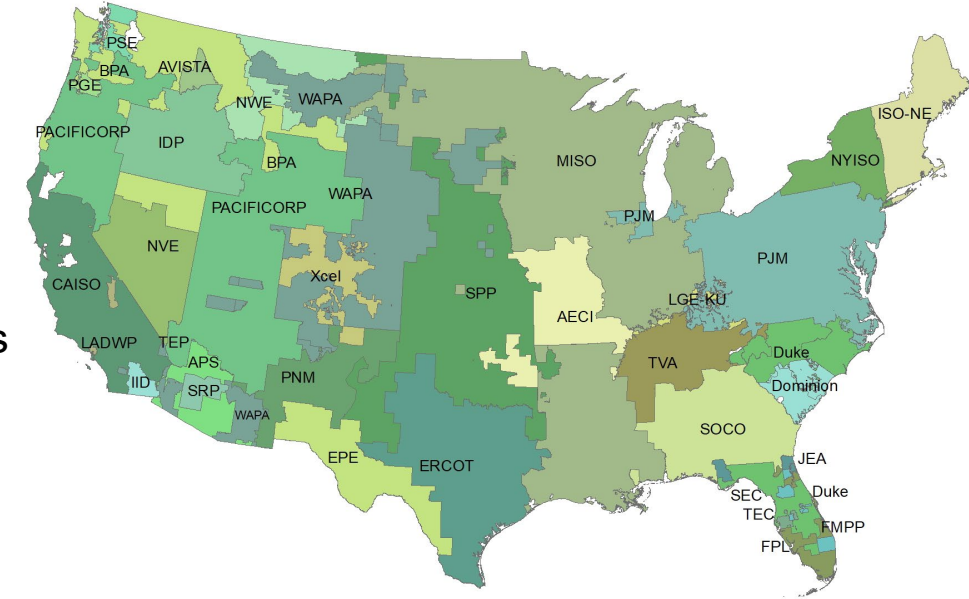
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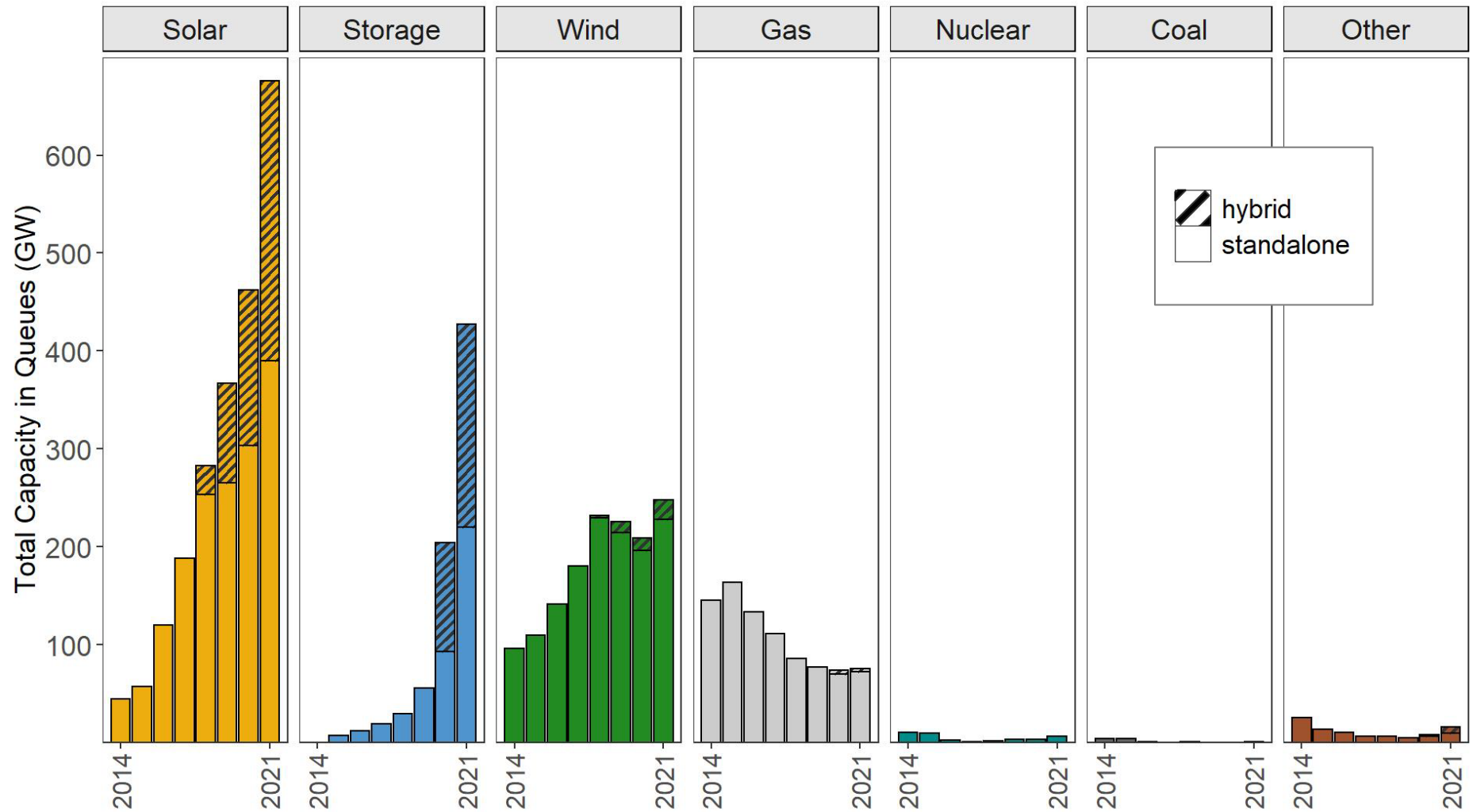
Methods and Data Sources

