BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY

The Rise of the Hybrid Power Plant

Will Gorman

Lawrence Berkeley National Laboratory

July 2020

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

Introduction and motivation

Integrating growing levels of variable renewable energy (wind and solar) may require strategies that enhance grid-system flexibility

- Storage technologies can be used for enhanced flexibility
- Due to declining costs, batteries have become a popular choice

Developers have increasing interest in co-locating generation with batteries at the point of interconnection, rather than siting separately

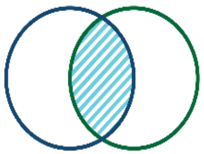
- Siting choice depends on multiple considerations…
- …which can also impact effective renewable integration

Wholesale market rules related to hybridization are under development within ISOs and at FERC

Need for information on ***advantages & disadvantages of hybridization, development trends, cost & value, and wholesale market participation options & issues*** to help inform these proceedings and the energy sector more broadly

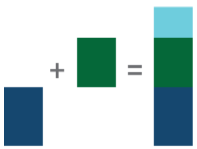
FERC Order 841

Pros and cons of hybridization vs. developing standalone battery and generator plants



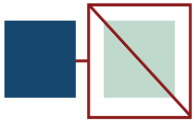
+ Cost Synergies

- Currently qualify for more financial incentives.
- Shared permitting, siting, equipment, interconnection, transmission, and transaction costs.



+ Market Value Synergies

- Policy driven market design rules may value hybrids more than standalone batteries.
- Batteries can capture otherwise “clipped” energy.
- Batteries can reduce wear and tear from thermal generator cycling.



- Operational and Siting Constraints

- Reduced operational flexibility.
- Potentially sub-optimal siting away from congested areas.

+/- Regulatory Uncertainty

- Market rules for standalone and hybrid batteries continue to evolve.
- Uncertainty related to the future availability of financial incentives (e.g., federal ITC).

Economic arguments for hybridization (vs. standalone plants) focus on opportunities to reduce project costs and enhance market value

Not all of these drivers reflect true system-level economic advantages, e.g., the federal ITC and some market design rules that may inefficiently favor hybridization over standalone plants

Possible disadvantages of hybridization include operational and siting constraints

If reduced operational flexibility is, in part, impacted by suboptimal market design then this too does not reflect true system-level economic outcomes

Existing Hybrid Projects: Installed by end of 2019

Hybrid / co-located projects of various configurations exist as of the end of 2019, but market remains limited in overall size

125 projects, 13.4 GW of generating capacity, 0.9 GW storage capacity

Installed at end of 2019	# projects	Gen 1 (MW)	Gen 2 (MW)	Gen 3 (MW)	Total Gen (MW)	Storage capacity (MW)	Storage energy (MWh)	Storage: generator ratio	Duration (hrs)
Wind+Storage	13	1,290	0	0	1,290	184	109	14%	0.6
Wind+PV+Storage	2	216	21	0	237	34	15	15%	0.4
Wind+Fossil+Storage	1	5	12	0	17	1	1	7%	0.8
Wind+PV+Fossil+Storage	1	0.1	0.1	1	1	0	1	25%	1.7
Wind+PV	6	535	212	0	747	0	0	0%	n/a
Wind+PV+Fossil	3	6	2	98	106	0	0	0%	n/a
Wind+Fossil	8	27	79	0	106	0	0	0%	n/a
PV+Storage	40	882	0	0	882	169	446	19%	2.6
PV+Fossil	26	77	6,876	0	6,953	0	0	0%	n/a
PV+Fossil+Storage	3	9	10	0	20	5	9	24%	1.9
PV+Biomass	3	4	15	0	19	0	0	0%	n/a
PV+Geothermal	2	18	85	0	103	0	0	0%	n/a
PV+Geothermal+CSP	1	22	47	2	71	0	0	0%	n/a
CSP+Storage	2	390	0	0	390	390	2,780	100%	7.1
Fossil+Storage	10	2,414	0	0	2,414	91	84	4%	0.9
Hydro+Storage	4	71	0	0	71	12	11	17%	0.9

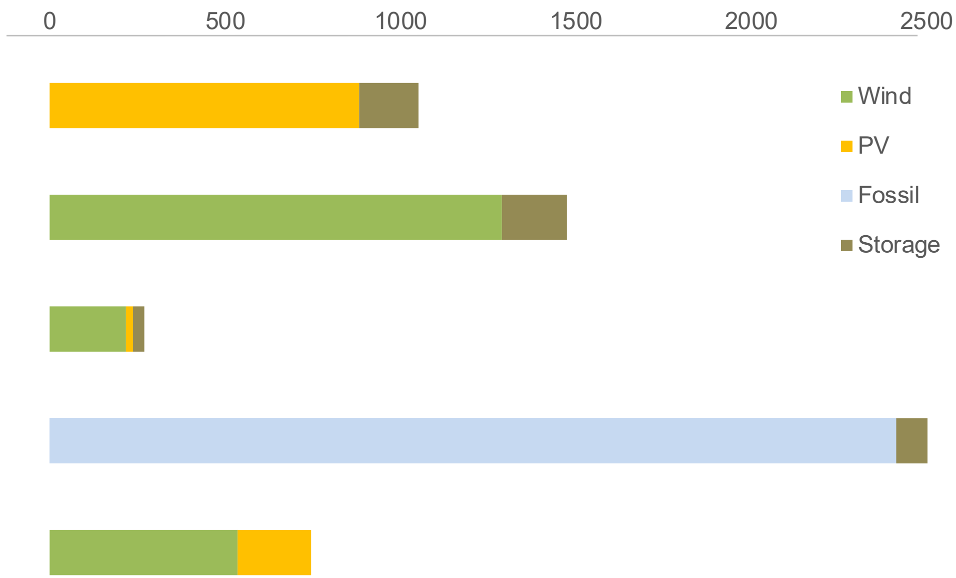
Sources: EIA 860 2019 Early Release, Berkeley Lab

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

Comparing the frequency and design of a subset of the various hybrid / co-located project configurations: end of 2019

	# projects	Storage ratio	Duration (hrs)
PV+Storage	40	19%	2.6
Wind+Storage	13	14%	0.6
Wind+PV+Storage	2	15%	0.4
Fossil+Storage	10	4%	0.9
Wind+PV	6	n/a	n/a

Total capacity (MW)

