BERKELEY LAB

Hybrid Power Plants

Status of Operating and Proposed Plants, 2023 Edition

Mark Bolinger, Will Gorman, Joe Rand, Seongeun Jeong

Lawrence Berkeley National Laboratory

August 2023

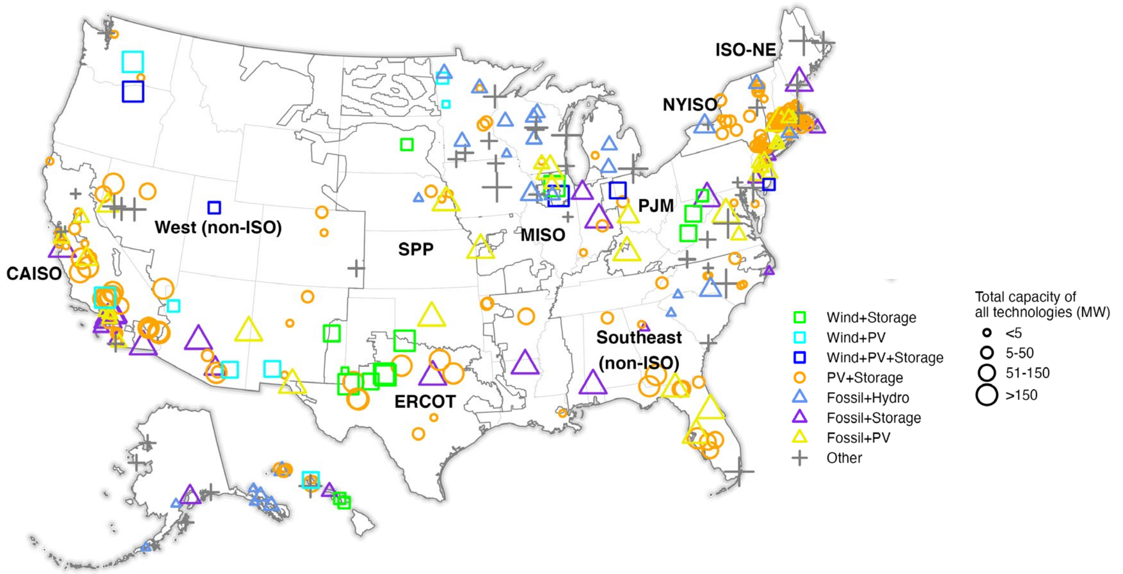
Funded by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Wind Energy Technologies Office and Solar Energy Technologies Office, under Contract No. DE-AC02-05CH11231.

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:
2022 was another big year for hybrids (particularly PV+Storage) in the US

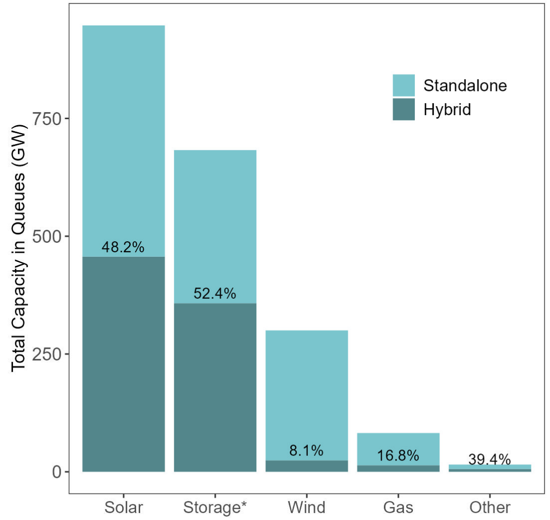
Hybrid / co-located plants exist in many configurations and are distributed broadly across the U.S.

- PV+Storage dominates in terms of number of plants (213), storage capacity (4 GW), and storage energy (12.5 GWh)
- As of the end of 2022, 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 types of generator+storage hybrids



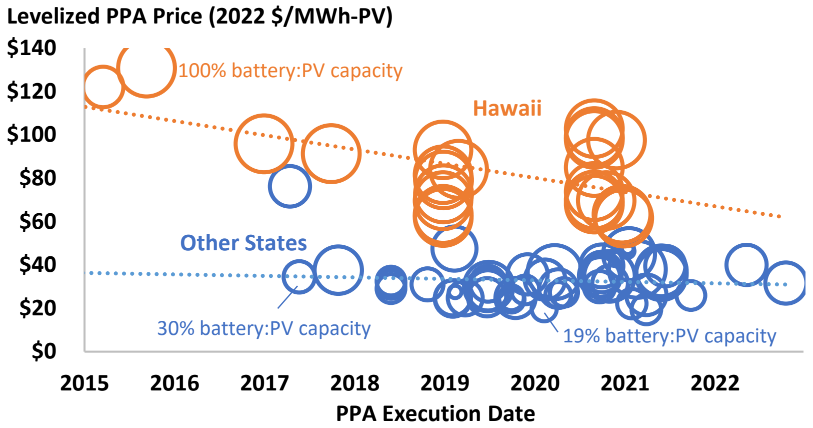
Hybrids comprise a large and growing share of proposed plants

- Hybrids represent 37% (500 GW) of generation capacity in interconnection queues (up from 31% in 2021), including 48% (457 GW) of all solar
- PV+storage dominates the hybrid development pipeline (>90% of plants)
- Proposed plants are concentrated in the West and CAISO



Prices from a sample of 81 PV+Storage PPAs in 10 states totaling 9.9 GW_{AC} of PV and 5.5 GW_{AC} / 21.8 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



Preface: Two important policy updates since last year's report

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 obviously removes some of the impetus to couple batteries with solar
- In this report, we don't yet see the possible impact of this policy shift on the trend toward hybridization, given that:
  - The IRA was passed in August 2022 and the market naturally takes time to react (particularly given the ongoing need for guidance on implementation, which has been slowly dribbling out)
  - The new standalone storage ITC came into effect in 2023 (while this deck focuses mostly on developments in 2022)
  - 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)
  - There are several countervailing reasons why the trend toward hybridization might continue, despite the standalone storage ITC

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"
- Too early to gauge the impact of this Order on hybridization—though some regions already follow these practices

Presentation Content

Operational Hybrid Plants:

Online as of the end of 2022

Hybrid PPA Terms:

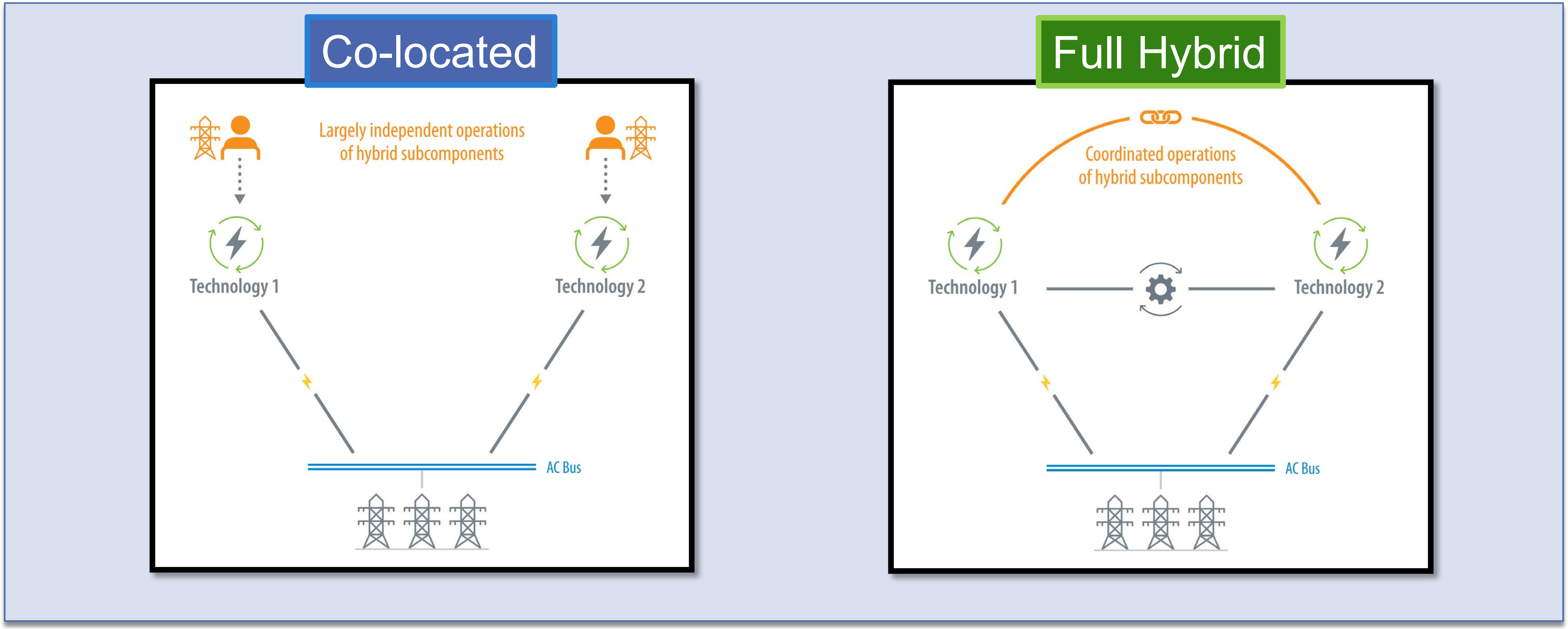
Among a sample of PV+battery plants with public PPAs

Hybrid Pipeline:

Hybrid plants in interconnection queues at the end of 2022

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.

Operational Hybrid Plants:
Online as of the end of 2022

Methods and Data Sources

- Form ***EIA-860 2022 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 2022

374 plants, 40.7 GW of generating capacity, 5.3 GW / 15.2 GWh storage capacity / energy

Operating at end of 2022	# 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	213	8,194	0	0	4,018	12,542	49%	3.1
Wind+Storage	14	1,425	0	0	198	122	14%	0.6
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	35	10,302	236	0	0	0	0%	n/a
Fossil+Storage	26	6,575	0	0	1,043	2,422	16%	2.3
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	3	116	6	2	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	51	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	111	18	0	0	0	0%	n/a
Geothermal+PV+CSP	1	47	22	2	0	0	0%	n/a

Sources: EIA 860 2022 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*

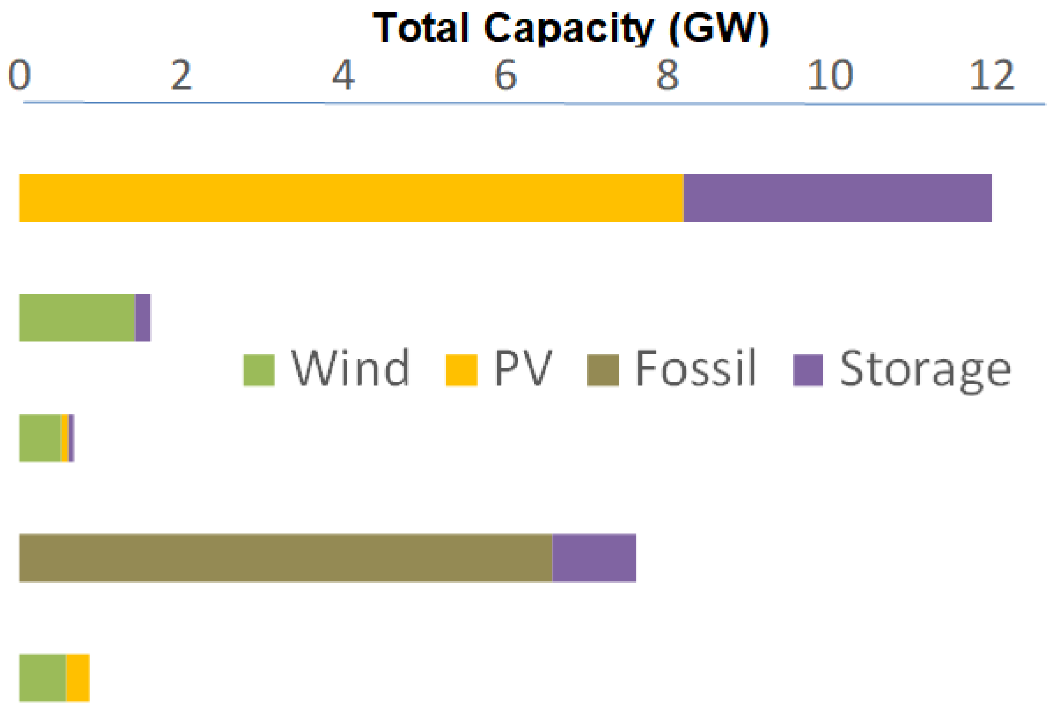
Four categories were dropped from this table due to having limited sizes: (1) Fossil+Wind+Storage, (2) Fossil+Wind+PV+Storage, (3) Biomass+Storage, and (4) Nuclear+Hydro

BERKELEY LAB

PV+Storage hybrids are the most numerous (213), and have by far the most storage capacity (4.0 GW) and energy (12.5 GWh) than other hybrids

Cumulative Statistics Year End 2022

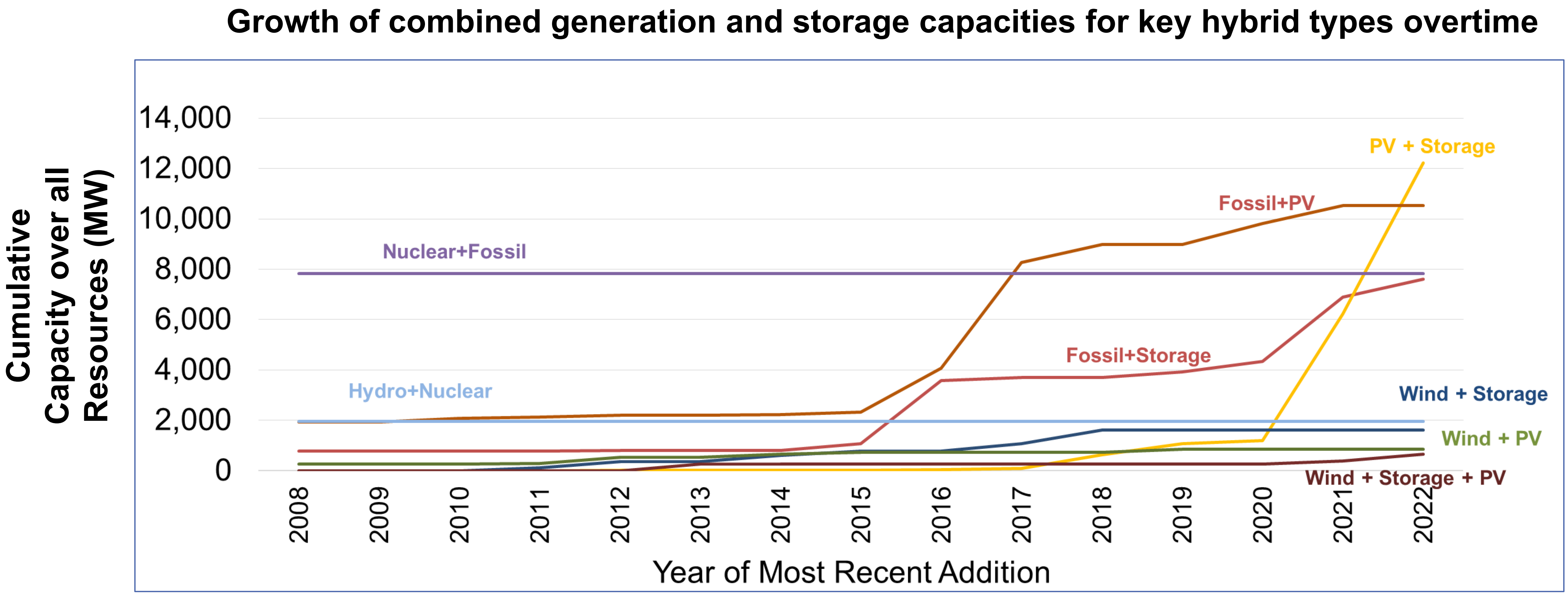
	# Plants	Weighted Average Storage Ratio	Total Storage Energy (MWh)	Weighted Average Duration (hrs)
PV+Storage	213	49%	12,542	3.1
Wind+Storage	14	14%	122	0.6
Wind+PV+Storage	5	11%	139	2.0
Fossil+Storage	26	16%	2,422	2.3
Wind+PV	8	n/a	n/a	n/a



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 8. ***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 2022 Early Release, Berkeley Lab

Growth of operational hybrid projects over last 2 years concentrated in the PV+Storage and Fossil+Storage types