- Data collected from interconnection queues for 7 ISOs / RTOs and 35 utilities, which represent >85% of U.S. electricity load
 - Plants that connect to the bulk power system: not behind-the-meter
 - Includes all plants in queues through the end of 2021
 - Full sample includes 8,133 “active” plants, of which 1,528 (19%) are in a hybrid or co-located configuration
 - Hybrids represent 315 GW (31%) of active generation 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

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



- “Wind” includes both onshore and offshore
- “Other” includes
 - ▣ 5 GW of “unknown” hybrid plants
 - ▣ Hydropower
 - ▣ Geothermal
 - ▣ Biomass/biofuel
 - ▣ Landfill gas
 - ▣ Solar thermal
 - ▣ Oil/diesel
- “Storage” is primarily (98%) battery, but also includes pumped storage hydro, compressed air, gravity rail, and fuel cell plants

**Hybrid storage capacity is estimated using storage:generator ratios from plants that provide separate capacity data.*

Storage capacity in hybrids was not estimated for years prior to 2020.

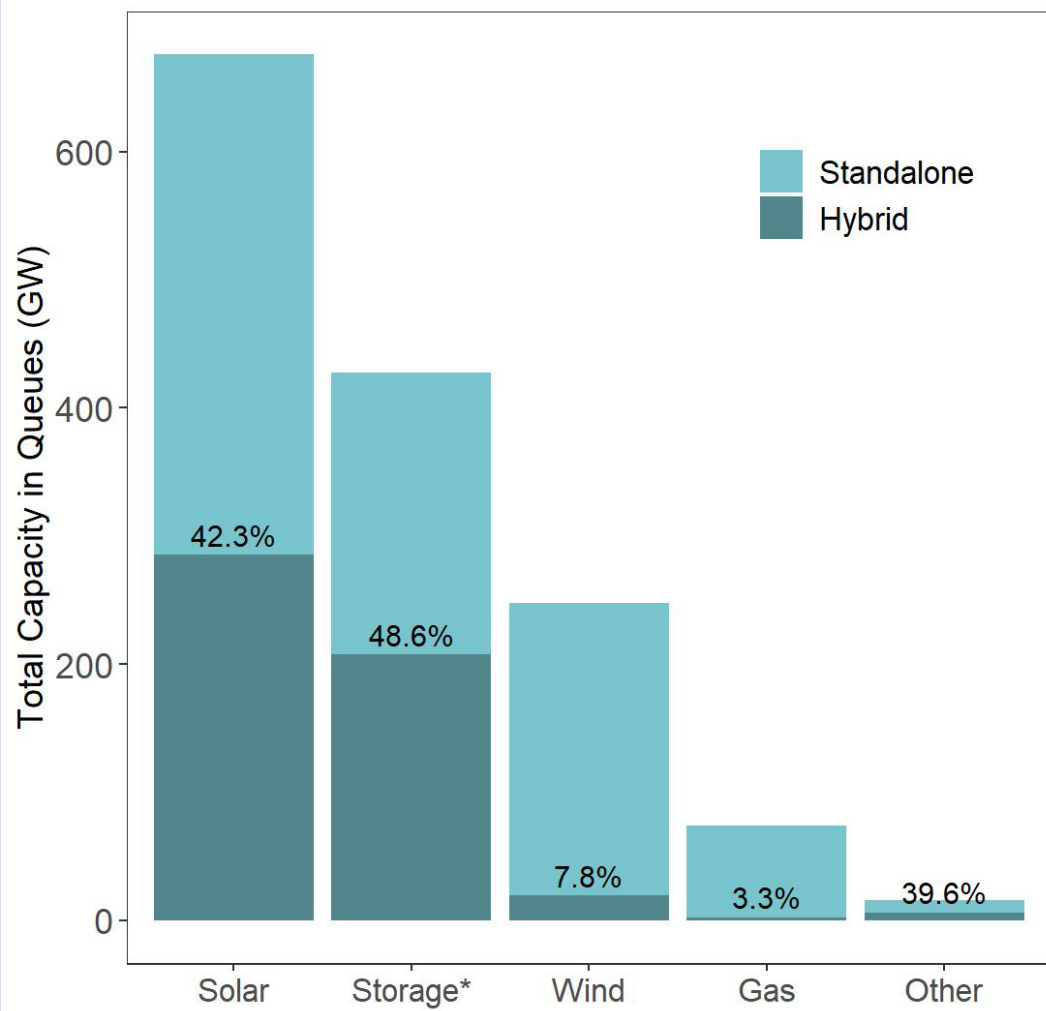
Note: Not all of this capacity will be built