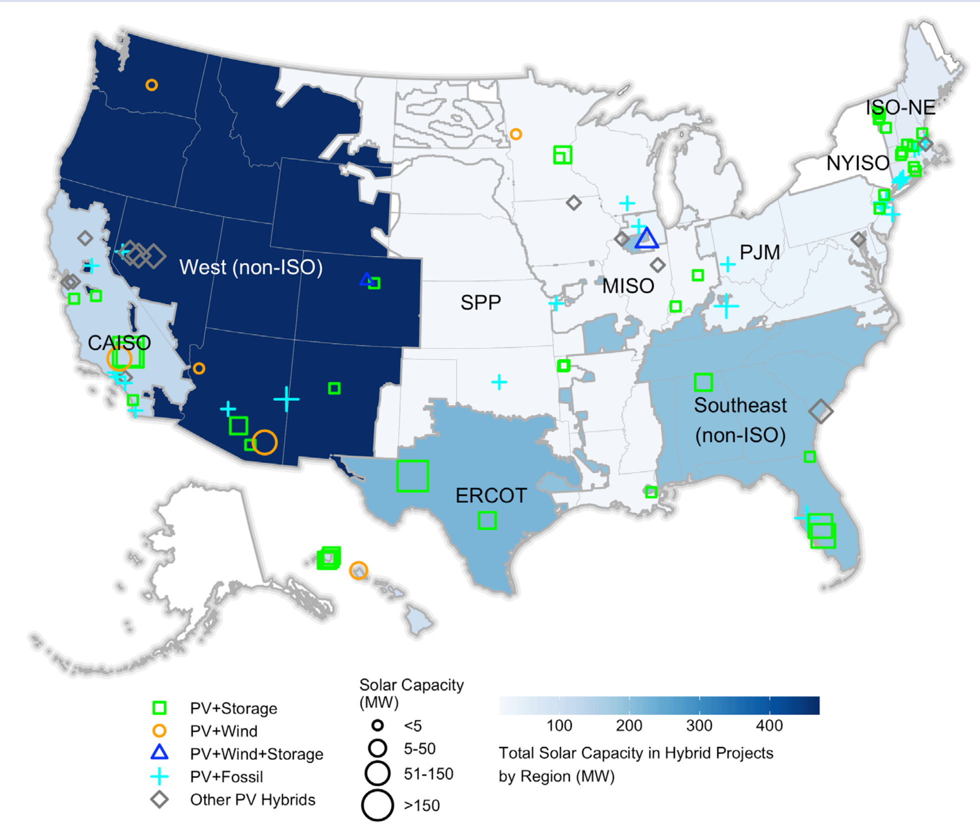


Notes: Not included in the figure are 54 other hybrid / co-located projects with other configurations; details on those projects are provided in the table on the previous slide.
***Storage ratio** defined as average storage capacity divided by total generation capacity.*
***Duration** defined as average MWh of storage divided by MW of storage.*

Sources: EIA 860 2019 Early Release, Berkeley Lab

PV hybrid / co-located projects of various configurations as of the end of 2019, and over time

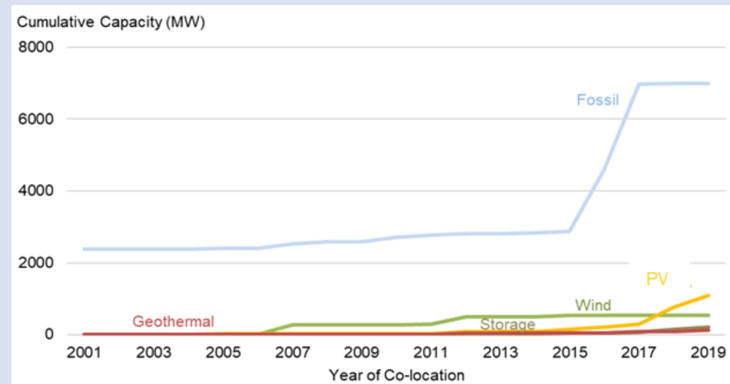
Online PV Hybrid / Co-located Projects



Note: The larger PV+storage projects in California are in LADWP's service territory, not CAISO

Growth in PV Hybrid / Co-located Projects over Time

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

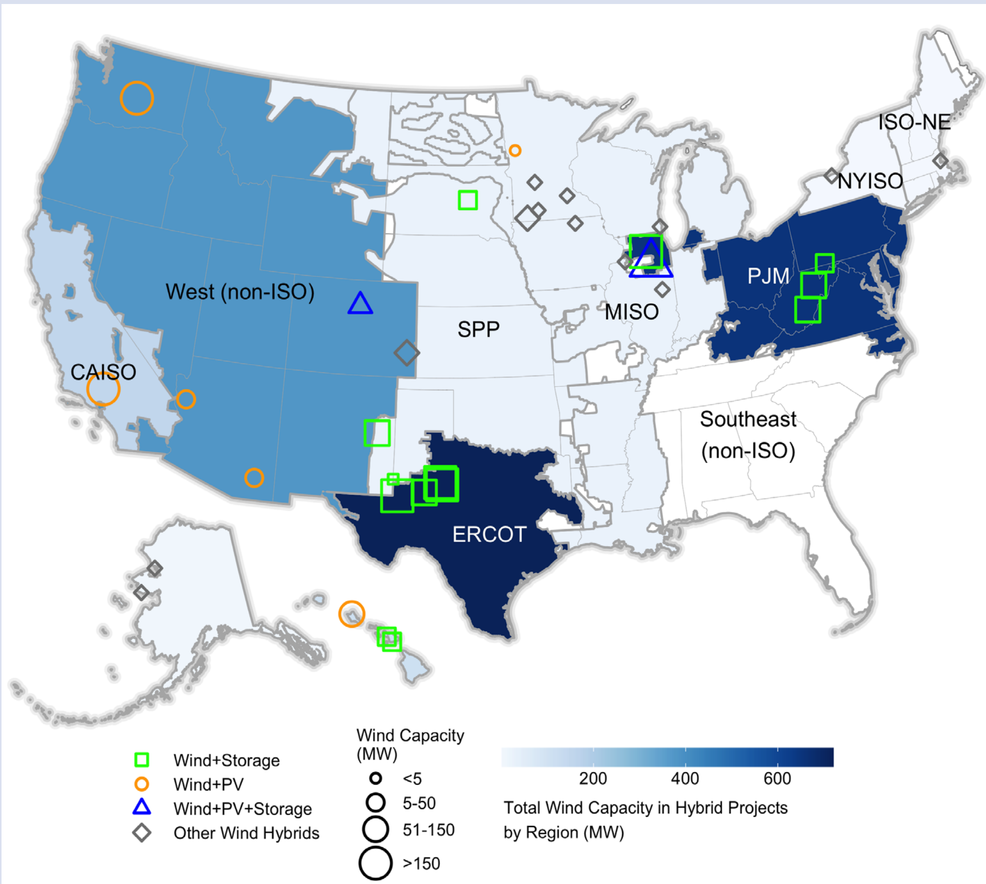


Note: PV+fossil plants involve minor amount of PV added to larger fossil units at the point of interconnection: thus, the fossil category dominates this figure