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

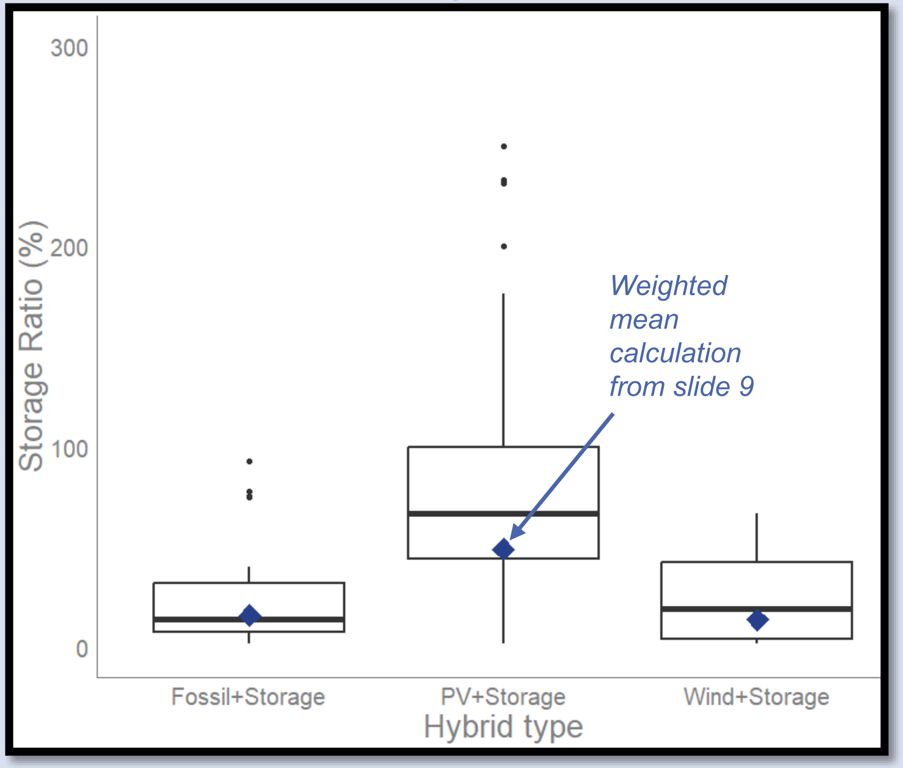
Sources: EIA 860 2022 Early Release, Berkeley Lab

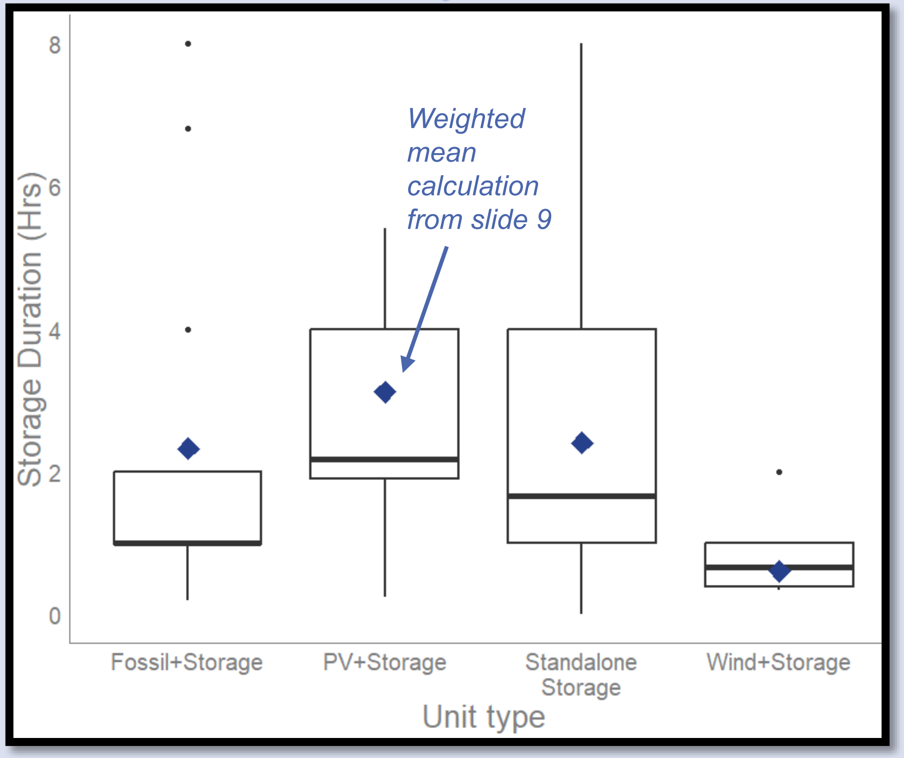
PV+Storage hybrids have higher storage-to-generator ratios and longer durations

PV+Storage median storage-to-generation ratio is highest at 66%

PV+Storage median storage duration is highest at 2.2 hours

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





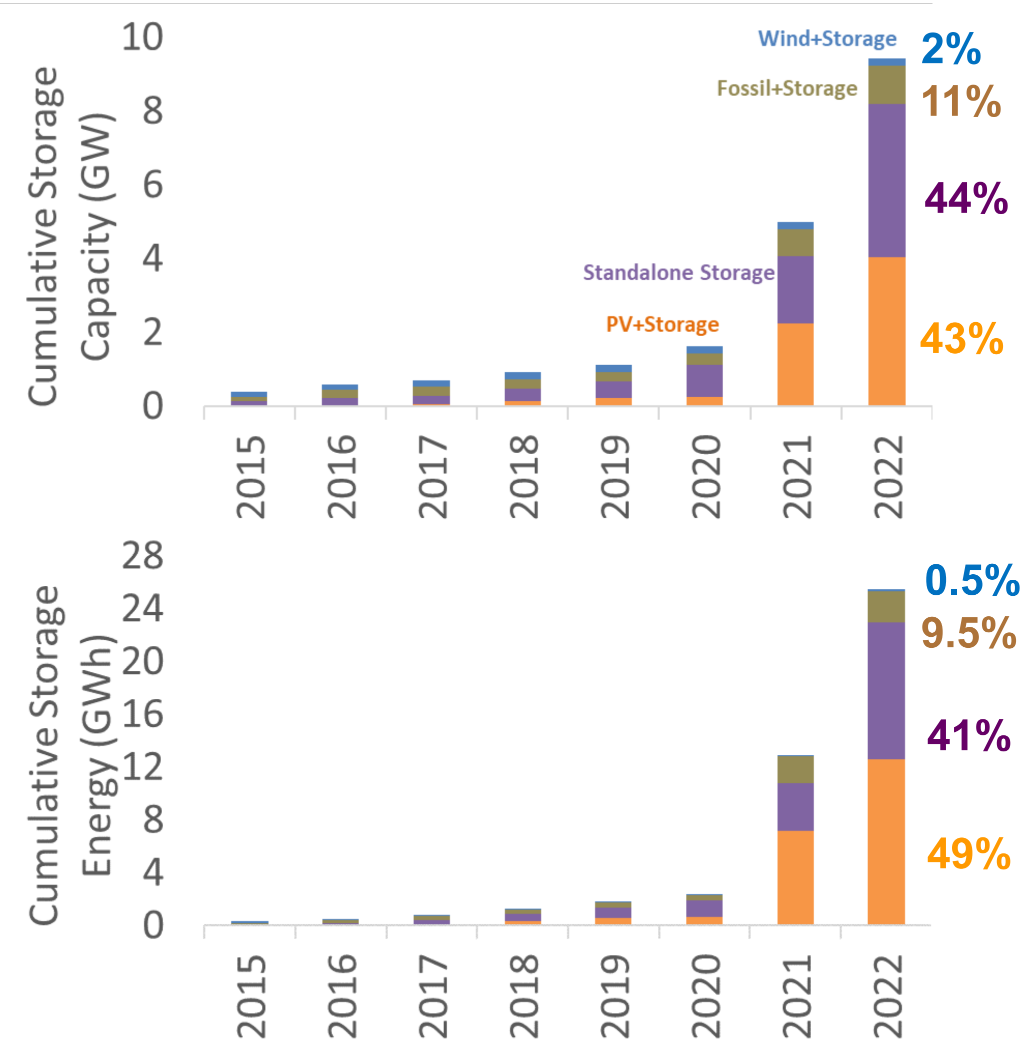
Sources: EIA 860 2022 Early Release, Berkeley Lab

BERKELEY LAB

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

- Through 2022, PV+Storage plants include ***about equivalent storage capacity*** (at ~4 GW) as standalone storage plants…
  - This is a slight change from last year, as there was a larger jump in standalone storage capacity in 2022

- …but roughly ***2,000 MWh more*** storage energy than standalone storage plants
  - Last year, however, PV+storage hybrids had almost double the cumulative energy capacity relative to standalone storage, so the gap is shrinking

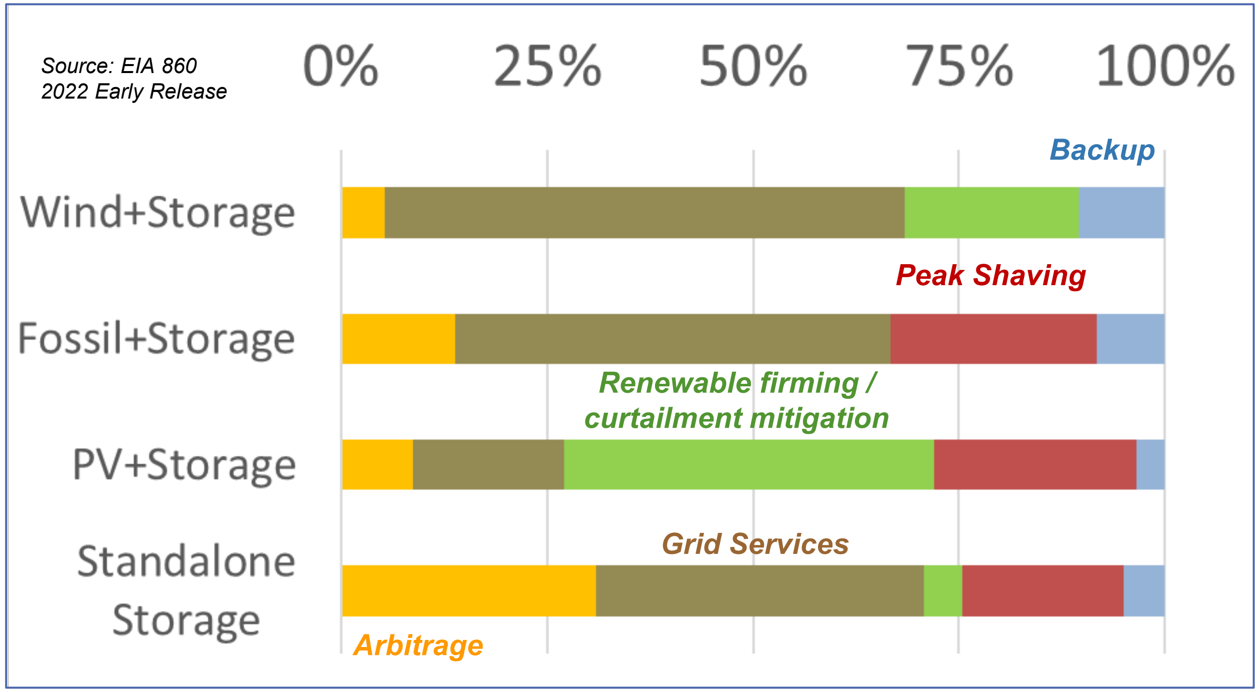


Note: These comparisons do not include pumped storage capacity or thermal storage from CSP plants. Rather, they only incorporate installed battery storage capacities, and limited amounts of flywheel and compressed air energy storage

Breakdown of self-reported use cases for battery storage is somewhat similar for standalone batteries and hybrids, 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 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



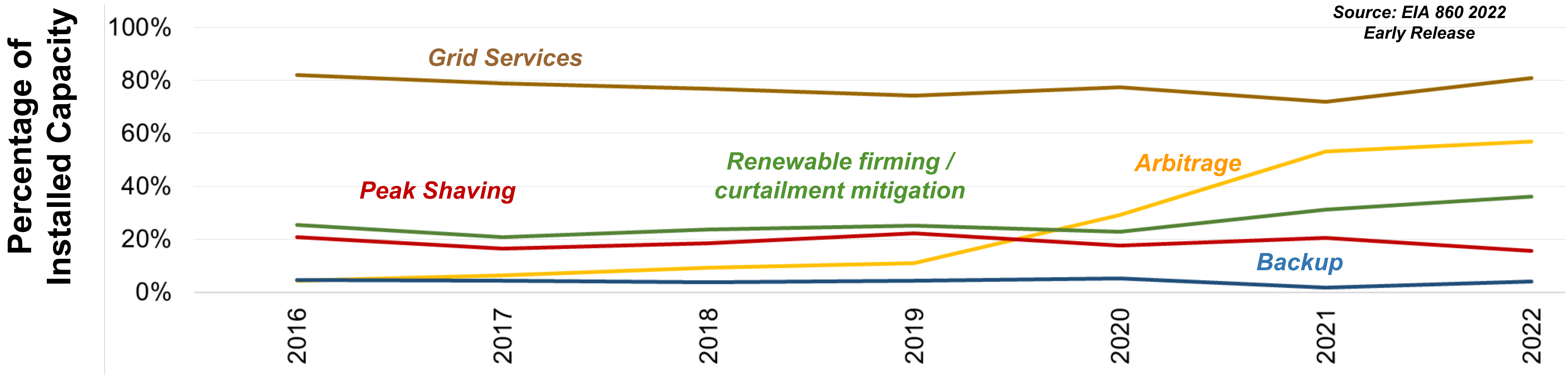
Grid services category includes the following: frequency regulation, load following, ramping/spinning reserve, load management, and voltage/reactive power support

BERKELEY LAB

Arbitrage use-case has increased overtime as a percentage of installed capacity

- Battery operators have selected grid services, peak shaving and backup use-cases at a ***relatively constant rate*** over the last 6 years.
- Over the ***last 3 years***, however, more operators are selecting the arbitrage use-case

Breakdown of battery use case for all batteries overtime



Percentages can add up to more than 100% because respondents can select more than one use-case

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

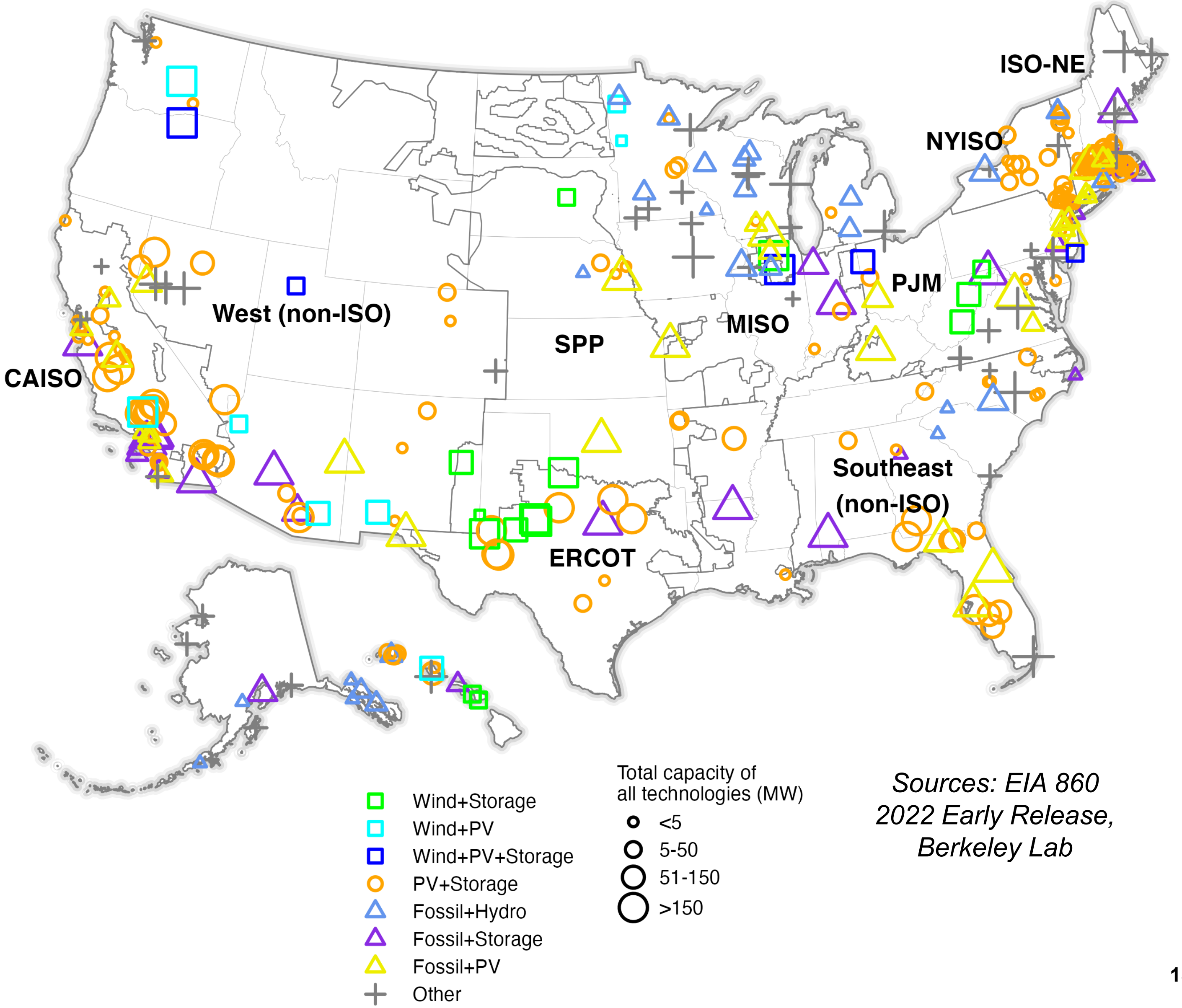
- Massachusetts contains the largest number of PV hybrid plants (80 plants total, 75 of which are PV+Storage), though plants all include <7 MW of PV
- With 52 total plants, California has the second highest number of PV hybrid plants across the United States, 21 of which have installed PV capacities ≥100 MW

Wind Hybrids / Co-Located Plants

- Wind hybrids are relatively sparse across United States, and only one new wind hybrid came online in 2022 (Wheatridge in Oregon)
- Texas contains 5 of the 10 largest wind hybrids by wind capacity