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

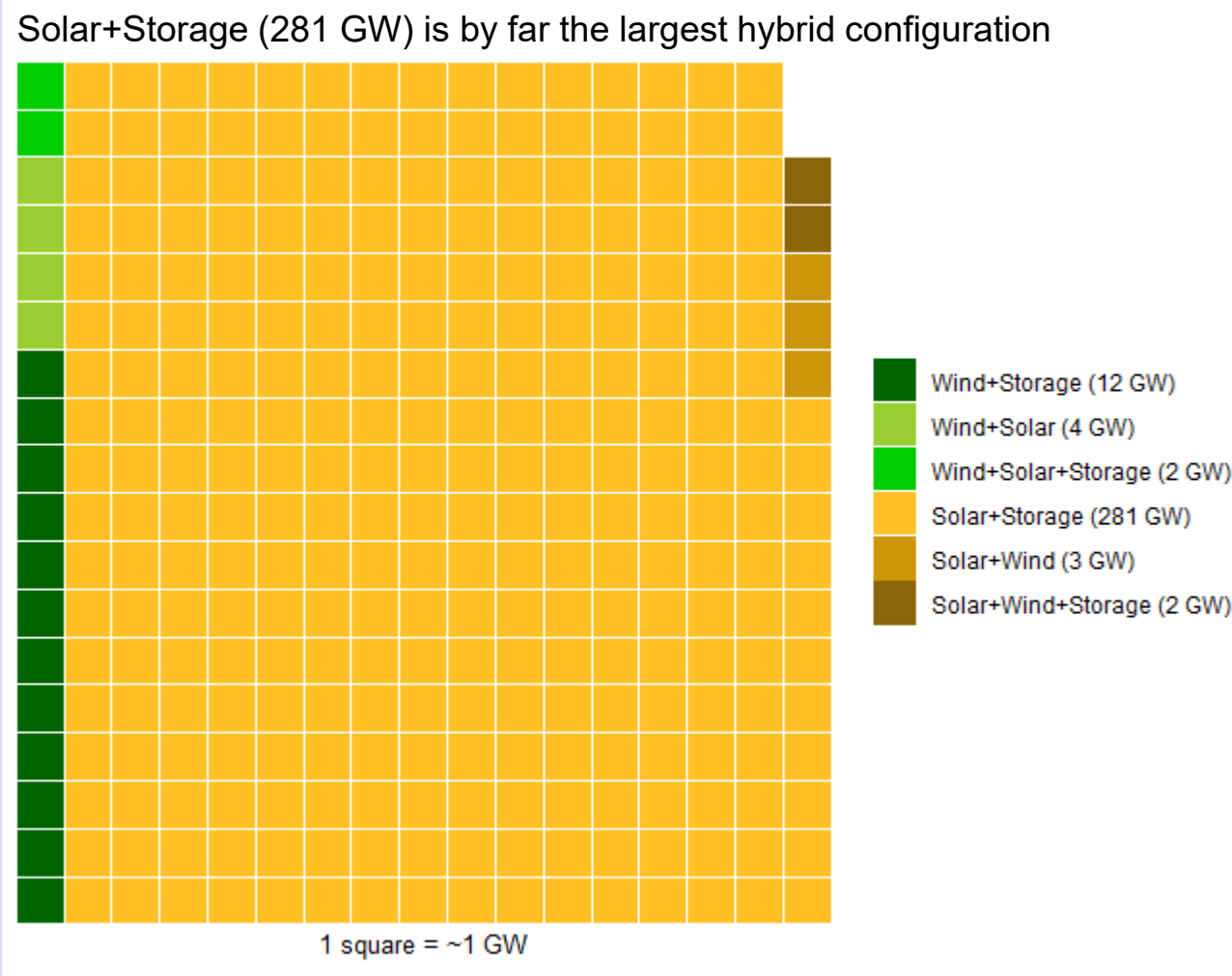
Hybrid Type	Number of Plants	Generator(s) Capacity (MW)
Solar+Battery	1,423	280,840
Wind+Battery	27	14,069
Unknown Hybrid	24	5,163
Solar+Wind	18	6,704
Gas+Battery	13	2,467
Solar+Wind+Battery	9	3,342
Hydro+Battery	6	1,032
Other+Battery	2	1,032
Solar+Hydro	1	200
Gas+Solar	1	5
Gas+Solar+Battery	2	unknown
Pumped Storage+Wind+Solar	1	unknown
Other+Other Storage	1	unknown
TOTAL	1,528	314,854