Sources: EIA 860 2019 Early Release, Berkeley Lab

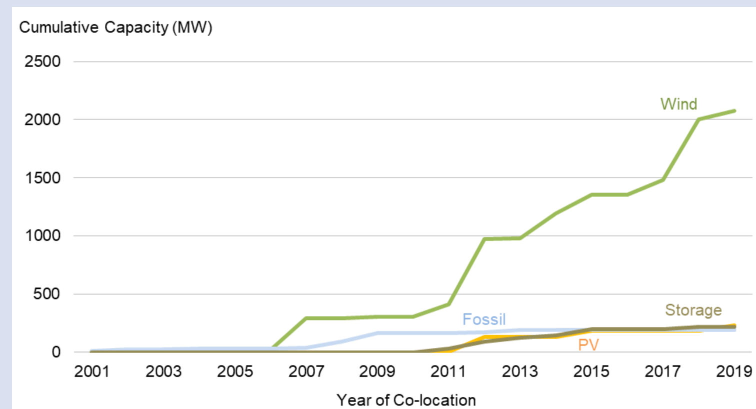
Wind hybrid / co-located projects of various configurations as of the end of 2019, and over time

Online Wind Hybrid / Co-located Projects



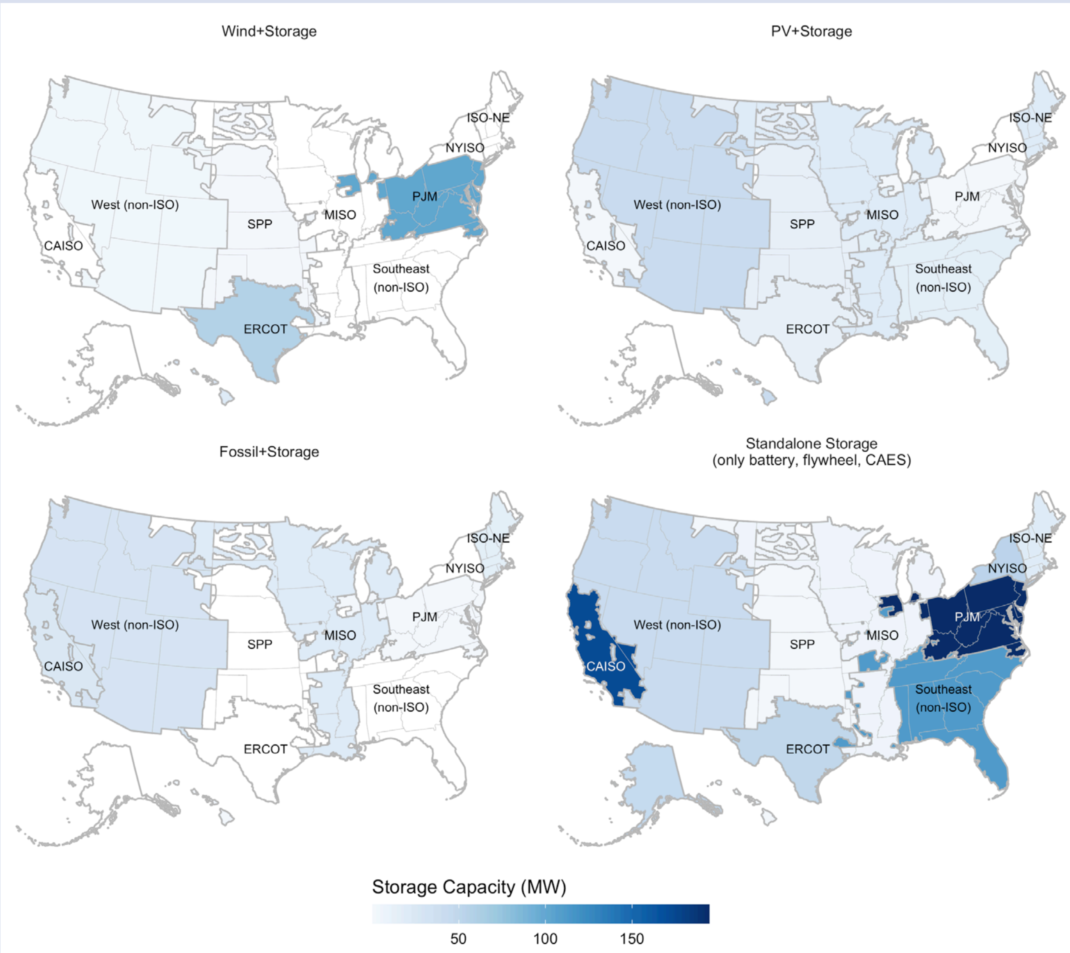
Growth in Wind Hybrid / Co-located Projects over Time

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



Sources: EIA 860 2019 Early Release, Berkeley Lab

Standalone storage (even excluding pumped hydro) capacity exceeds the storage capacity included in existing hybrids