Fossil Hybrids / Co-Located Plants

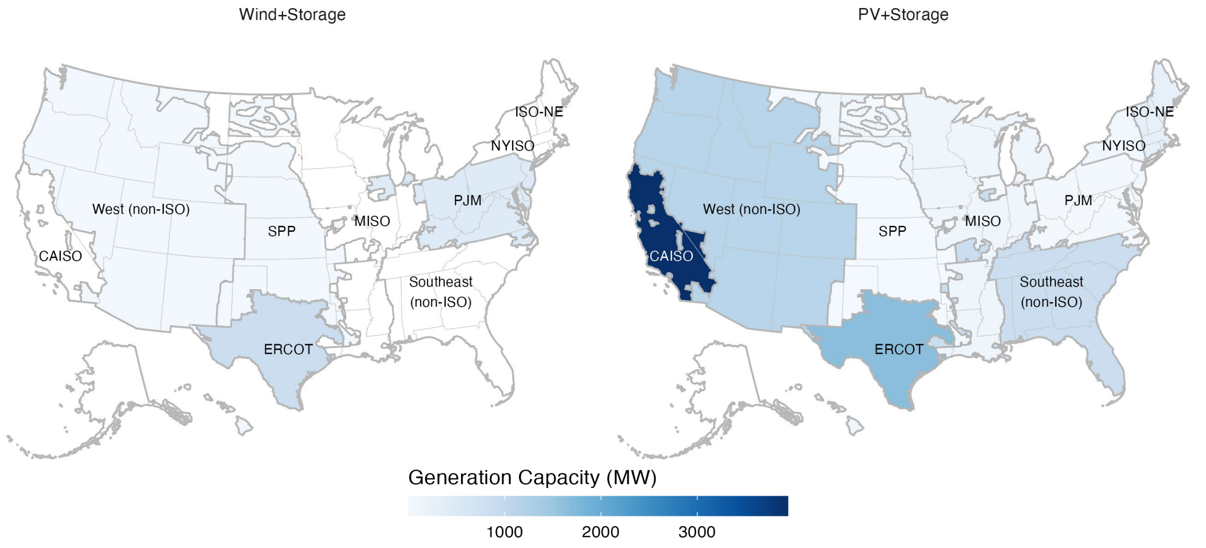
- California has almost half of all Fossil+Storage hybrids across the country (9), the next closest state only has 2 installations
- Fossil+PV is relatively spread out across the county with small amounts of PV added to larger fossil units



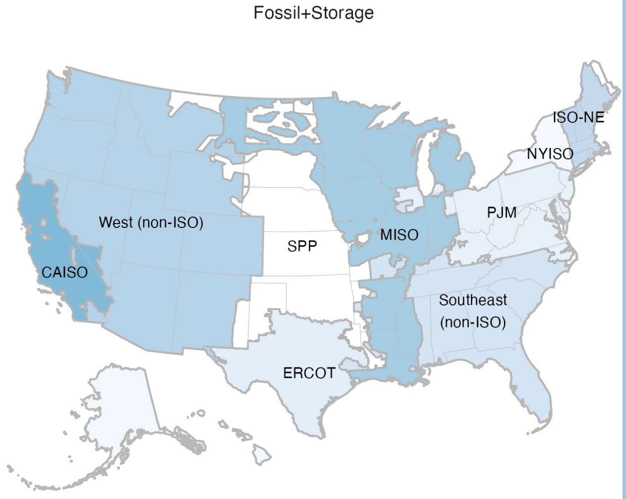
Sources: EIA 860 2022 Early Release, Berkeley Lab

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

Aggregate Generator Capacity by Hybrid Type and ISO

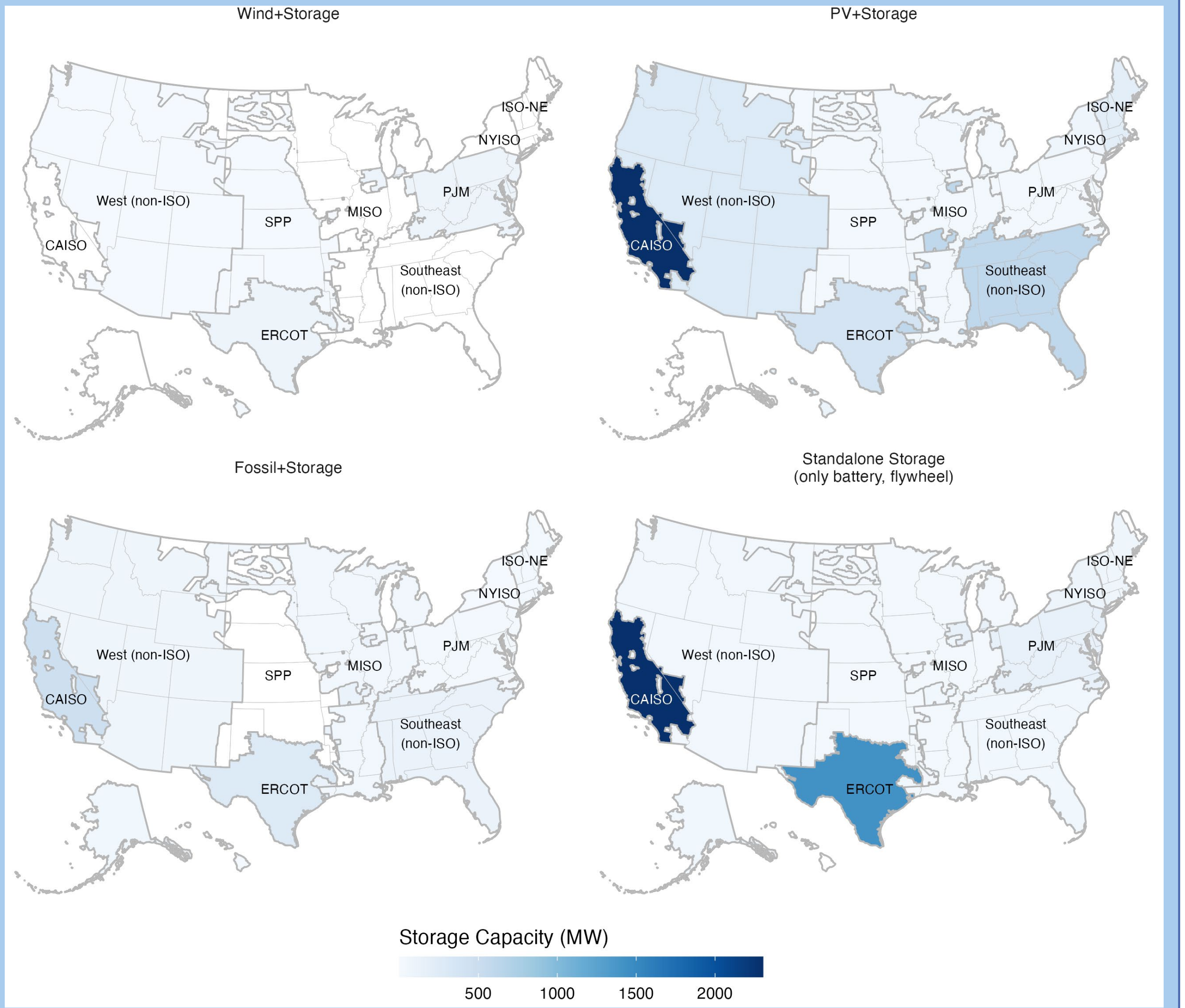


For hybrid/co-located plants, the generation capacity is depicted. For standalone storage, the storage capacity is depicted.



Across all four plant types depicted in the right figure, CAISO (5 GW) has roughly equal amounts of storage capacity as all other regions combined (4 GW) but **more than double** the storage energy (18 GWh vs. 7.5 GWh)

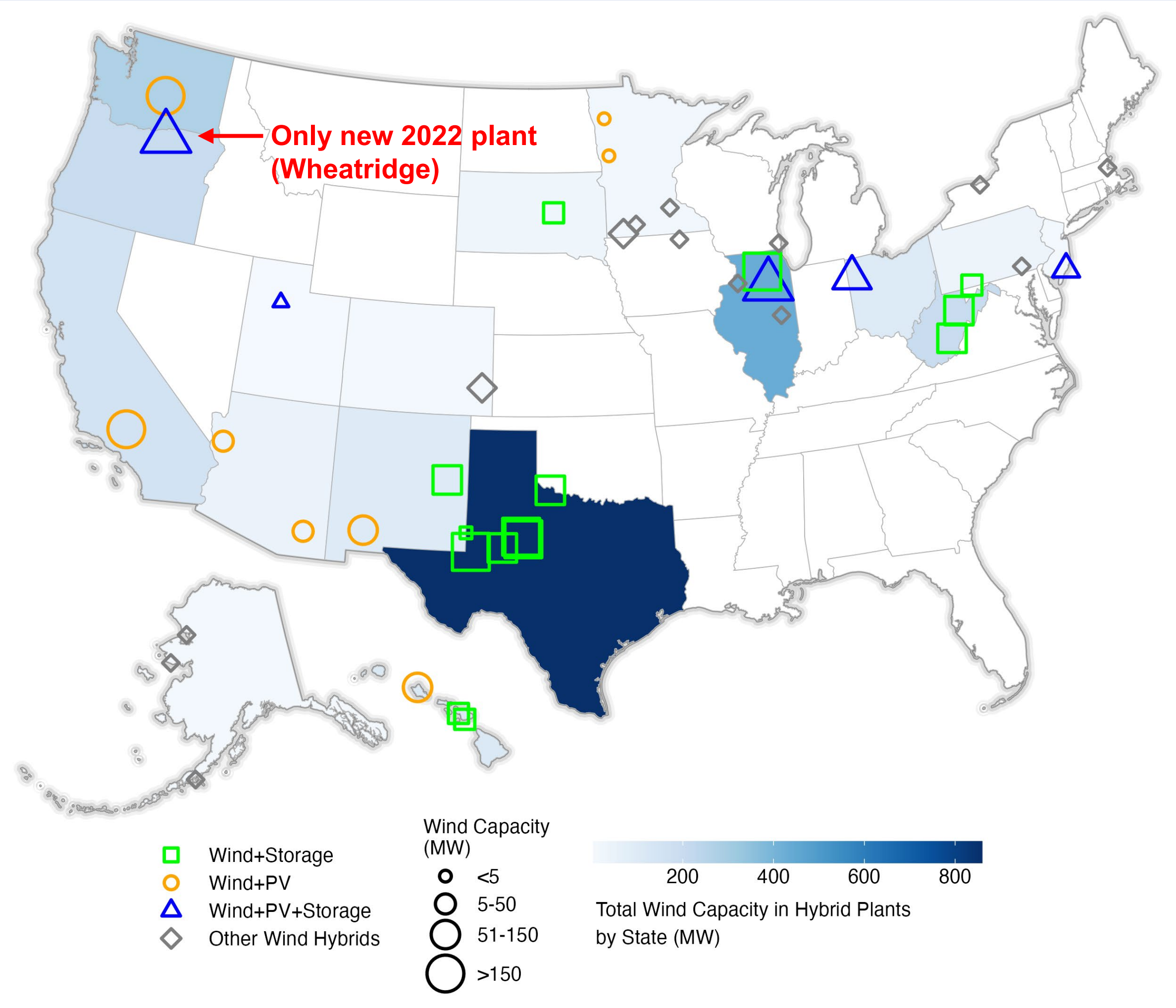
Aggregate Storage Capacity by Plant Type and ISO



Sources: EIA 860 2022 Early Release, Berkeley Lab

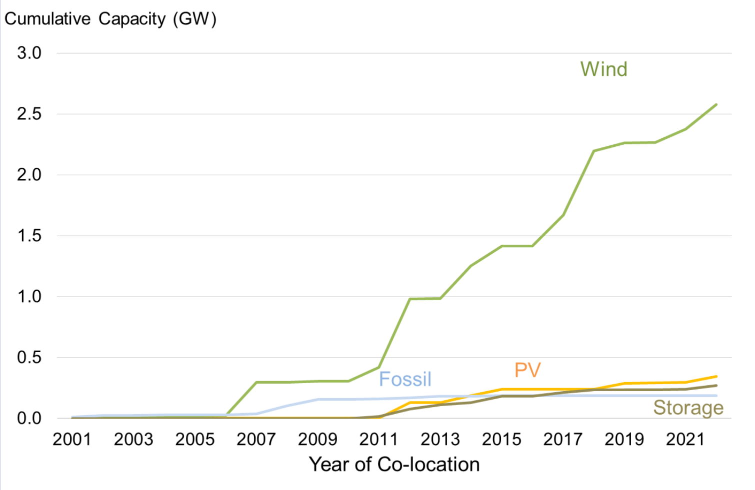
Hybrid wind plants that pair wind with storage saw only one new project in 2022

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



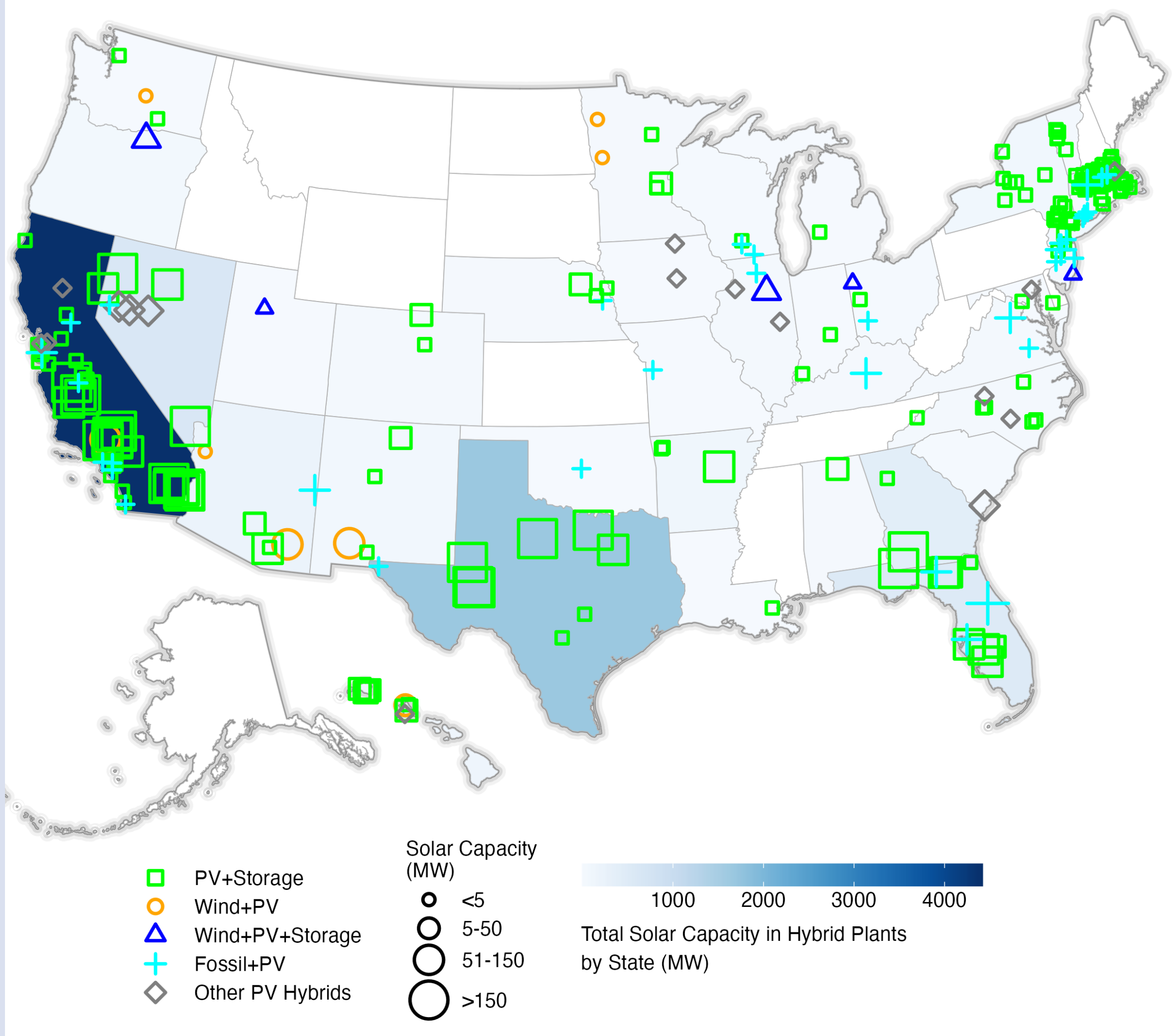
Note: Duration of storage for wind hybrids tends to be limited (typically <1 hr)

Sources: EIA 860 2022 Early Release, Berkeley Lab

BERKELEY LAB

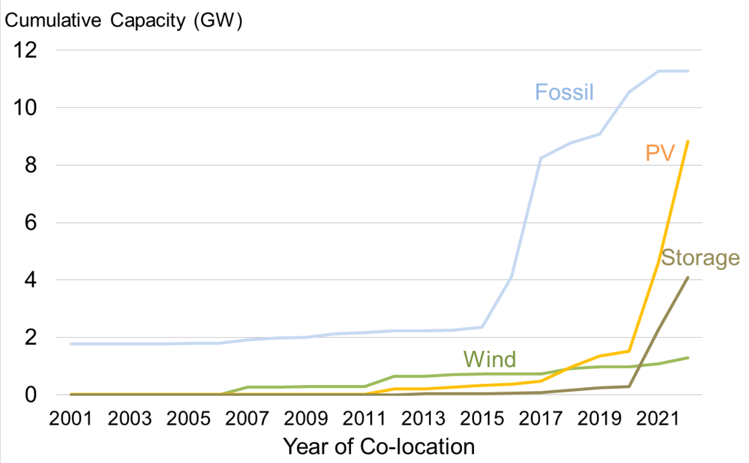
PV+Storage dominates the various PV+ hybrid configurations in terms of number of plants, PV capacity, storage energy, and year-over-year growth

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.