- Over 93% of all hybrid plants are Solar+Battery, representing nearly 90% of all known hybrid generation capacity in the queues
- The next two largest configurations - Wind+Battery and Solar+Wind - account for only ~4% and ~2% of known hybrid capacity in the queues, respectively
- The 24 “Unknown” hybrids are plants from SPP for which details were unavailable.
 - These are presumed to be predominantly solar+battery and wind+battery plants
- There were 70% more hybrid plants – representing 77% more generating capacity – in the queues at the end of 2021 compared to 2020

Interest in hybrid plants has increased: 42% of solar (285 GW) proposed as hybrids, 8% of wind (19 GW) proposed as hybrids (up from 34% and 6% in 2020, respectively)



*Hybrid storage capacity is estimated using storage:generator ratios from plants that provide separate capacity data



Only the **generator** capacity is illustrated here (not storage); for hybrid configurations with multiple generator types, each color represents **only the first generator type**

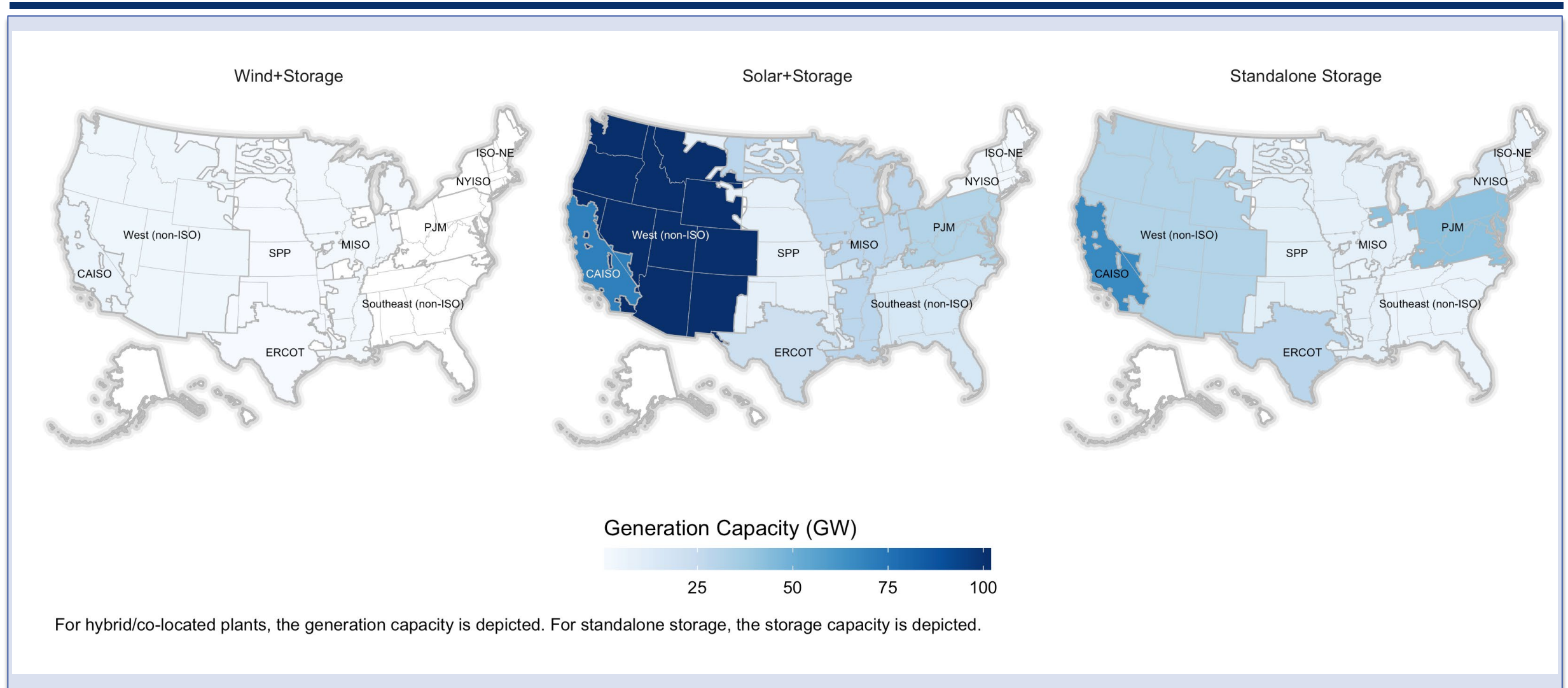
Hybrids comprise a sizable fraction of all proposed solar plants in multiple regions; wind hybrids are less common overall but still a large proportion in CAISO