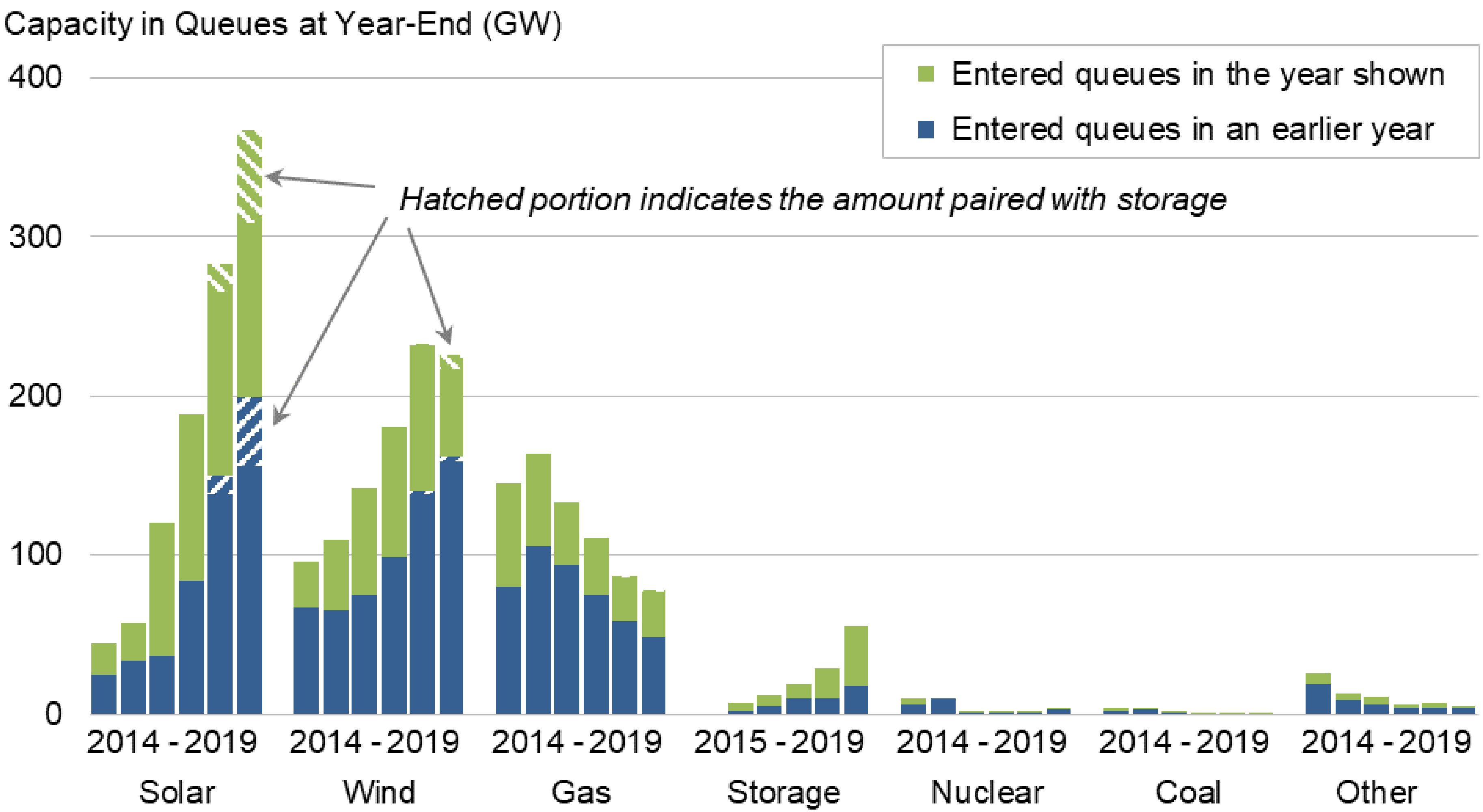


Sources: EIA 860 2019 Early Release, Berkeley Lab

- Standalone storage capacity (battery, flywheel and CAES, excluding pumped hydro) is greatest in PJM, CAISO, Southeast
- Standalone storage capacity exceeds storage capacity included in wind+storage, PV+storage, and fossil+storage hybrids
- Storage capacity included in hybrids is located roughly in proportion to where the hybrid plants are located

Longer-term Pipeline: Interconnection Queues at end of 2019

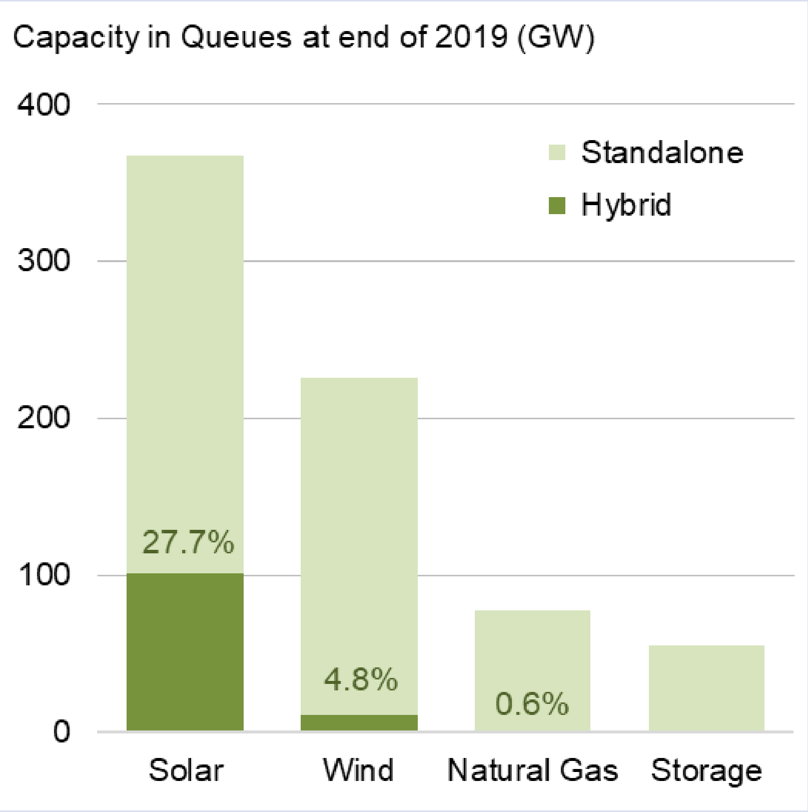
Interconnection queues indicate that commercial interest in solar, wind and storage has grown, including via hybridization



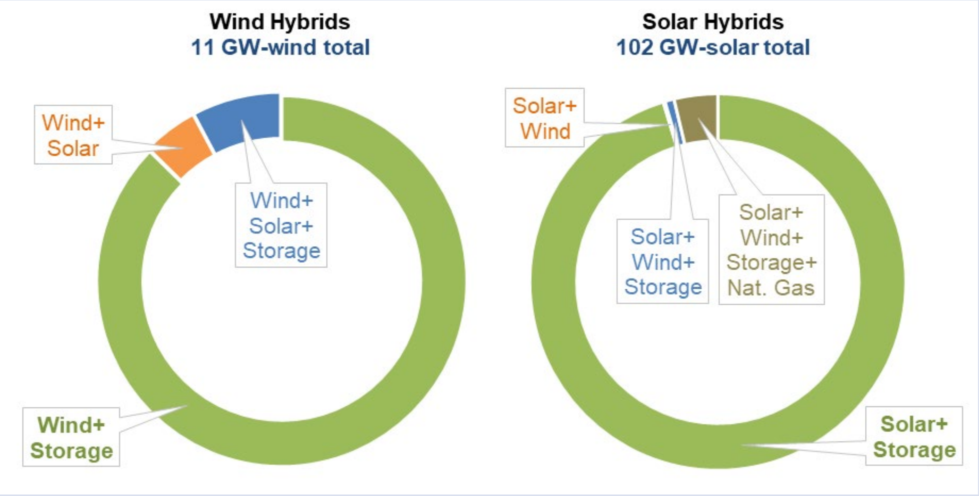
Source: Berkeley Lab review of 37 ISO and utility interconnection queues