Sources: EIA 860 2022 Early Release, Berkeley Lab

BERKELEY LAB

AC versus DC coupling for PV+Storage plants

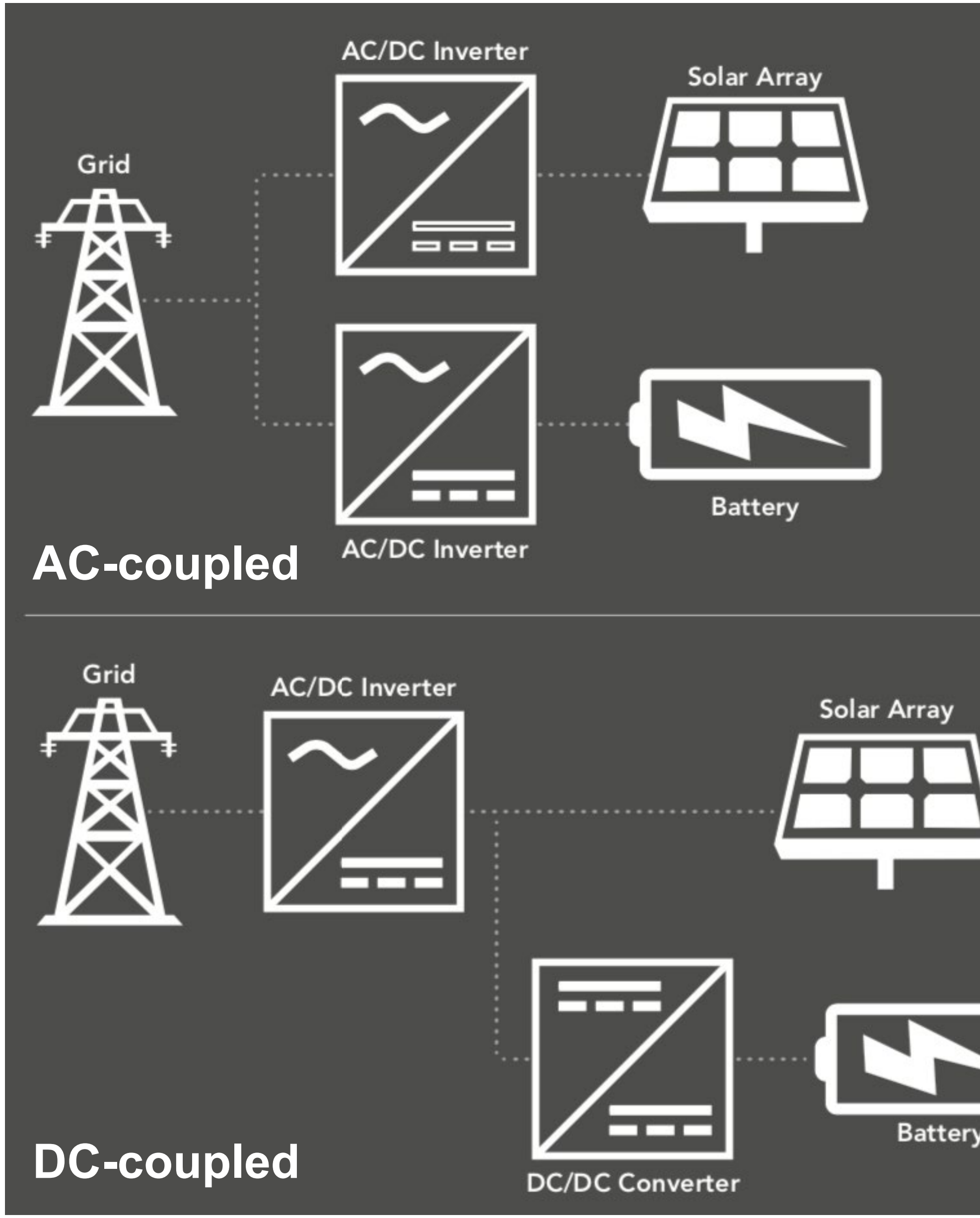
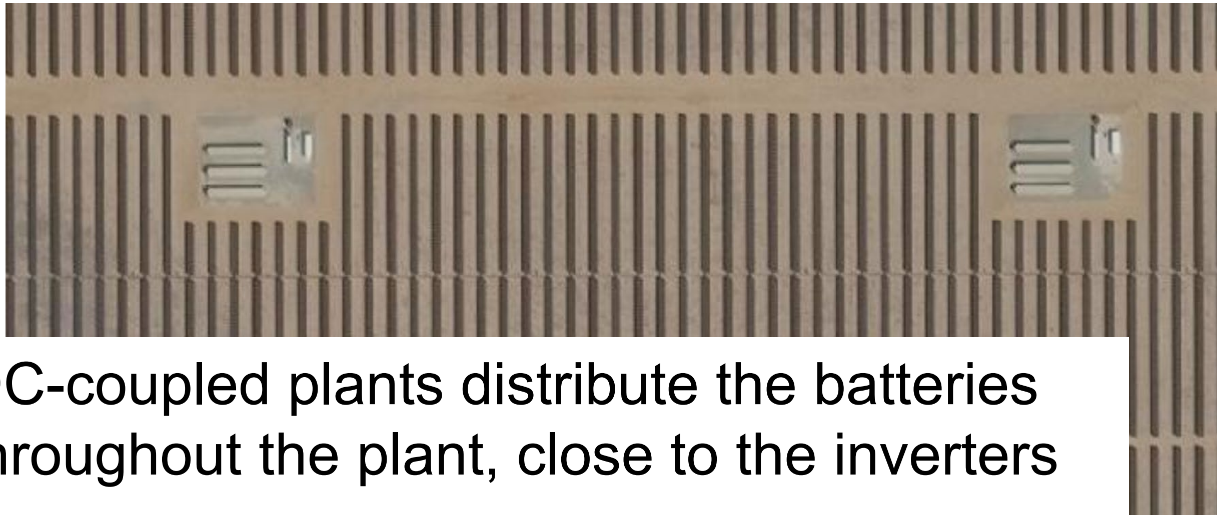


Figure credit: Verbruggen, S. 2019. "Go big, go DC: an in-depth look at DC-coupled solar-plus-storage." Energy Storage News, October 9, 2019, https://www.energy-storage.news/go-big-go-dc-an-in-depth-look-at-dc-coupled-solar-plus-storage/

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

Three notable stats from the 53 operating PV+Storage plants with PV capacity >5 MW_{AC}

This 53-plant sub-sample accounts for >90% of the total PV capacity, storage capacity, and storage energy of the 213 PV+Storage plants that were operational at the end of 2022

1) 17 of these 53 plants are battery retrofits (just 2 retrofits in 2022, down from 11 in 2021)

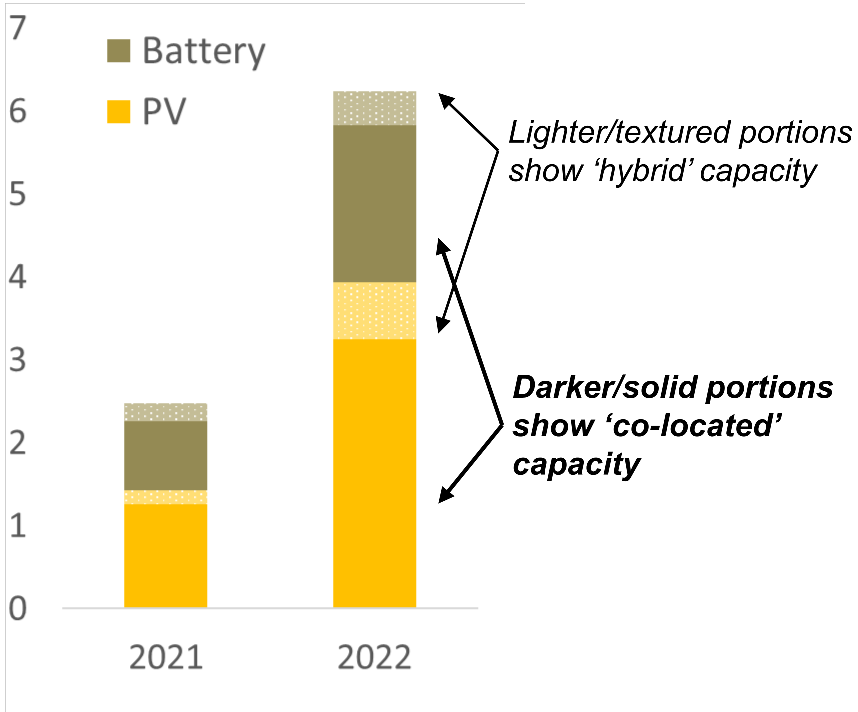
2) 41 of these 53 plants are AC-coupled and 12 are DC-coupled
   - Battery retrofits favor AC coupling (i.e., centralized battery yards): 16 of the 17 retrofits are AC-coupled
   - Focusing on just the 36 greenfield plants (i.e., excluding retrofits), 25 are AC-coupled and 11 are DC-coupled
     - 4 of the 11 greenfield DC-coupled plants came online in 2022 (along with 13 of the 25 greenfield AC-coupled plants)
     - Surprisingly, no real difference in average DC:AC ratios: 1.34 for DC-coupled versus 1.33 for AC-coupled (though the difference in medians is slightly more, at 1.39 DC-coupled versus 1.30 AC-coupled)

3) 21 of these 53 plants are in CAISO, and 6 of these 21 CAISO plants operate as “true hybrids” (i.e., PV+Storage is scheduled as a single unit) while the other 15 are “co-located hybrids” (i.e., the PV and Storage are scheduled as two separate units)

CAISO data on online solar+storage continues to suggest 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)
- Though generators selecting the ‘hybrid’ model remain the minority, almost 700 MW of PV and 400 MW of batteries suggests that developers consider the participation model as viable.

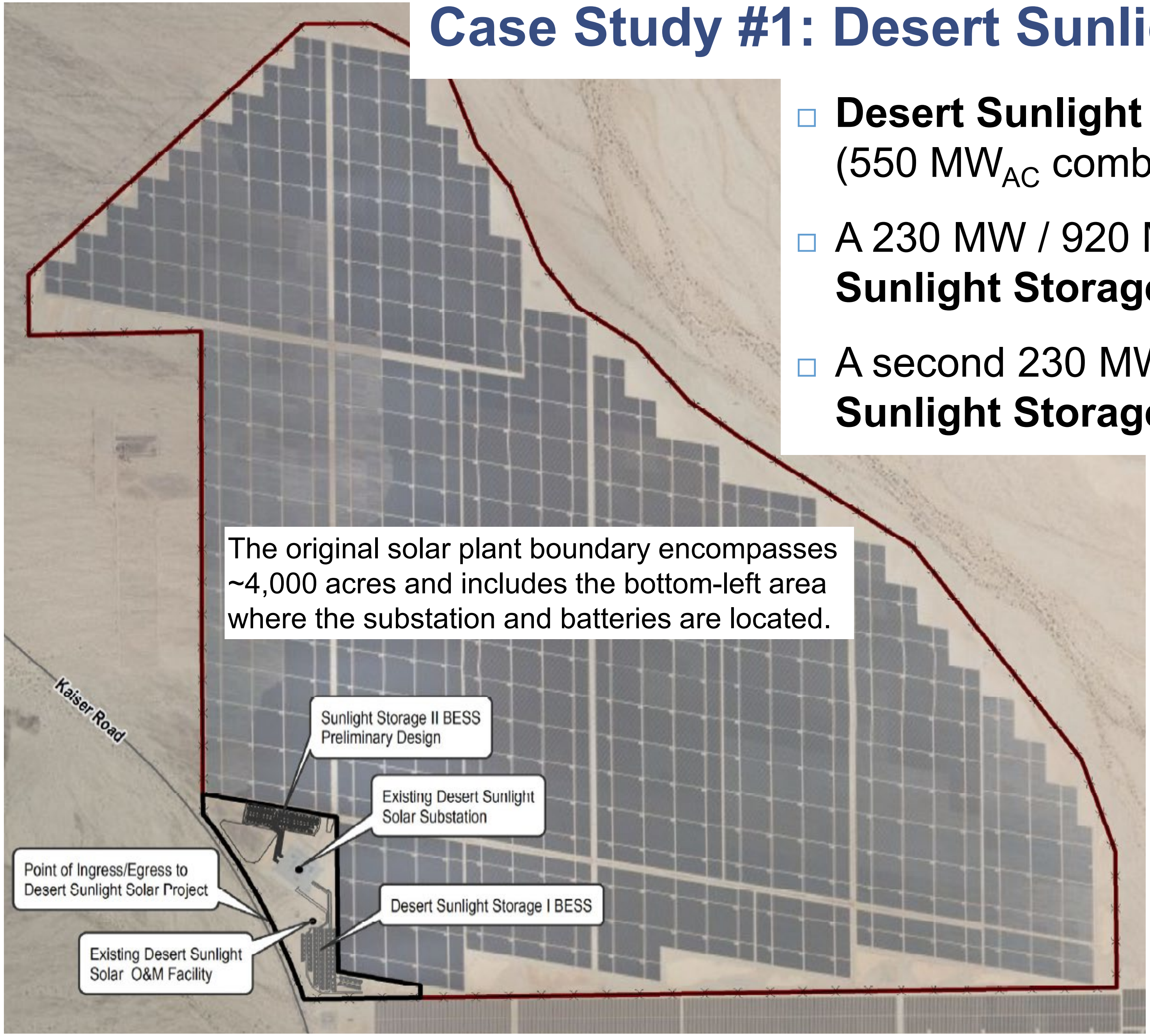
Cumulative CAISO Solar+Storage capacity online



Source: CAISO Master Generating Capability List

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

Case Study #1: Desert Sunlight PV and Co-Located Storage

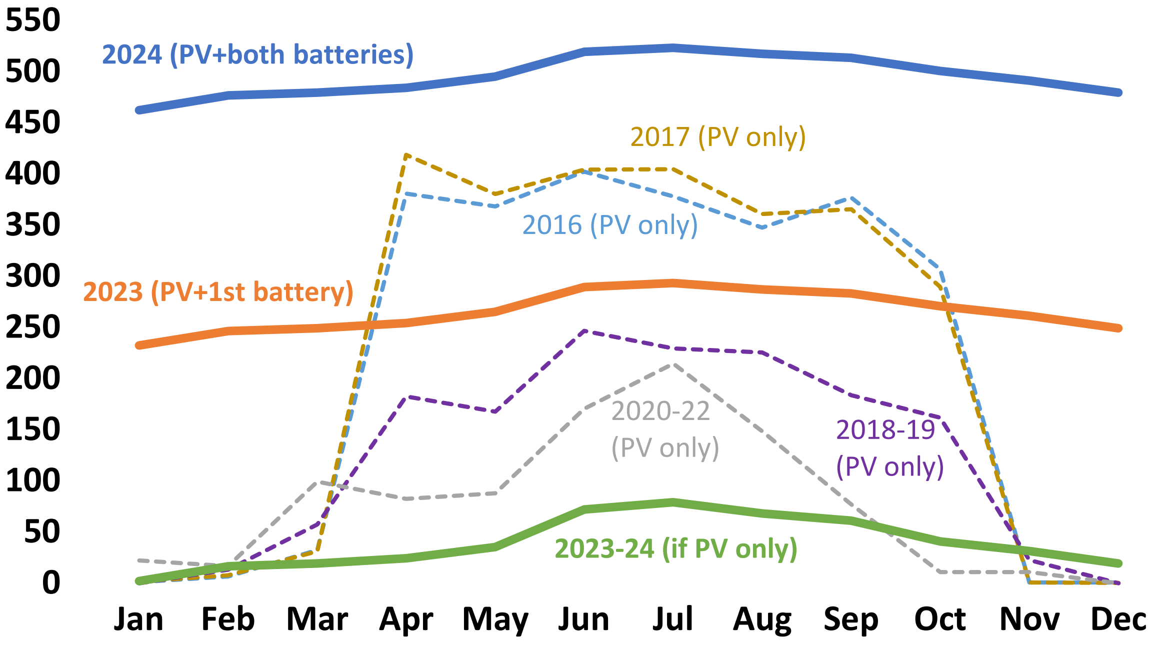


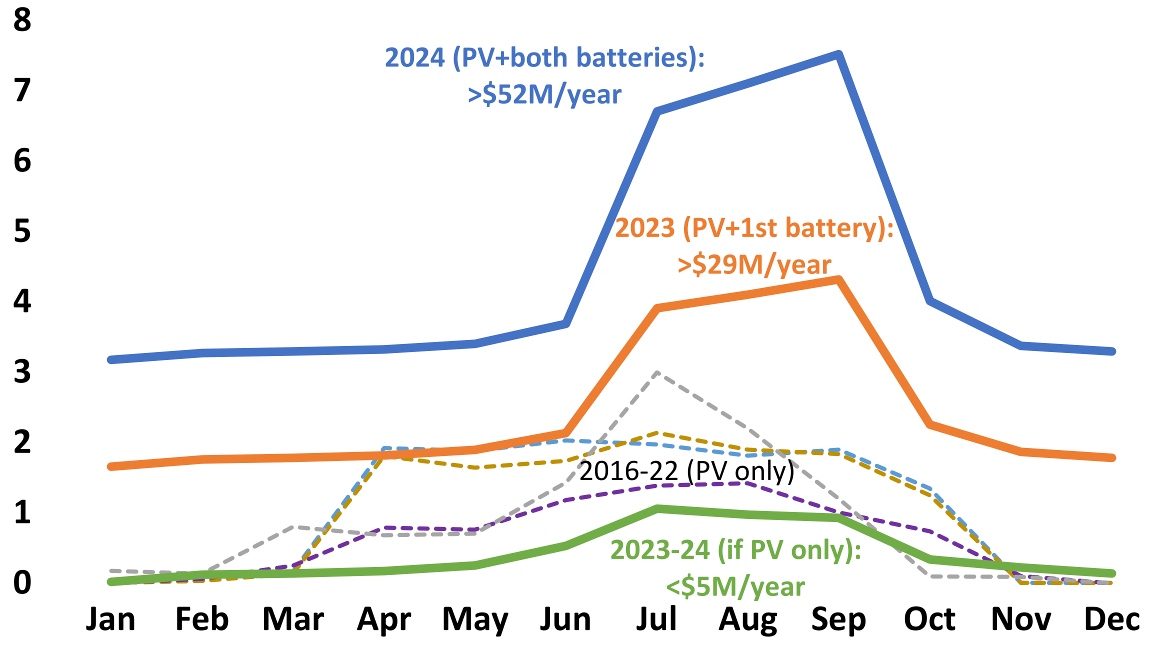
- **Desert Sunlight 250** and **Desert Sunlight 300** PV plants (550 MW_{AC} combined) came online in 2014
- A 230 MW / 920 MWh battery was added in August 2022: **Sunlight Storage I BESS**
- A second 230 MW / 920 MWh battery is coming in 2024: **Sunlight Storage II BESS**
- **No additional interconnection capacity is required:** The batteries will operate within the original 550 MW_{AC} interconnection limit (no need to re-enter the interconnection queue)
- **No extra land required:** Both batteries fit within the original ~4,000 acre footprint of the combined PV plants
- **Sunlight Storage I went from PPA to COD in just 10 months!**