Region	% of Proposed Capacity Hybridizing in Each Region			
	Solar	Wind	Nat. Gas	Battery
CAISO	95%	42%	15%	51%
ERCOT	27%	4%	27%	33%
SPP	18%	1%	0%	24%
MISO	27%	8%	0%	n/a
PJM	21%	1%	0%	n/a
NYISO	6%	3%	0%	3%
ISO-NE	24%	0%	0%	n/a
West (non-ISO)	75%	15%	0%	n/a
Southeast (non-ISO)	28%	0%	0%	n/a
TOTAL	42%	8%	3%	n/a

Note: Hybrid percentages for SPP are likely undercounted, since the SPP queue data contains a number of unknown / unclassified hybrid plants

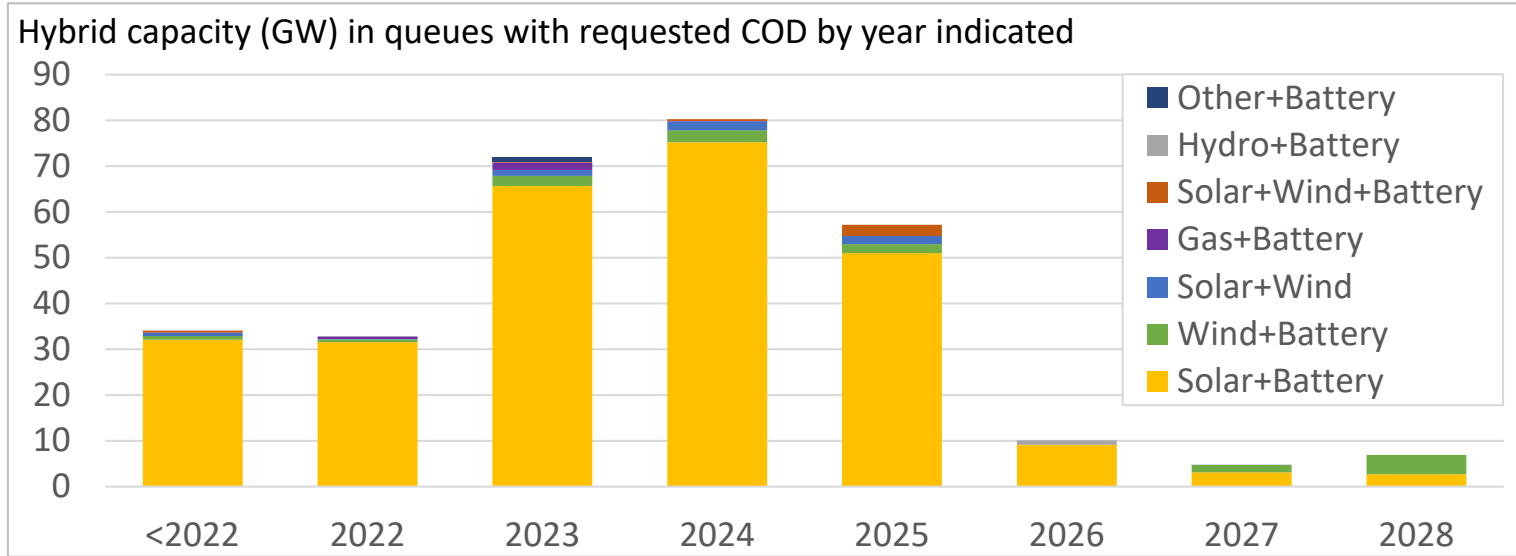
- **Solar** hybridization relative to total amount of solar in each queue is highest in CAISO (95%) and non-ISO West (75%), and is above 20% in all but NYISO and SPP
- **Wind** hybridization relative to total amount of wind in each queue is highest in CAISO (42%) and non-ISO West (15%), and is less than 9% in all other regions
- The few proposed **gas** hybrids are only in CAISO and ERCOT, and hybrid **battery** capacity data are not available in most regions

Solar+Storage is dominant hybrid type in queues, with nearly 20x the proposed capacity of Wind+Storage; CAISO & West are of greatest interest, but other regions are growing