Note: Not all of this capacity will be built

Interest in hybrid plants has increased: 28% of solar proposed as hybrids (102 GW), 5% of wind proposed as hybrids (11 GW)



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

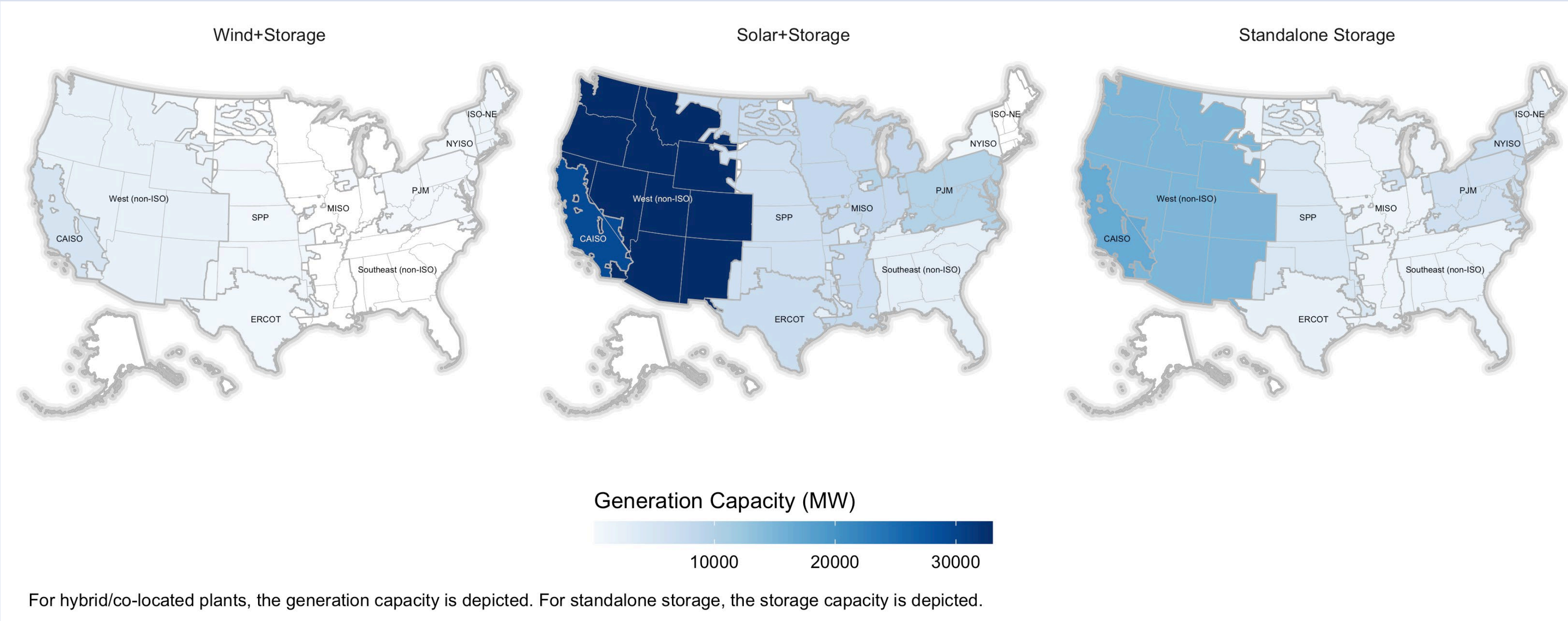


Source: Berkeley Lab review of interconnection queues

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

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

Solar+storage is dominant hybrid type in queues, wind+storage is much less common; CAISO & West of greatest interest so far



Average storage:generation capacity ratio for solar+storage (66%) is higher than for wind+storage (27%), in subset of ISO queues; these are both much higher than for existing hybrid plants shown earlier

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

Source: Berkeley Lab review of interconnection queues

Note: Not all of this capacity will be built

Hybrids comprise a sizable fraction of all proposed solar plants in multiple regions; proposed wind hybrids dominated by CAISO

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

Source: Berkeley Lab review of interconnection queues

Note: Not all of this capacity will be built

- **Solar** hybridization relative to total amount of solar in each queue is highest in CAISO (67%) and non-ISO West (50%), and is above 10% in PJM, MISO, ERCOT
- **Wind** hybridization relative to total amount of wind in each queue is highest in CAISO (50%), and is less than 7% in all other regions

BERKELEY LAB

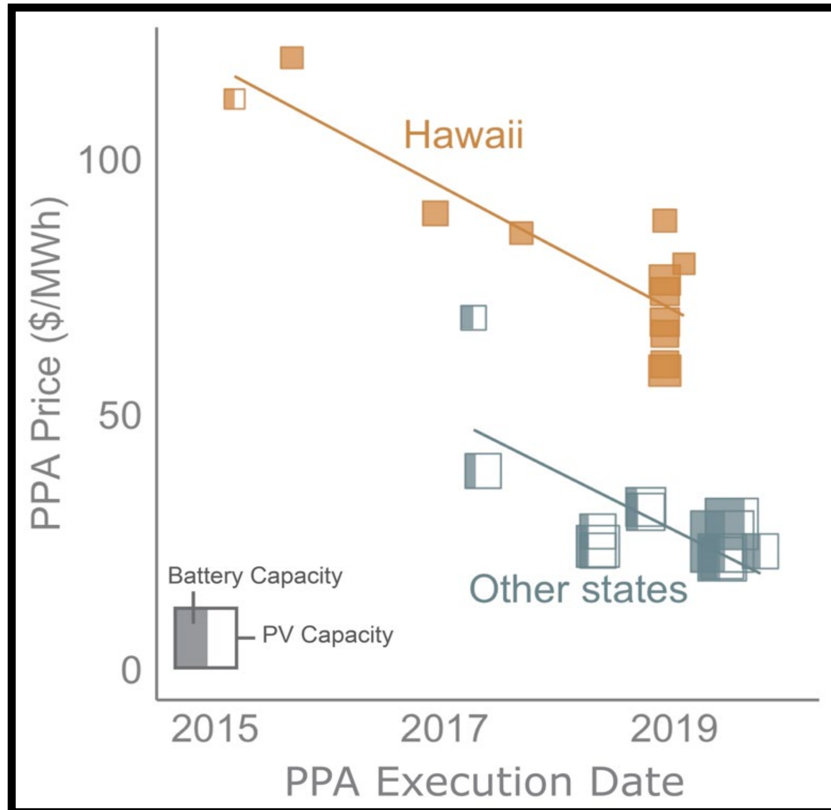
Cost and Valuation of Hybrid Projects

Levelized PPA prices for PV-battery projects are declining

- ***Hawaiian*** prices dropped from around $120/MWh in 2015 to around $70/MWh by the end of 2018