Image: https://eplanning.blm.gov/public_projects/2023119/200546548/20078441/250084623/Sunlight%20Storage%20II%20BESS%20POD_acc.pdf

Case Study #1: Desert Sunlight PV and Co-Located Storage (Capacity Value)

- The capacity credit (left graph), and hence the capacity value (right graph), of standalone PV has declined over time with increasing PV market share in CAISO
- Adding 460 MW of 4-hour batteries to the 550 MW_{AC} Desert Sunlight PV plant boosts the capacity credit to near the 550 MW_{AC} interconnection limit and adds almost $50M/year of capacity value

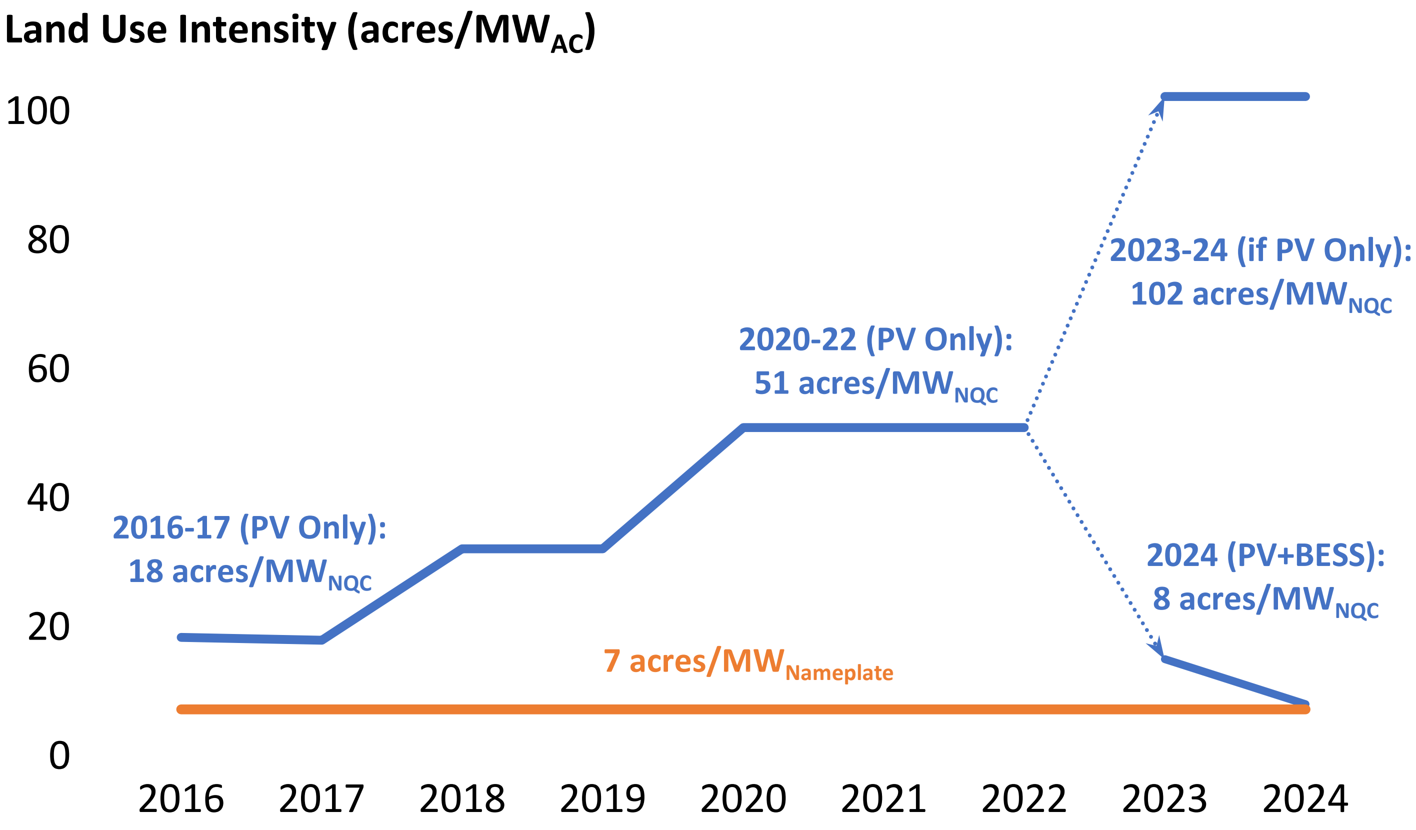




Capacity credit (i.e., NQC) is based on annual Net Qualifying Capacity reports found at: http://www.caiso.com/planning/Pages/ReliabilityRequirements/Default.aspx
Capacity prices are based on annual Resource Adequacy reports at: https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/electric-power-procurement/resource-adequacy-homepage
4-hour battery assumed to have 100% capacity credit (i.e., NQC); monthly PV+S hybrid capacity credit estimated as the lesser of (PV MW_{NQC} + Battery MW_{NQC})/PV $MW_{Nameplate}$ or 100%

Case Study #1: Desert Sunlight PV and Co-Located Storage (Land-Use Intensity)

- Solar has a relatively high land-use intensity (~7 acres/$MW_{Nameplate}$ for Desert Sunlight—see orange line in graph) that looks worse when considering Net Qualifying Capacity (NQC) rather than nameplate capacity (see blue line in graph)
- Deterioration in the capacity credit (i.e., NQC) of standalone PV over time has increased its effective land-use intensity: from ~18 acres/MW_{NQC} in 2016 to ~102 acres/MW_{NQC} in 2023
- But adding the 2 x 230 MW 4-hour batteries within the solar plant footprint brings the land-use intensity of the hybrid plant back down to near nameplate levels: ~15 acres/MW_{NQC} in 2023 (first battery) and ~8 acres/MW_{NQC} in 2024 (second battery)



Note: To compare these land-use numbers to a broader industry survey, see: https://emp.lbl.gov/publications/land-requirements-utility-scale-pv

Case Study #2: Extreme Makeover at Kramer Junction, CA

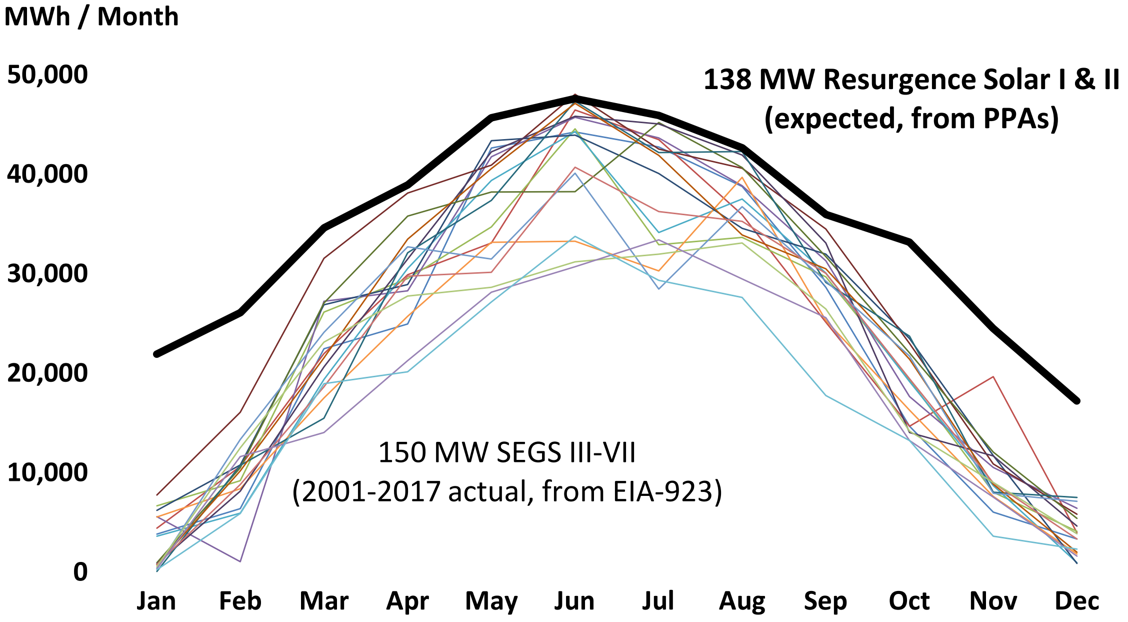
Same site/footprint, but big increase in energy and net qualifying (RA) capacity, at a much lower price

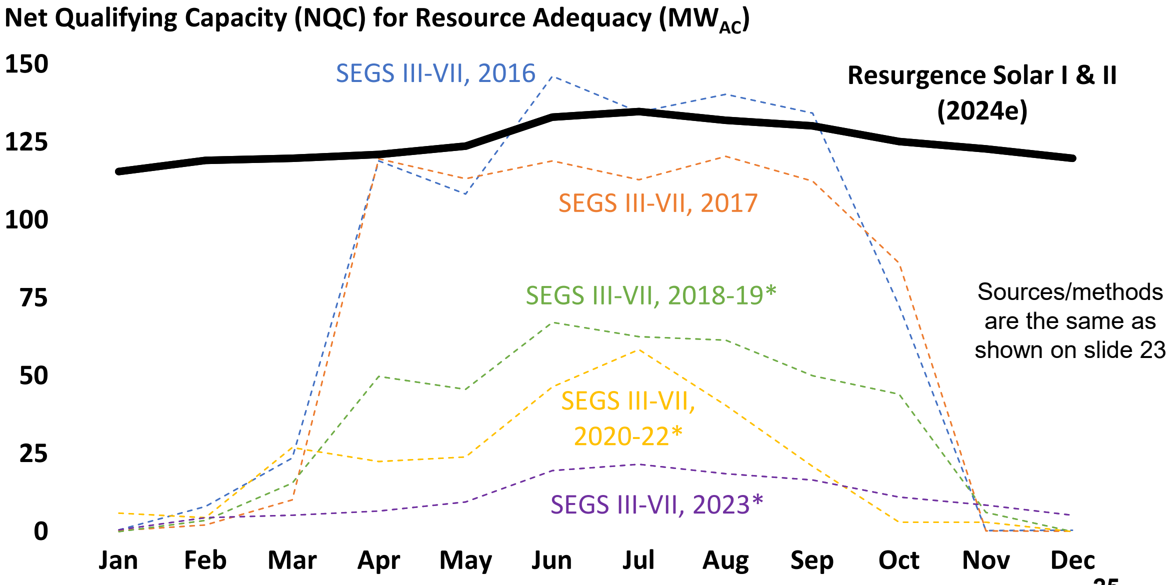
BEFORE:

- Solar Energy Generating Systems (SEGS) III-VII
- 150 MW_{AC} of parabolic trough concentrating solar thermal power (CSP) plants
- Built >35 years ago (CODs from 1986-1988)—among the very first utility-scale solar plants in the world
- Gradually decommissioned from 2018-2021
- 21% avg capacity factor from 2001-2017 (range of 15-26%)
- Power sales prices averaged $126/$MWh_{PV}$ (in nominal dollars) from 2011-2016, with a range of $110-$138/MWh_{PV}

AFTER:

- Resurgence Solar I & II
- 138 MW_{AC} PV plus 115 MW_{AC} / 460 MWh BESS
- Built on the former site of SEGS III-VII, COD in summer 2023
- 34% first-year capacity factor (expected)
- 20-year PPAs with two Community Choice Aggregators (CCAs) who will control the battery dispatch
- 20-year levelized PPA price (in 2022 dollars) of $45/$MWh_{PV}$ ($26/$MWh_{PV}$ for PV plus $19/$MWh_{PV}$ for the BESS)





*2018-2023 are estimated as if SEGS III-VII had remained fully online post-2017

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

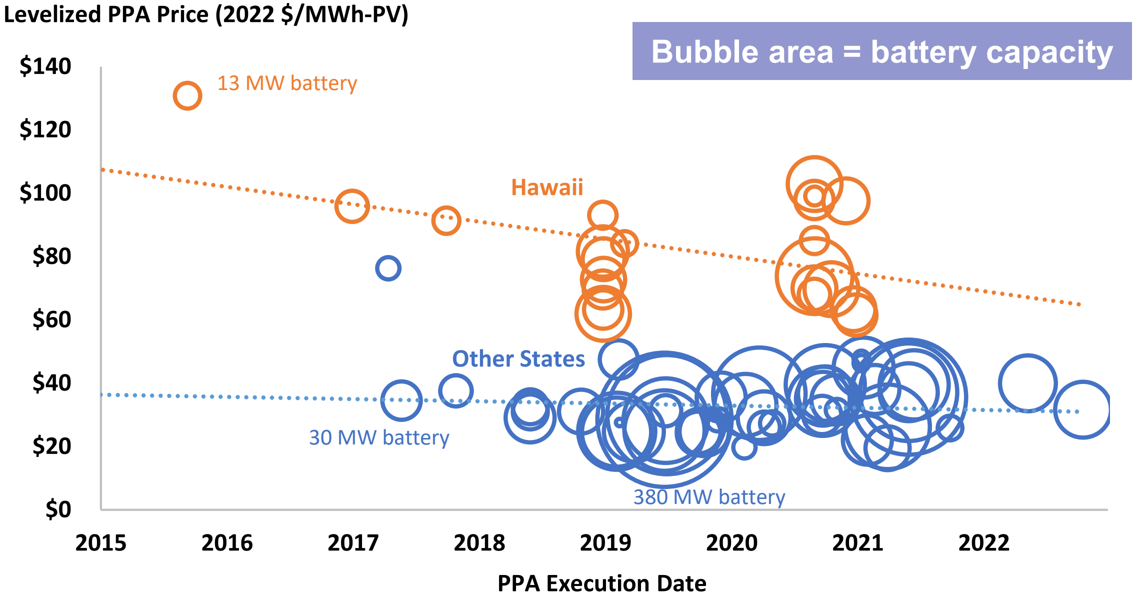
We have PPA prices from a sample of 81 PPAs in 10 states totaling 9.9 GW_{AC} of PV and 5.5 GW_{AC} / 21.8 GWh of batteries

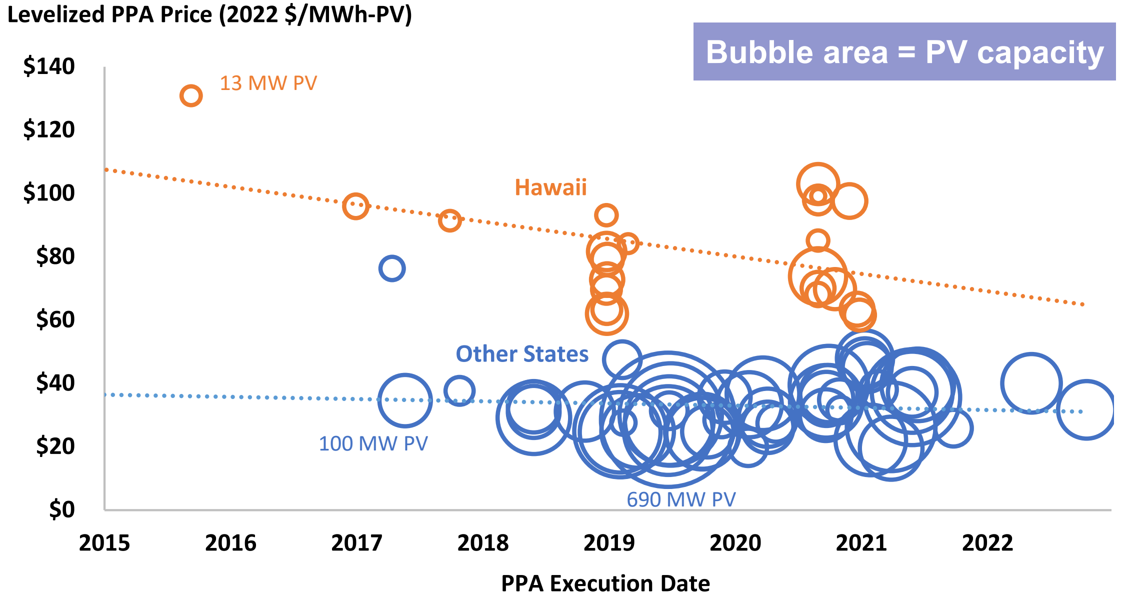
State	# of Plants	Total Capacity (MW_{AC}) PV	Total Capacity (MW_{AC}) Battery	Average Battery:PV Capacity	Battery Storage Avg Duration	Battery Storage Total MWh
AZ	3	173	50	29%	4.0	200
CA	26	3,429	2,162	63%	4.0	8,619
CO	3	595	226	38%	4.0	902
FL	1	50	12	24%	2.0	24
GA	2	409	80	20%	2.0	160
HI	23	803	797	99%	4.1	3,258
NM	9	1,520	655	43%	4.0	2,620
NV	11	2,644	1,473	56%	4.0	5,863
NY	2	213	10	5%	4.0	40
OR	1	50	30	60%	4.0	120
Total	**81**	**9,884**	**5,495**	**56%**	**4.0**	**21,806**