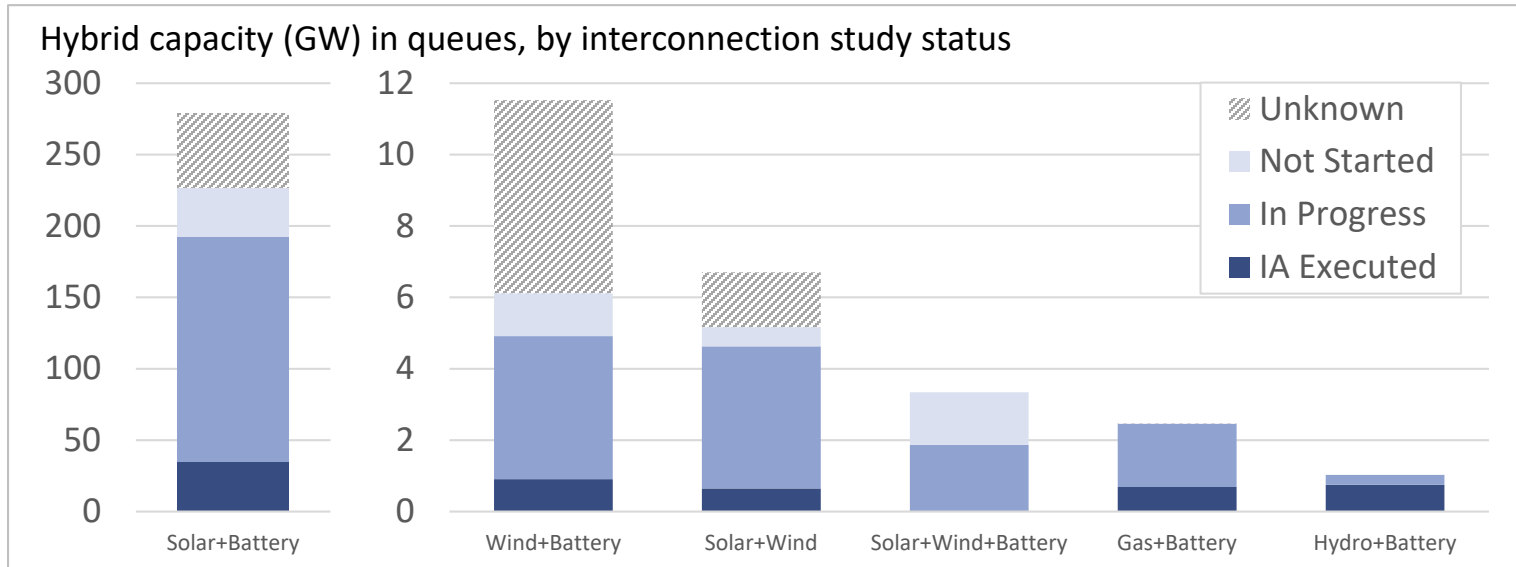


Note: Not all of this capacity will be built

The majority (71%) of hybrid (generator) capacity in the queues has requested to come online by the end of 2024; 12% has an executed interconnection agreement (IA)