- For ***southwestern U.S. projects***, prices dropped from $40–$70/MWh in 2017 to $20–$30/MWh in 2018 and 2019

- Hawaiian hybrids priced at premium; may be attributable to higher construction cost and higher battery-generator ratios

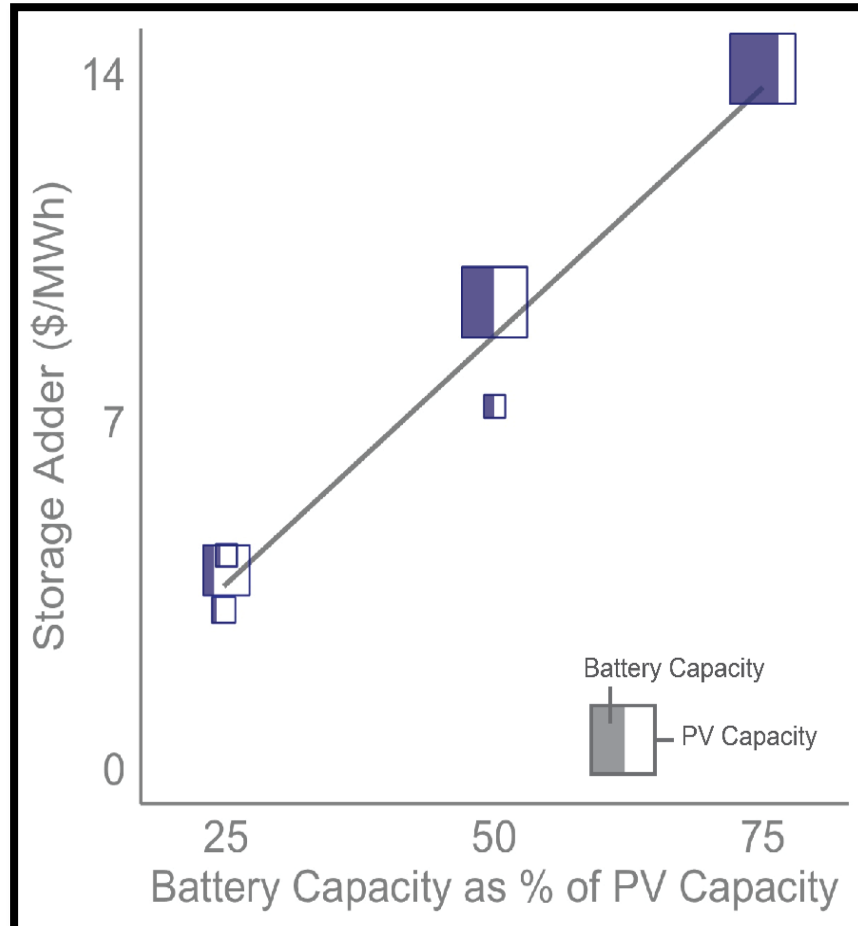


BERKELEY LAB

Battery PPA premium for 4-hr duration storage is ~$4-14/MWh depending on battery size relative to PV capacity

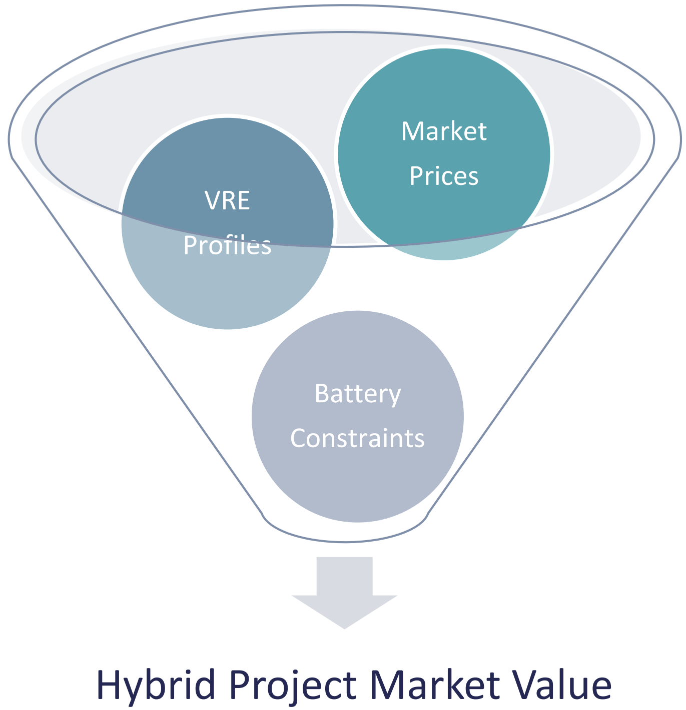
- ***Six of the 23*** PV-battery PPAs provide information to enable calculation of a ***battery adder*** (e.g., through separate capacity payments for battery component)

- For 4-hr duration storage, as the battery capacity increases from 25% to 50% and 75% of the PV capacity, the levelized battery adder increases linearly from ***$4/MWh-delivered*** to about ***$10/MWh-delivered*** and ***$14/MWh-delivered***, respectively