- Sample dominated by CA, NV, NM, and HI
- 42 of these 81 PPAs are for plants that are operational (other 39 still in development/construction)
- 9 of the operational plants are battery retrofits to pre-existing PV plants (all in CA)

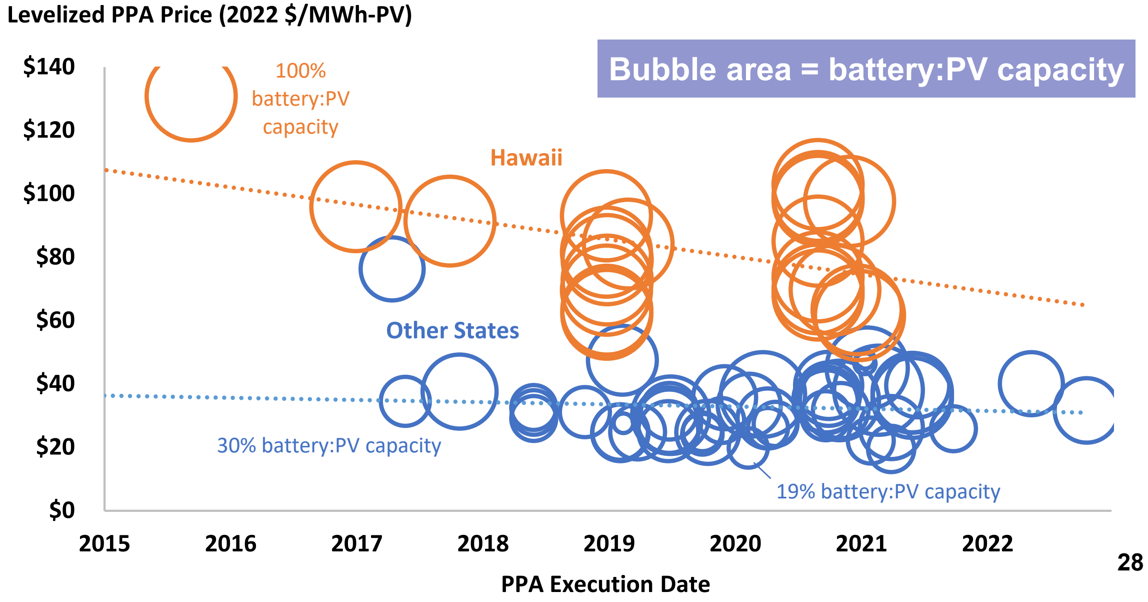
BERKELEY LAB

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



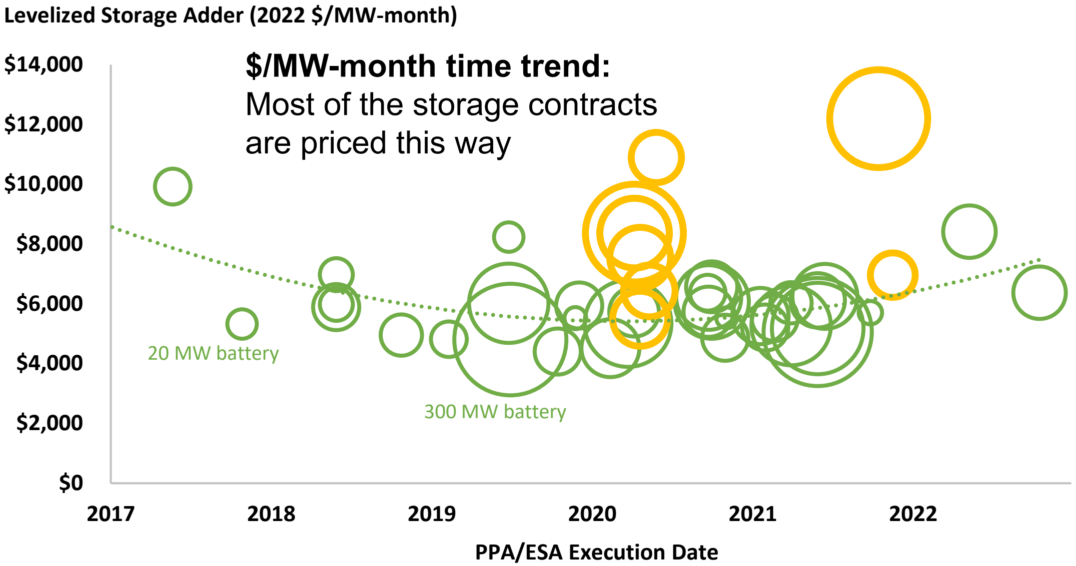


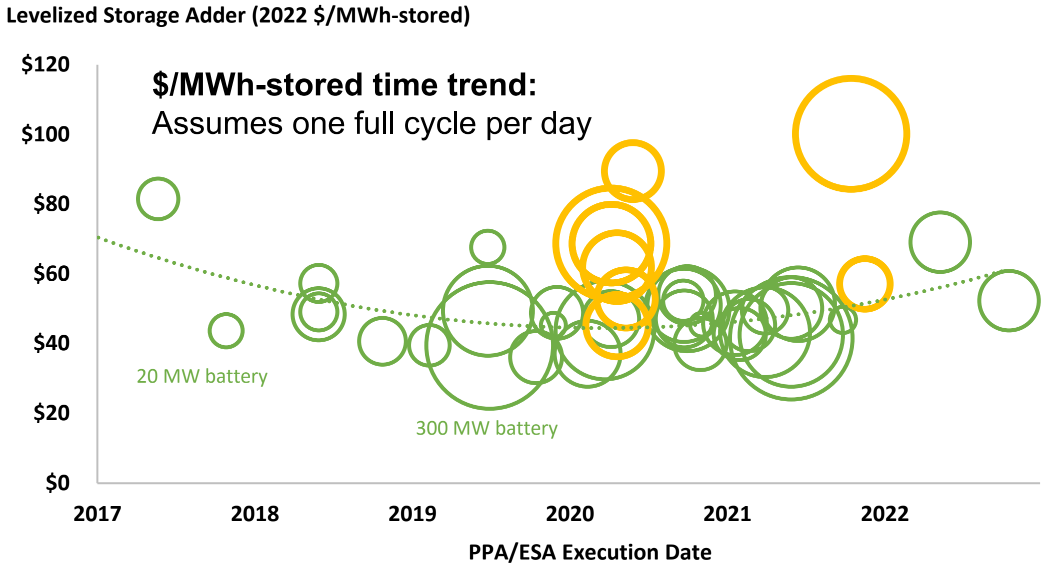
- All 3 graphs show same data from sub-sample of 71 plants (retrofits not included); the only difference is what the bubble size represents
  - ➢ Hawaii (orange): 22 plants, 0.8 GW_{AC} PV, 0.8 GW_{AC} battery
  - ➢ Other States (blue): 49 plants, 7.6 GW_{AC} PV, 3.7 GW_{AC} battery
- Downward trend 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; 59 of the 71 plants have 4-hour duration (other 12 are 5x2 hr, 1x2.5, 1x3.7, 4x5, 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 44 PV hybrids in CA (25), NM (9), NV (6), AZ (3) and OR (1) totaling 3.7 GW_{AC} of batteries, all with 4-hour duration

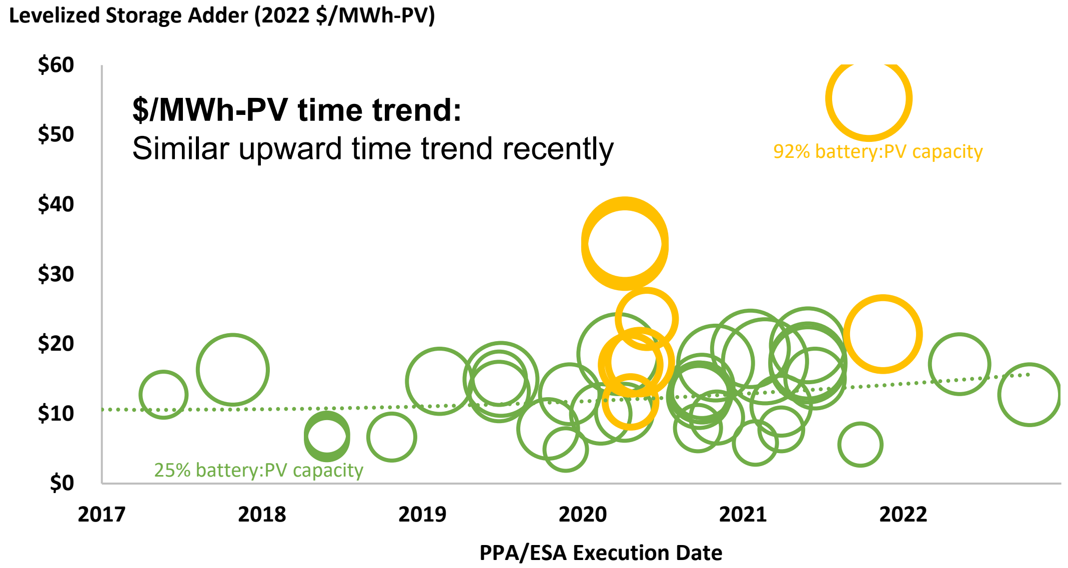


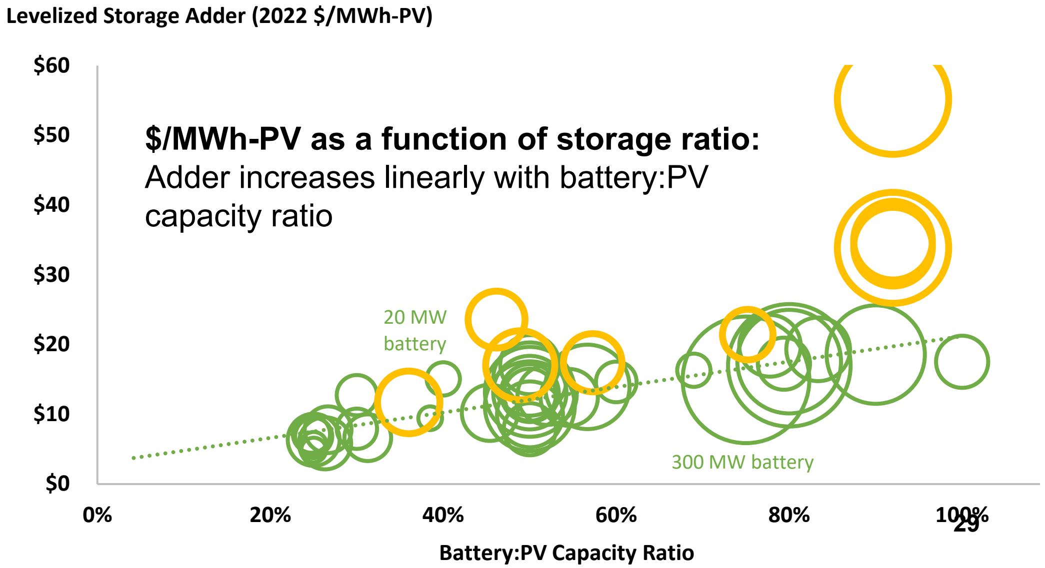


Green = greenfield

Gold = battery retrofit

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

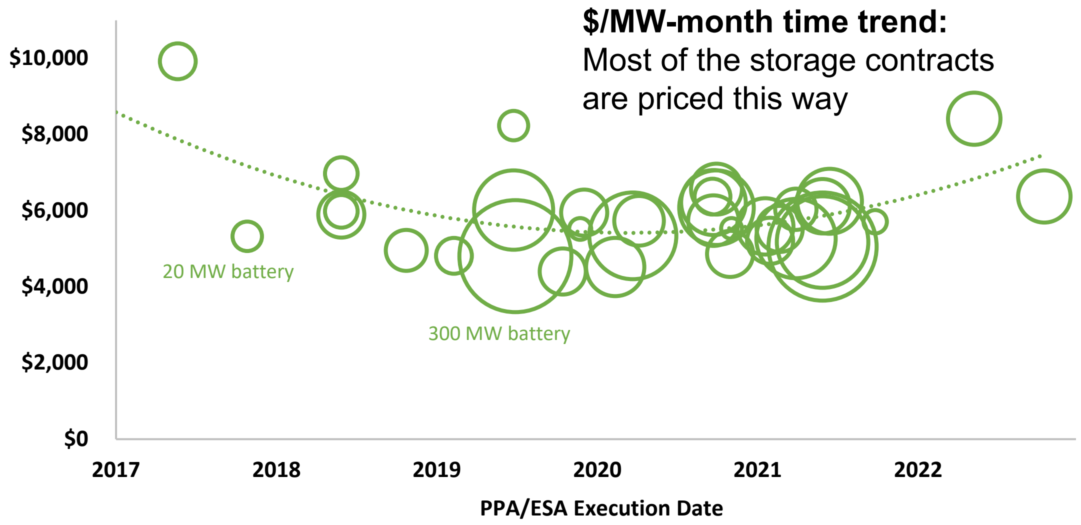




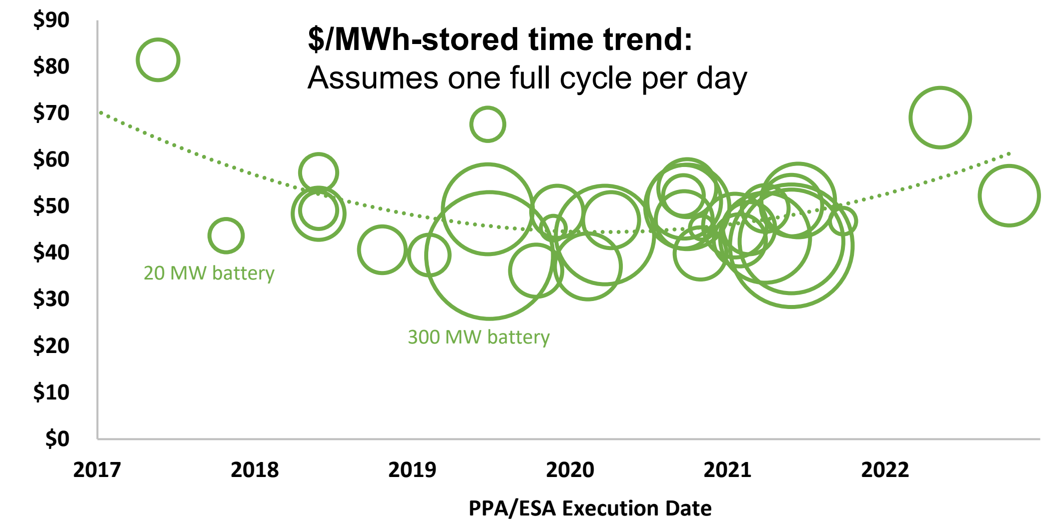
PPAs that price the PV and storage separately enable us to calculate a “levelized storage adder,” shown here 4 different ways—all recently increasing

Graphs show adders from 35 PV hybrids in CA (16), NM (9), NV (6), AZ (3) and OR (1) totaling 2.7 GW_{AC} of batteries, all with 4-hour duration

Levelized Storage Adder (2022 $/MW-month)



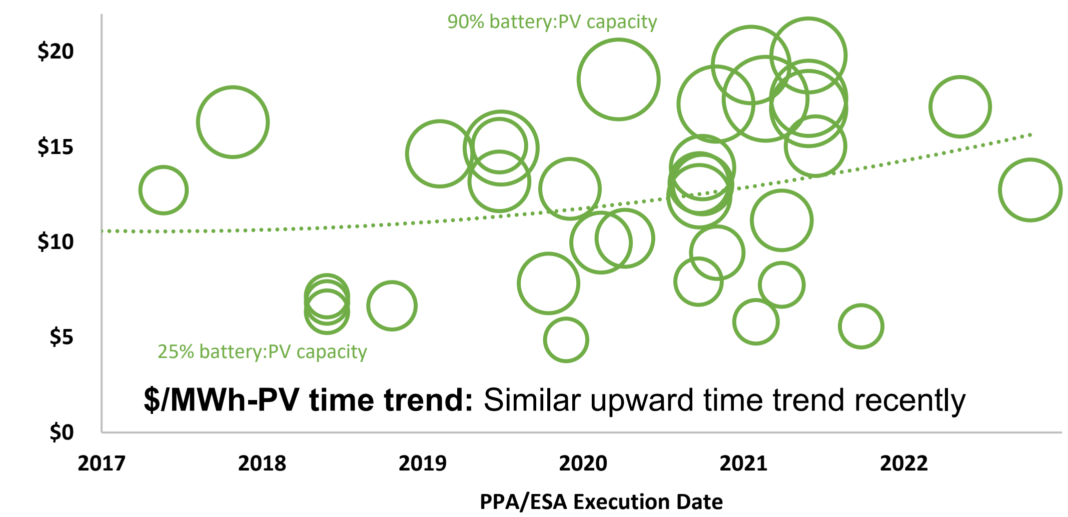
Levelized Storage Adder (2022 $/MWh-stored)