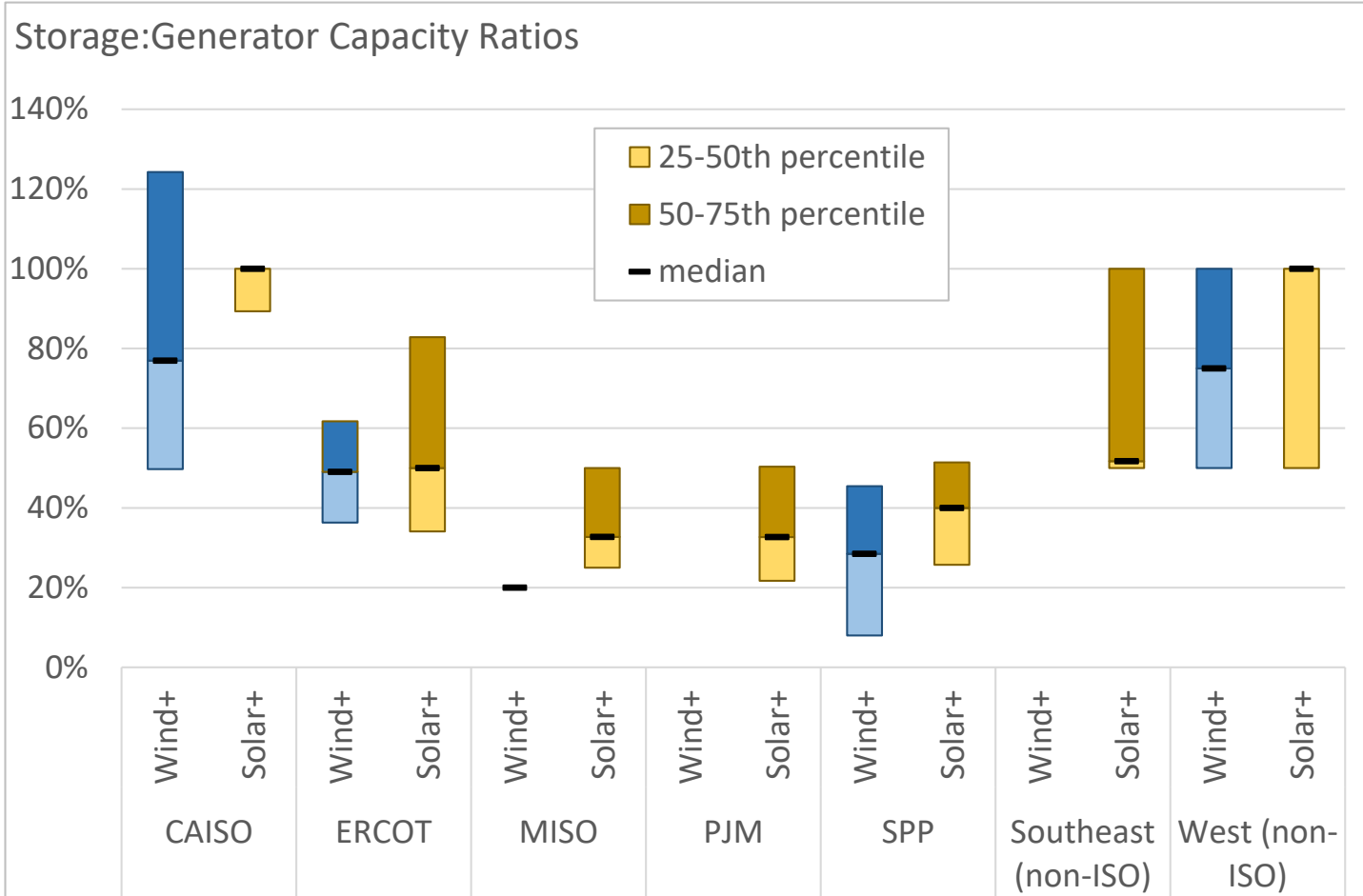


- Nearly all hybrid capacity in the queues is requesting to come online before 2026
- Solar+Battery dominates requested hybrid capacity additions through 2027



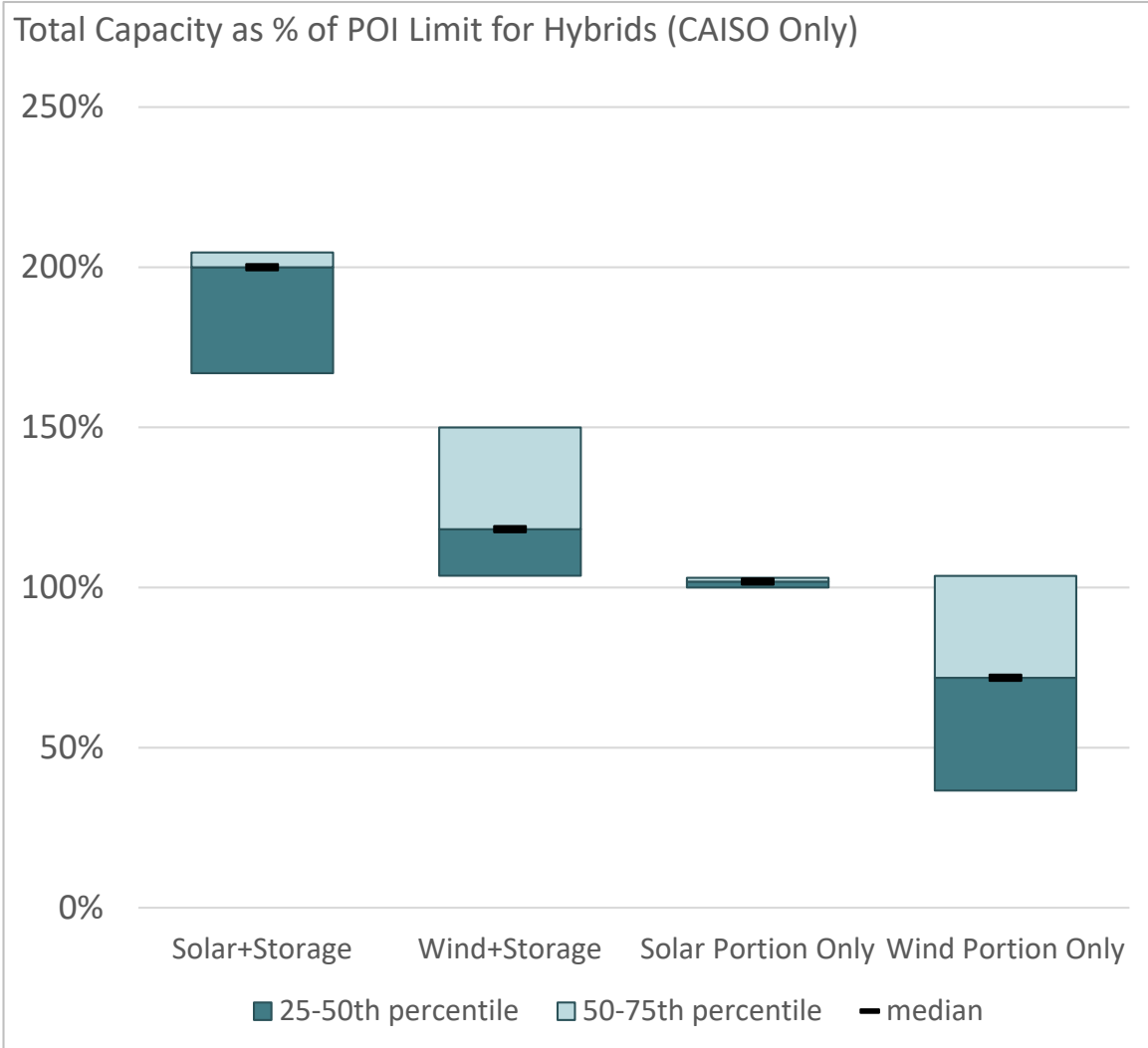
- Over 35 GW of Solar+ Battery has an executed IA, compared to <1 GW of each of the other hybrid types
- Proportions of interconnection status are fairly similar across types