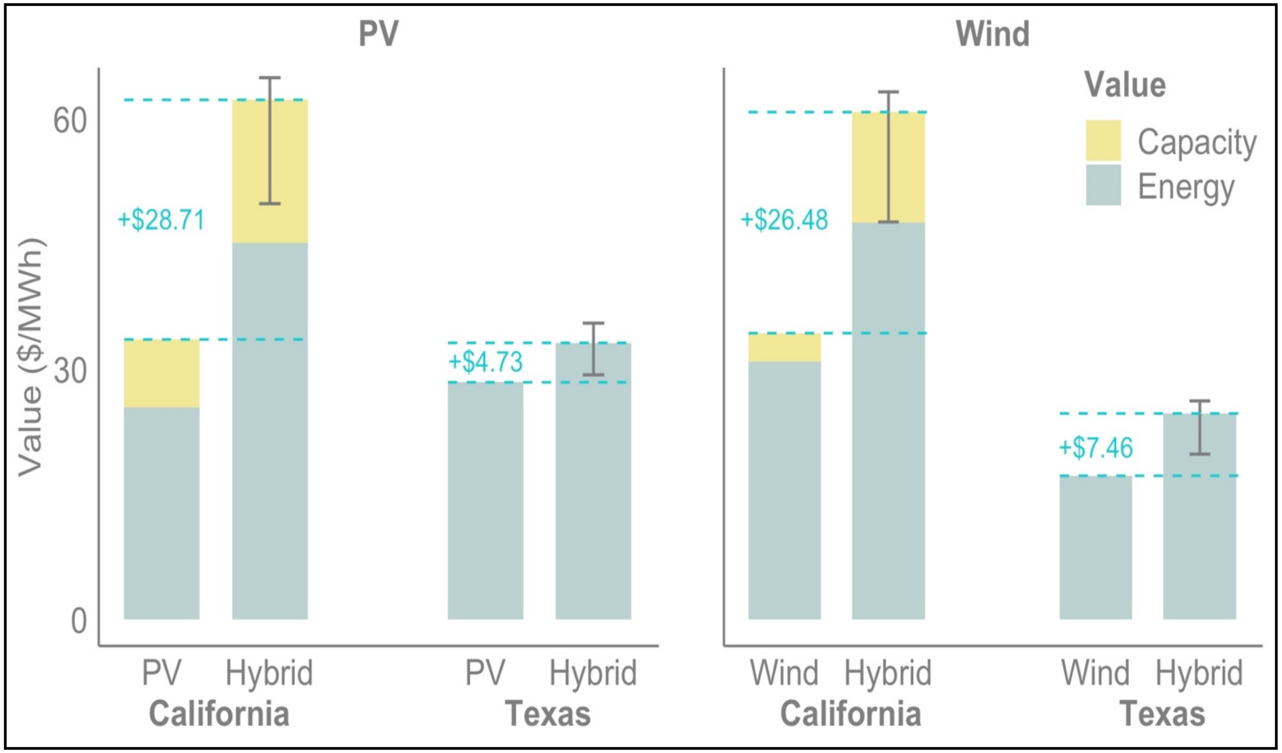


Simple optimization model used to provide preliminary insights into value of hybridization, vs. standalone

- System specifications
  - 4-hour, AC-coupled battery (81% roundtrip efficiency)
  - Battery sized to 50% of renewable capacity
  - No battery degradation cost
- Optimization
  - Storage dispatch maximizes hourly real-time energy market revenue with perfect foresight (exclude AS, given relatively small size of AS markets)
  - Alternative bounding scenarios using 15-minute real-time prices and perfect foresight (highest case) and day-ahead persistence method (low case)
  - Hybrid charges from generator only (not from grid), given federal ITC
- Inputs
  - Price taker analysis using SP15 (CA) and West Hub (ERCOT) prices from 2016-2018
  - PV profiles modeled from weather data; wind profiles represent aggregate production in SP15 and West Texas regions
  - Same renewable profiles used for hybrid and standalone system
  - Standalone batteries assumed to access same pricing nodes as in hybrid
  - In CA, hybrids get the wind/solar capacity credit plus 100% capacity credit of storage, capped at the generator nameplate capacity (also assumed to be POI limit)



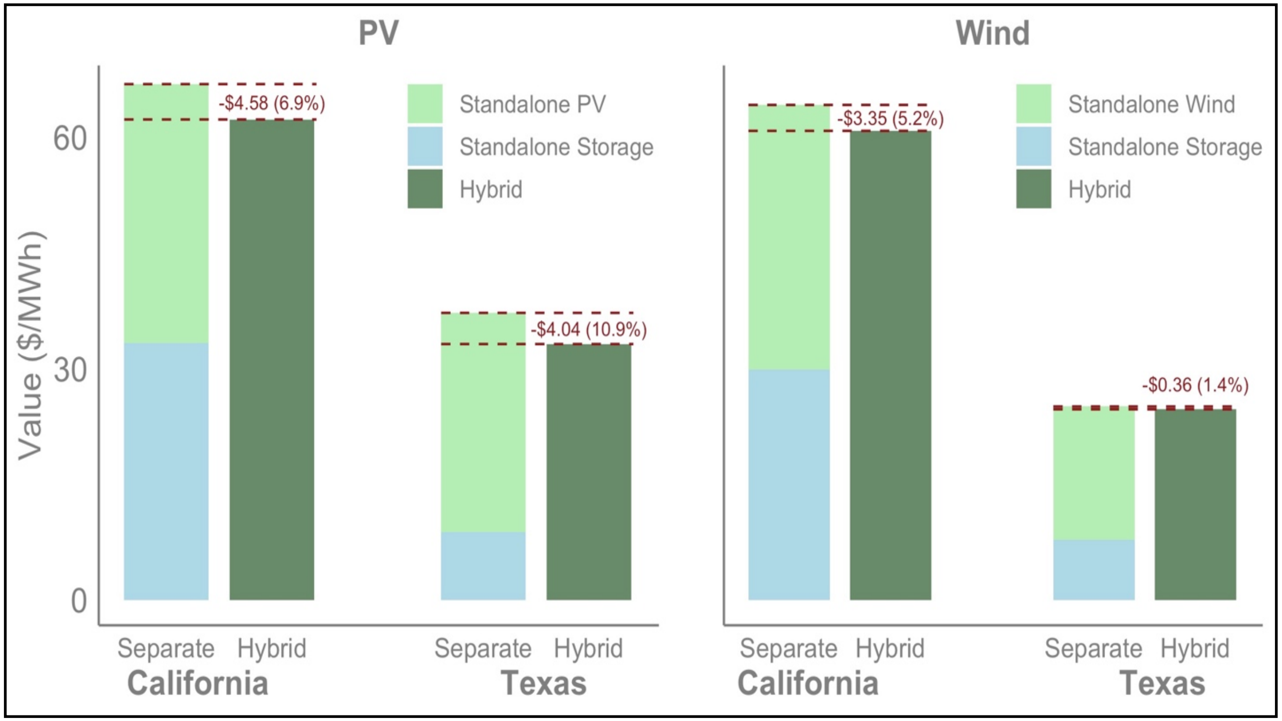
Hybrid projects in CA would have added more value than in TX, considering energy & capacity prices from 2016-2018



(1) Upper gray bar represents 15-minute perfect foresight dispatch case
(2) Lower gray bar represents day ahead persistence case, where storage is dispatched based on previous day's optimal schedule

- ***Adding storage*** to standalone PV or wind results in a value premium between ***\$26-29/MWh*** in CA and ***\$5-7/MWh*** in TX
- PV hybrid storage value adder somewhat higher in CA than wind hybrid, and vice versa in TX; ***differences across markets much larger than differences across technology***
- Optimization ***algorithm impacts value premium*** (see gray bars): low-value case ~\$13-16/MWh premium in CA, ~\$1-3/MWh TX
- ***Compare results to ~\$10/MWh price/cost*** adder shown earlier

Constraints on hybrid projects lead to somewhat lower value relative to standalone projects without constraints



Two constraints drive difference

(1) Hybrid ***cannot charge*** from grid

- Would disappear or be relaxed ***post-ITC***

(2) ***Point of interconnection*** limit

- Developer ***choice*** but queues suggest hybrids sizing POI limit close to ***size of generator***

NOTE: Analysis assumes standalone battery delivers to same pricing node as hybrid; as such, analysis likely understates value of standalone storage and so also understates value-reduction due to hybridization

Benefits of hybridization from receiving the investment tax credit and reducing interconnection costs need to be weighed against this value loss from hybridization

Questions?