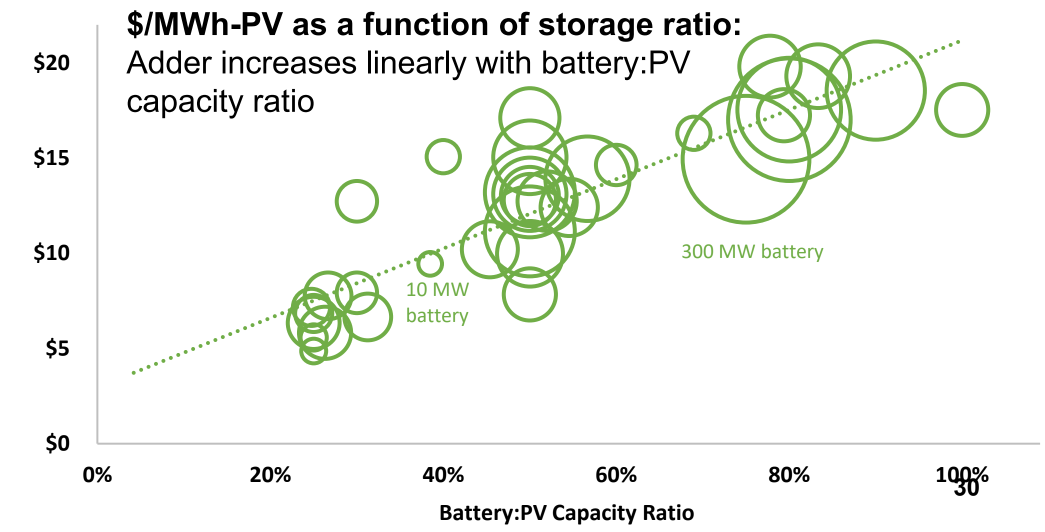
Greenfield plants only

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

Levelized Storage Adder (2022 $/MWh-PV)



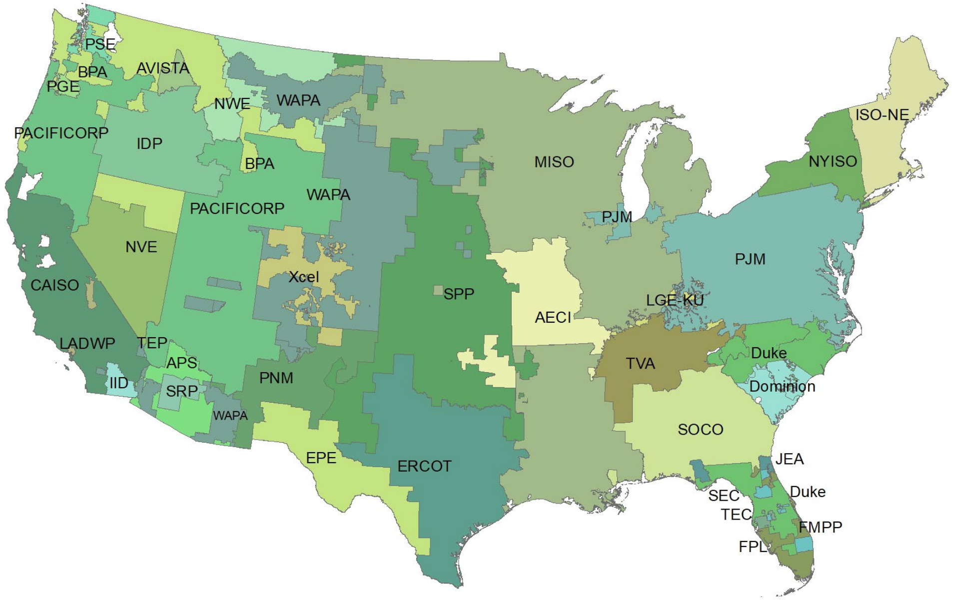
Levelized Storage Adder (2022 $/MWh-PV)



Hybrid Pipeline:
Hybrid plants in interconnection queues at the end of 2022

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 distribution connections
  - Includes all plants in queues through the end of 2022
  - Full sample includes 10,262 “active” plants, of which 2,308 (22%) are in a hybrid or co-located configuration
  - Hybrids represent 500 GW (37%) of active generation capacity in queues, and 358 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 ~33% of proposed hybrid plants
  - For the remainder, storage capacity was estimated using known storage:generator ratios from other plants

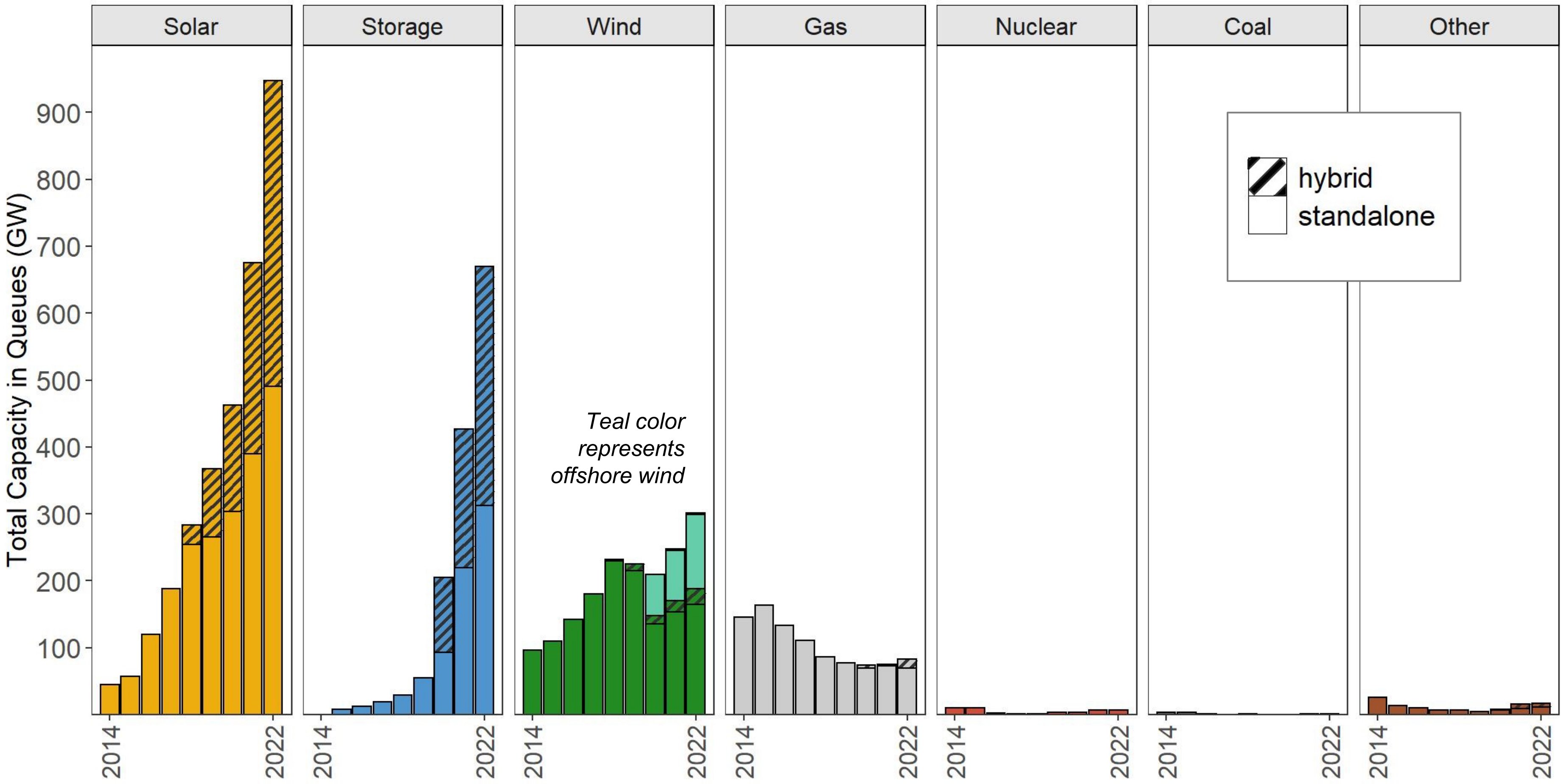


Coverage area of entities for which data was collected
Data source: Homeland Infrastructure Foundation-Level Data (HIFLD)
Note that service areas can overlap
No data collected for Hawaii or Alaska

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
  - 3.6 GW of "unknown" hybrid plants
  - 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.*

BERKELEY LAB

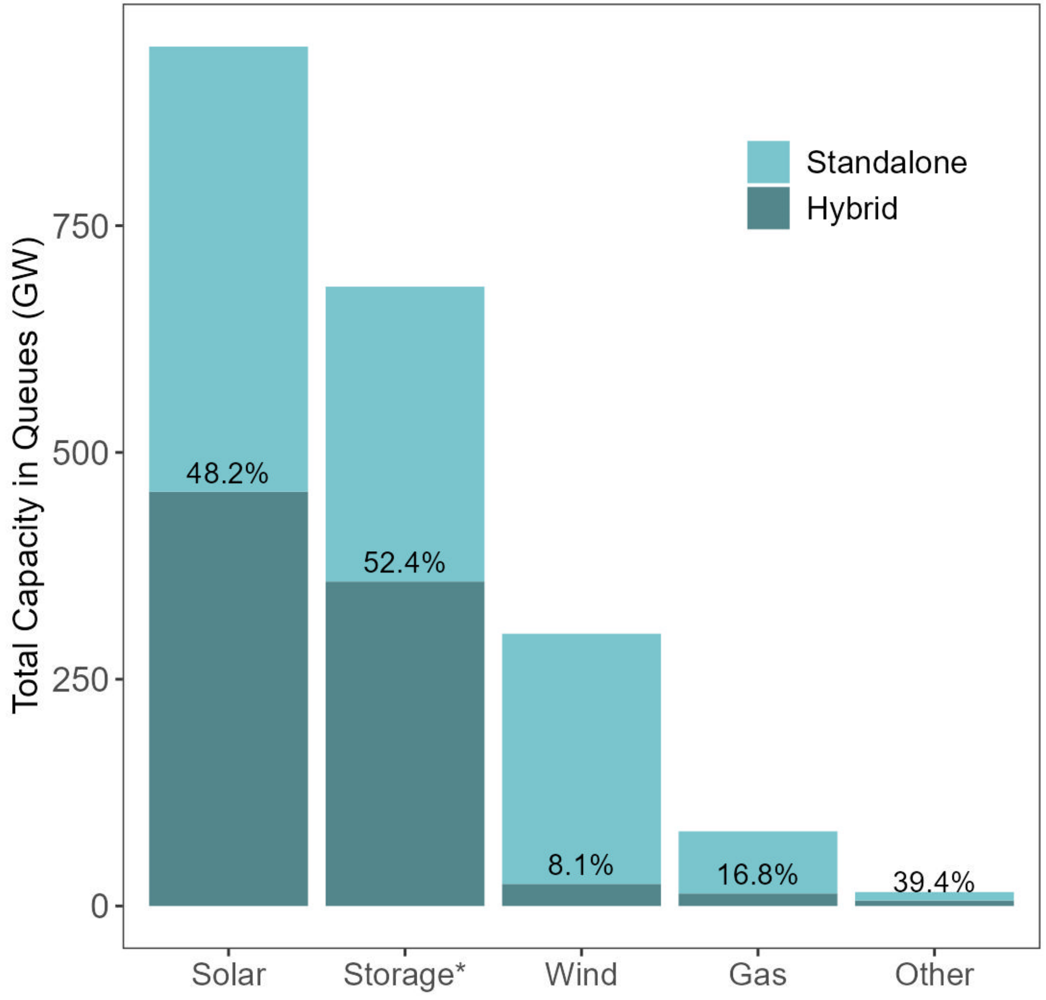
Numerous hybrid configurations exist in the queues, but Solar+Battery is dominant in both number of proposed plants and total capacity

Hybrid Type	Number of Plants	Generator(s) Capacity (MW)
Solar+Battery	2161	430,908
Gas+Solar+Battery	18	27,950
Wind+Battery	55	17,935
Solar+Wind+Battery	28	12,038
Solar+Wind	14	4,076
Unknown Hybrid	18	3,619
Offshore Wind+Battery	1	1,190
Battery+Other	4	1,112
Gas+Battery	6	428
Gas+Solar	1	307
Other+Solar	1	7
Coal+Battery	1	0
Hybrid Total	**2,308**	**499,570**
Non-Hybrid Total	*7,954*	*1,183,508*

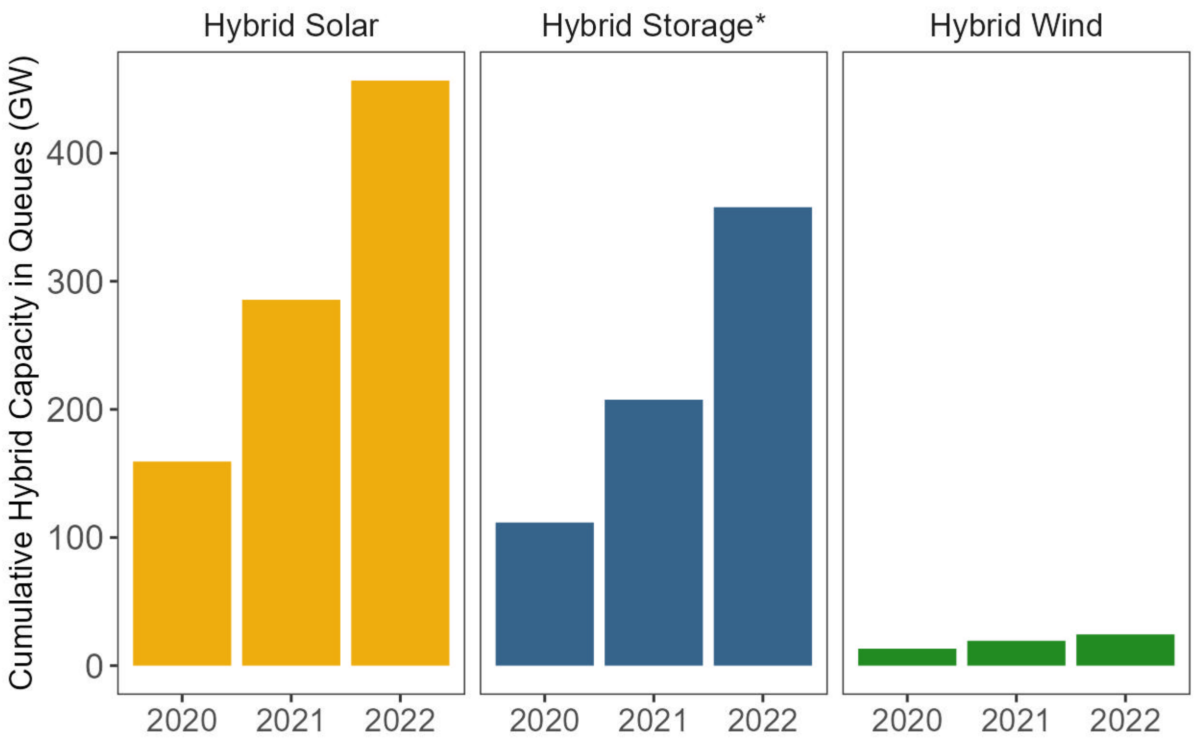
- Over 93% of all hybrid plants are Solar+Battery, representing 86% of all known hybrid generation capacity in the queues
- The next two largest configurations – Gas+Solar+Battery and Wind+Battery - account for only ~6% and ~4% of known hybrid capacity in the queues, respectively
- The 18 “Unknown” hybrids are plants from SPP for which details were unavailable
  - These are presumed to be predominantly solar+battery and wind+battery plants
- There were 51% more hybrid plants – representing 59% more generating capacity – in the queues at the end of 2022 compared to 2021
  - By comparison, standalone storage capacity in the queues increased by 48% year-over-year

BERKELEY LAB

Interest in hybrid plants has increased over time: Hybrids comprise 52% of active storage capacity (358 GW), 48% of solar (457 GW), and 8% of wind (24 GW)



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



- **Solar Hybrids** include: Solar+Storage (431 GW), Solar+Wind (3 GW), Solar+Wind+Storage (8 GW), Solar+Gas+Storage (15 GW)
- **Wind Hybrids** include: Wind+Storage (19 GW), Wind+Solar (1 GW), Wind+Solar+Storage (4 GW)
- **Storage Hybrids** may be paired with any generator type; most are paired with solar
- **Gas Hybrids** include: Gas+Solar+Storage (13 GW), Gas+Storage (0.4 GW), Gas+Solar (0.3 GW) [not shown above]

BERKELEY LAB

Notes: (1) Some hybrids shown may represent storage capacity added to existing generation; only the net increase in capacity is shown; (2) Hybrid plants involving multiple generator types (e.g., Wind+Solar+Storage) show up in all generator categories, presuming the capacity is known for each type.