Solar+storage plants typically feature a higher storage contribution than wind+storage



- 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 (88%) is higher than for wind+storage (50%), and the ratio is generally higher where solar penetration is higher
- The ratios shown here for proposed plants are higher than those for existing plants of the same type.

Solar+storage plants in CAISO base POI limits on generator capacity; wind+storage plants may leave some “headroom” for storage to fill



- Point of interconnection (POI) capacity limits were only provided in CAISO’s queue
- For solar+storage plants, the solar capacity alone equals or exceeds the POI limit in 90% of plants, and the median combined (solar+storage) capacity is double (200%) the POI limit
- For wind+storage plants, the wind capacity alone equals or exceeds the POI limit in 50% of plants, and the median total (wind+storage) capacity is 118% of the POI limit
- These values suggest that these plants (particularly the solar hybrids) 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



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Conclusions: 2021 was a big year for hybrids in the US

At the end of 2021, there were nearly 36 GW of operational hybrid / co-located plants, and nearly 315 GW in the queues. More batteries were operating as part of hybrid plants than on a standalone basis.

In 2021, 74 new hybrid plants (+32% year-over-year) added 6.1 GW (+21%) of operational generating capacity and 2.4 GW / 6.9 GWh (+305% / +578%) of operational storage capacity. There were also 70% more hybrid plants in the queues at the end of 2021 compared to 2020.

There are many different hybrid configurations currently operating in the US, but PV+Storage dominates, with by far the most plants (140), storage capacity (2.2 GW), and storage energy (7 GWh). The vast majority of new hybrid plants added in 2021—67 out of 74—are PV+Storage.

Similarly, PV+Storage accounts for >90% of the 1,528 hybrids totaling 315 GW of generation capacity in interconnection queues across the US. Nationally, 42% of all solar capacity in the queues is proposed in hybrid format; in CAISO and the non-ISO West, it's 95% and 75% respectively.

Much of the battery capacity added in hybrid format in 2021 was via retrofits to pre-existing PV plants in CA and FL. Though retrofits favor AC-coupling, a number of DC-coupled greenfield PV+Storage plants also achieved commercial operations in 2021.

On average, operational PV+Storage plants have significantly higher storage ratios (53%) and longer durations (3.2 hours) than other hybrid types. Proposed PV+Storage plants tend to have even higher storage ratios and longer durations (though seldom >4 hours).

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 declined over time. That said, levelized storage adders for PV+Battery plants on the mainland have recently increased slightly to ~\$5500/MW-month, ~\$45/MWh-stored, and ~\$15/MWh-PV (depending on the storage ratio).



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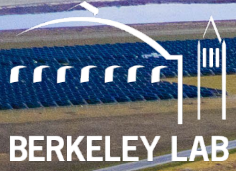
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Hybrid Power Plants

Status of Operating and Proposed Plants, 2022 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