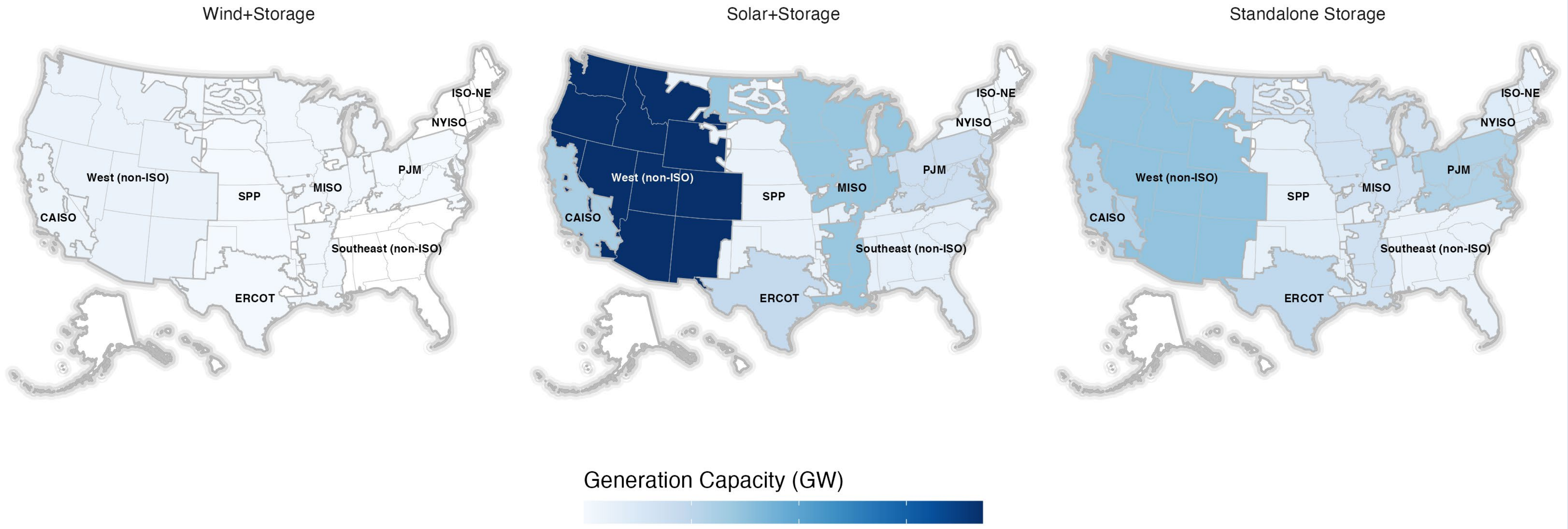
Hybrids comprise a sizable fraction of all proposed solar plants in multiple regions; wind hybrids are less common overall but still a large proportion in CAISO

Region	% of Proposed Capacity Hybridizing in Each Region			
	Solar	Wind	Gas	Storage*
CAISO	97%	45%	15%	53%
ERCOT	42%	4%	3%	42%
ISO-NE	33%	0%	0%	8%
MISO	34%	12%	0%	53%
NYISO	19%	0%	0%	0%
PJM	24%	1%	0%	21%
SPP	18%	1%	0%	26%
Southeast (non-ISO)	21%	0%	0%	66%
West (non-ISO)	81%	17%	74%	75%
TOTAL	**48%**	**8%**	**17%**	**52%**

**Hybrid storage capacity is estimated for some projects. 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 (97%) and non-ISO West (81%), and is above or near 20% in all regions
- **Wind** hybridization relative to total amount of wind in each queue is highest in CAISO (45%), the non-ISO West (17%), and MISO (12%), and is less than 5% 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

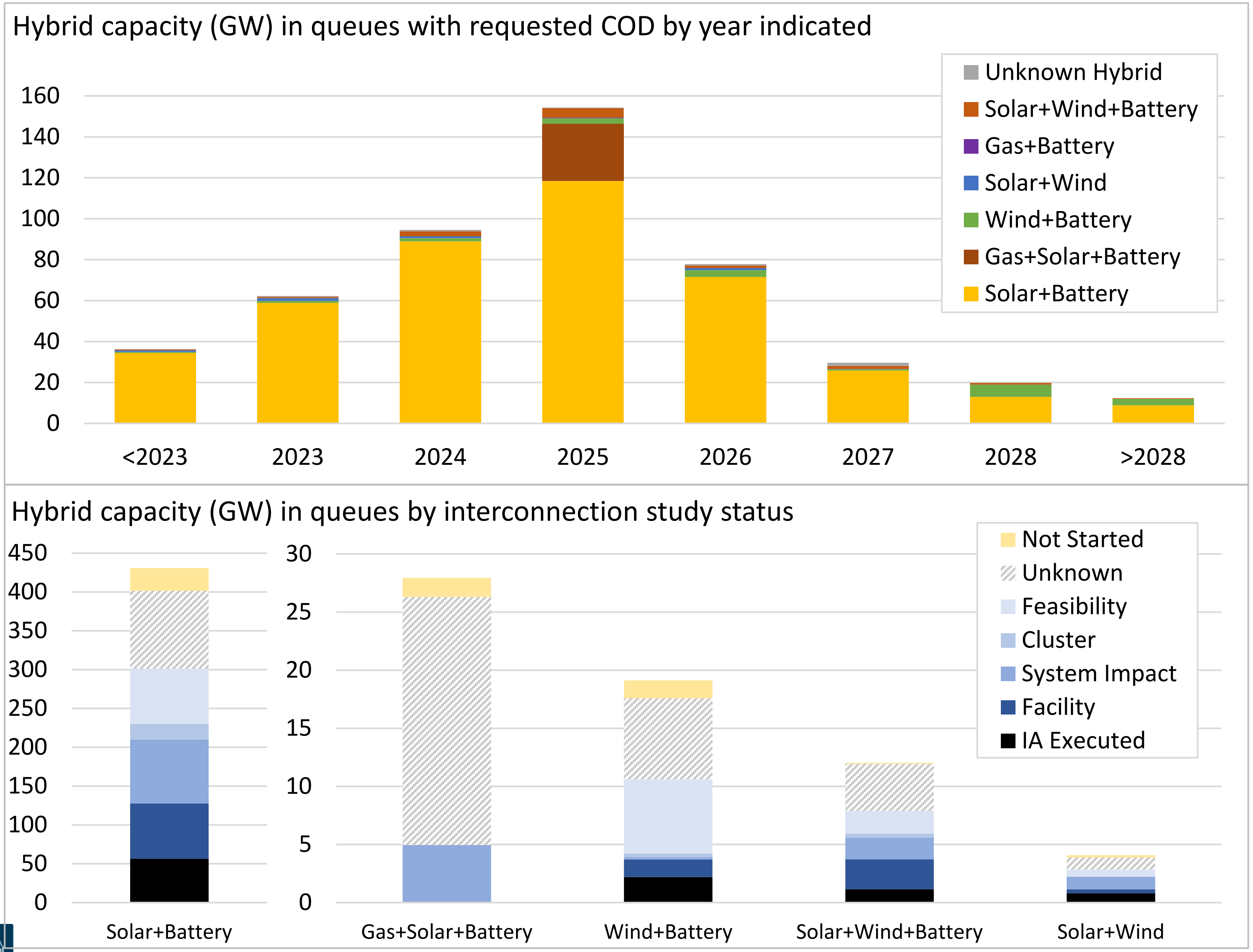
Solar+Storage is dominant hybrid type in queues, with over 20x the proposed capacity of Wind+Storage; CAISO & West are of greatest interest, but other regions are growing



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

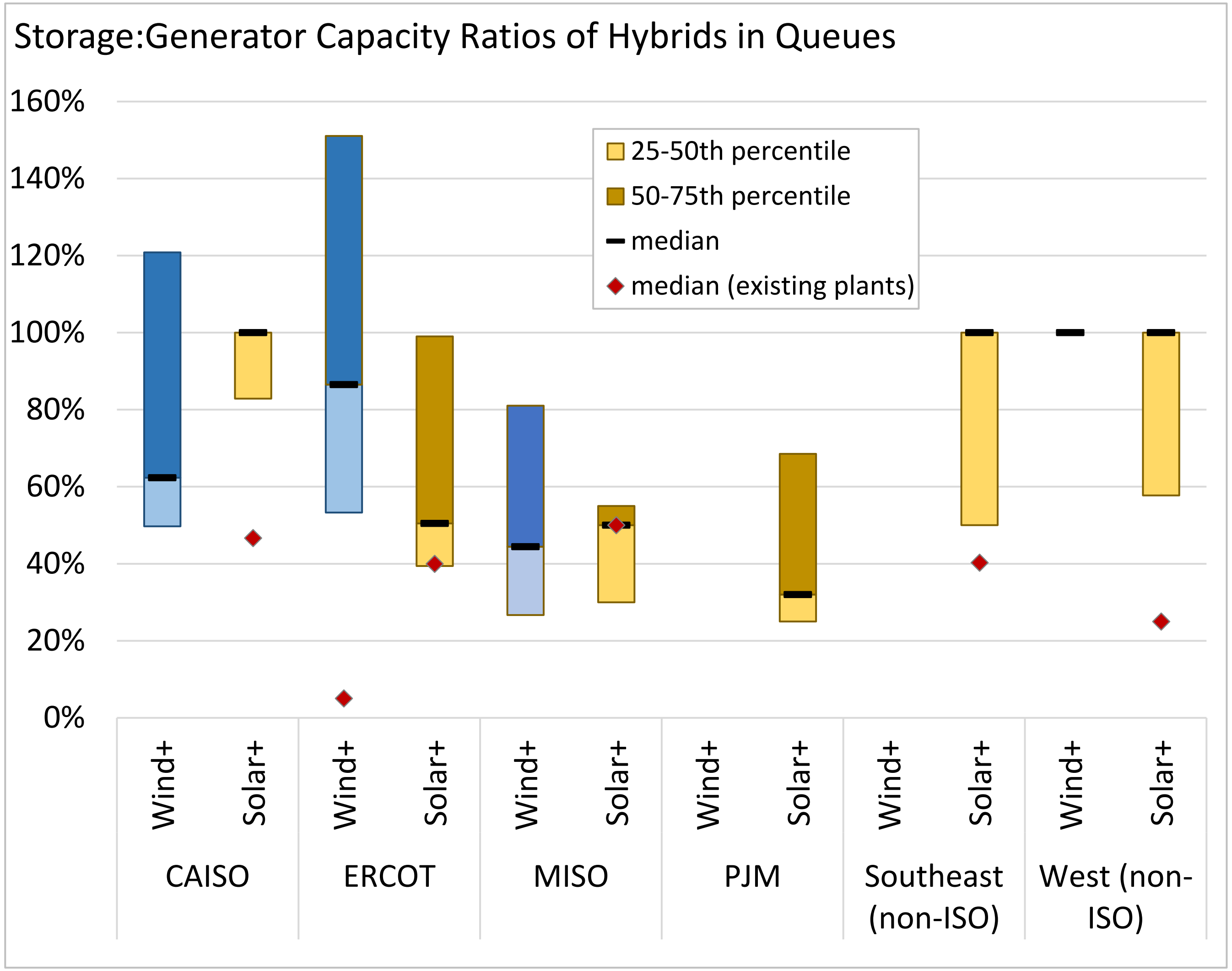
The majority (70%) of hybrid (generator) capacity in the queues has requested to come online by the end of 2025; 12% has an executed interconnection agreement (IA)



- Nearly all (92%) hybrid capacity in the queues is requesting to come online before 2028
- Solar+Battery dominates requested hybrid capacity additions through 2028
- Over 56 GW (13%) of Solar+ Battery have an executed IA, compared to <2.5 GW of each of the other hybrid types
  - This compares to 23 GW (7%) of standalone storage having an executed IA
- Proportions of interconnection status are similar across types

BERKELEY LAB

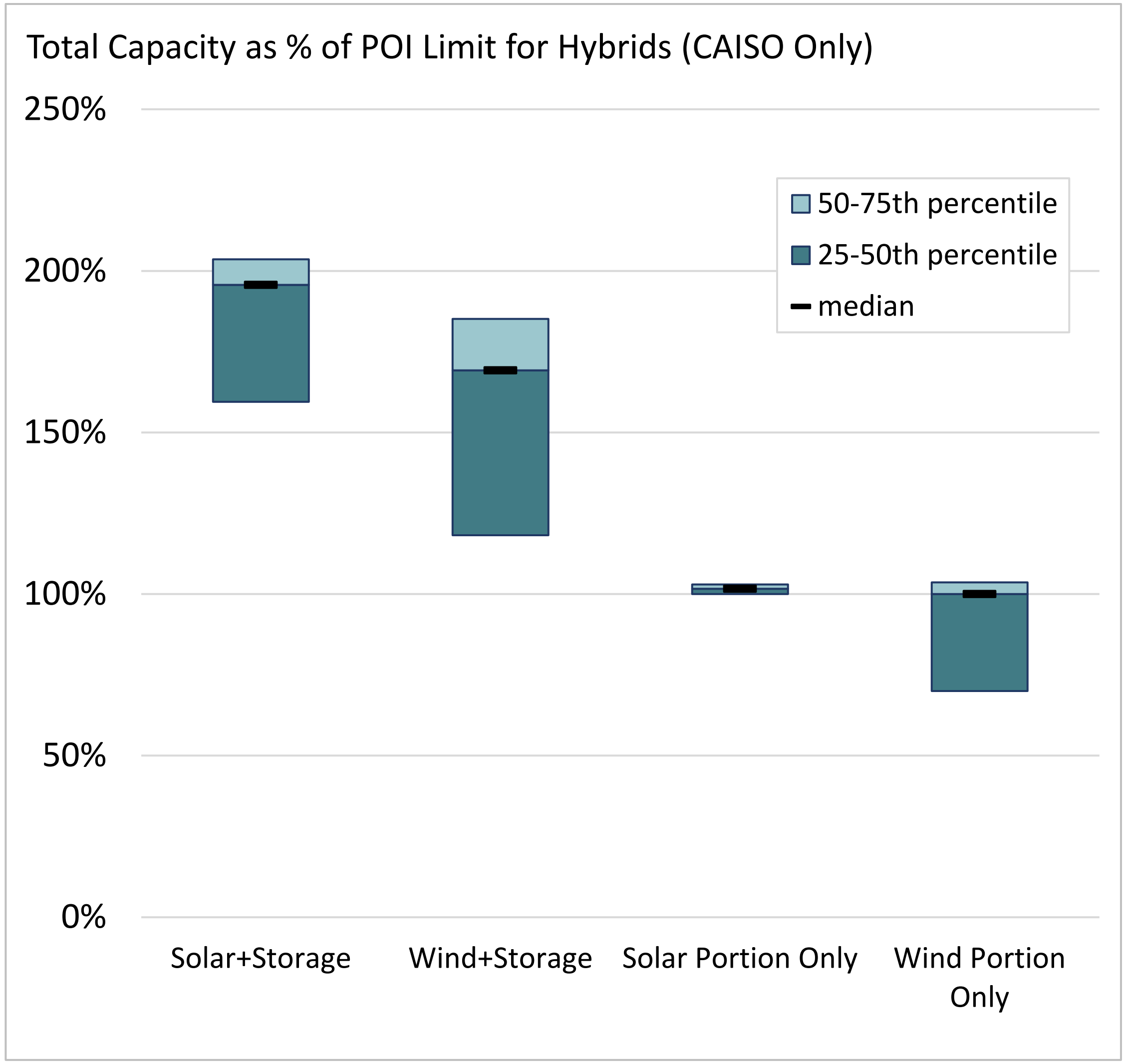
Proposed hybrid plants typically feature a higher storage contribution than existing hybrids; median storage:generator ratio is higher for wind than solar hybrids



- 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 wind+storage (100%, *n = 32*) is higher than for solar+storage (88%, *n* = 666), but the opposite trend is found in CAISO where solar penetration is higher
- The ratios shown here for *proposed* plants are higher than those for *existing* plants of the same type in nearly all cases (see red diamonds in plot, and slides 8-9)

BERKELEY LAB

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 89% of plants, and the median combined (solar+storage) capacity is nearly double (196%) 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 71% of plants, and the median total (wind+storage) capacity is 169% 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

Conclusions

Conclusions: 2022 was another big year for hybrids (particularly PV+Storage) in the US

At the end of 2022, there were nearly 41 GW of operational hybrid / co-located plants, and nearly 500 GW in the queues. More batteries were operating as part of hybrid plants than on a standalone basis.

- In 2022, 62 new hybrid plants (+20% year-over-year) added 4.8 GW (+13%) of operational generating capacity and 2.1 GW / 5.9 GWh (+66% / +63%) of operational storage capacity. There were also 51% more hybrid plants in the queues at the end of 2022 compared to 2021.
- There are many different hybrid configurations currently operating in the US, but PV+Storage dominates, with by far the most plants (213), storage capacity (4 GW), and storage energy (12.5 GWh). The vast majority of new hybrid plants added in 2022—59 out of 62—are PV+Storage.
- Similarly, PV+Storage accounts for >90% of the 2,308 hybrids totaling 500 GW of generation capacity in interconnection queues across the US. Nationally, 48% of all solar capacity in the queues is proposed in hybrid format; in CAISO and the non-ISO West, it's 97% and 81% respectively.
- On average, operational PV+Storage plants have significantly higher storage ratios (49%) and longer durations (3.1 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 to ~$7000/MW-month, ~$60/MWh-stored, and ~$15/MWh-PV (depending on the storage ratio).
- The IRA, passed in August 2022, made standalone storage eligible for the ITC, thereby removing some of the impetus to couple batteries with PV. But hybridization can still be advantageous; for example, as a way to bypass clogged queues (see FERC Order 2023) and boost a PV plant's capacity credit.

BERKELEY LAB

Hybrid Power Plants

Status of Operating and Proposed Plants, 2023 Edition

Contacts

Mark Bolinger: mabolinger@lbl.gov

Will Gorman: wgorman@lbl.gov

Joe Rand: jrand@lbl.gov

Download other publications from the Electricity Markets & Policy Department: https://emp.lbl.gov/publications

Sign up for our email list: https://emp.lbl.gov/mailing-list

Follow the Electricity Markets & Policy Department on Twitter: @BerkeleyLabEMP

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