- Contact the presenter
  - Will Gorman (wgorman@lbl.gov)
- Additional project team at Lawrence Berkeley National Laboratory:
  - Andrew Mills
  - Ryan Wiser
  - Mark Bolinger
  - Joe Rand
  - Cristina Crespo
  - Jo Seel
  - Cody Warner
  - Ben Paulos

Download all of our work at:

http://emp.lbl.gov/reports/re

Follow the Electricity Markets & Policy Group on Twitter:

@BerkeleyLabEMP

This work is funded by the Office and Electricity and the Office of Energy Efficiency and Renewable Energy of the U.S. Department of Energy

Extra Slides

Methods and Data Source: Online Projects

- Form **EIA-860 2019 early release**
  - Generator specific information for power plants with **>1 MW combined** capacity
  - Very limited amount of spot checking for corrections to EIA data
- Hybrids identified by having the **same EIA ID**
  - **Suggests co-location of generators** at one plant / point of interconnection, but not necessarily co-controlled generators
  - Virtual hybrids cannot be identified; smaller 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

Independent Statistics & Analysis
U.S. Energy Information Administration

FORM EIA-860
INSTRUCTIONS
ANNUAL ELECTRIC
GENERATOR REPORT

Approval: OMB No. 1905-0129
Approval Expires: 05/31/2023
Burden: 16.0 Hours

PURPOSE

Form EIA-860 collects data on the status of existing electric generating plants and associated equipment (including generators, boilers, cooling systems and air emission control systems) in the United States and Puerto Rico, and those scheduled for initial commercial operation within 5 or 10 years, as applicable. The data from this form appear in EIA publications and public databases. The data collected on this form are used to monitor the current status and trends of the electric power industry and to evaluate the future of the industry.

REQUIRED RESPONDENTS

Existing plants are required to respond to the EIA-860 if:

- The plant's total generator nameplate capacity is 1 Megawatt (MW) or greater **and**
- The plant's generator(s), or the facility in which the generator(s) resides, are connected to the local or regional electric power grid and have the ability to draw power from or deliver power to the grid

If the existing plant is jointly-owned, only the operator of that plant should respond to the EIA-860.

Hybrid / co-located projects of various configurations exist as of the end of 2019, but market remains limited in overall size

Wind Hybrids / Co-Located Projects

- Wind+Storage dominates configurations: 13 projects, 1,290 MW wind, 184 MW storage
  - Small storage:generator ratios (14%) and storage durations (0.6 hrs) on average, built for AS markets
- Wind+PV (535 MW wind) and Wind+PV+Storage (216 MW wind) also present
- Configurations that include fossil involve minor amounts of wind

PV Hybrids / Co-Located Projects

- PV+Storage dominates configurations: 40 projects, 882 MW solar, 169 MW storage
  - Small storage:generator ratios (19%), but longer storage durations (2.6 hrs) on average
- PV+Fossil is common (26 projects) but involves minor amount of PV (77 MW) added to fossil units (6,876 MW, including 3 coal plants totaling 5 GW) at point of interconnection
- Other configurations w/ wind, fossil, biomass, geothermal, CSP involve small amount of PV

Fossil Hybrids / Co-Located Projects

- Fossil+PV is most common: small amount of PV added to larger fossil units (6,876 MW)
- Fossil+Storage also relatively common (10 projects, 2,414 MW fossil, 91 MW storage)
  - Small storage:generator ratios (4%) and storage durations (0.9 hrs) on average, built for AS markets

CSP, Geothermal, Hydropower, Biomass Hybrids / Co-located Projects

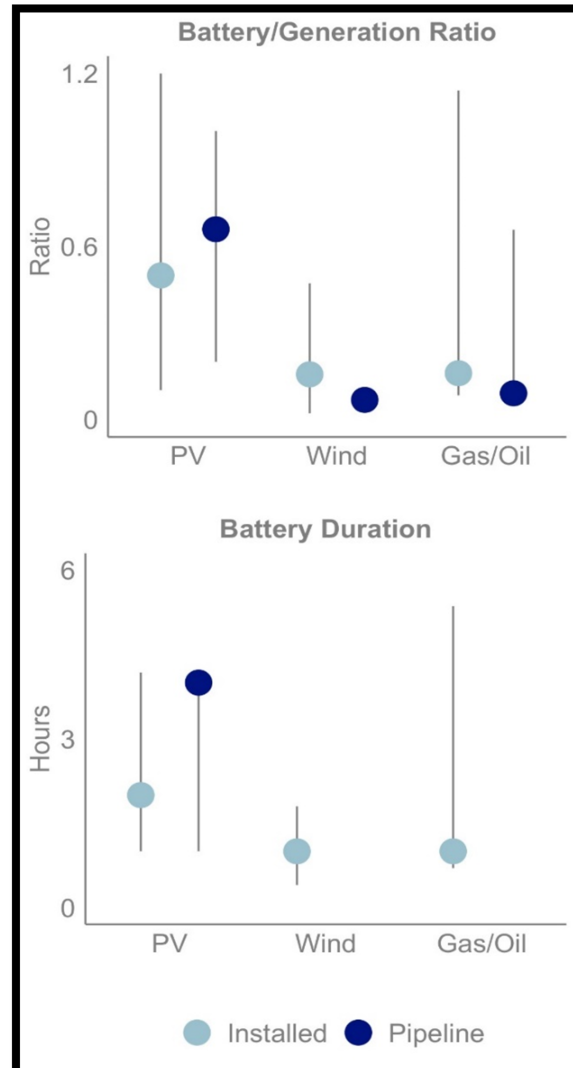
- Multiple configurations, with CSP+Storage involving the most capacity

Hybrid project characteristics vary depending on generator type and are changing as market develops

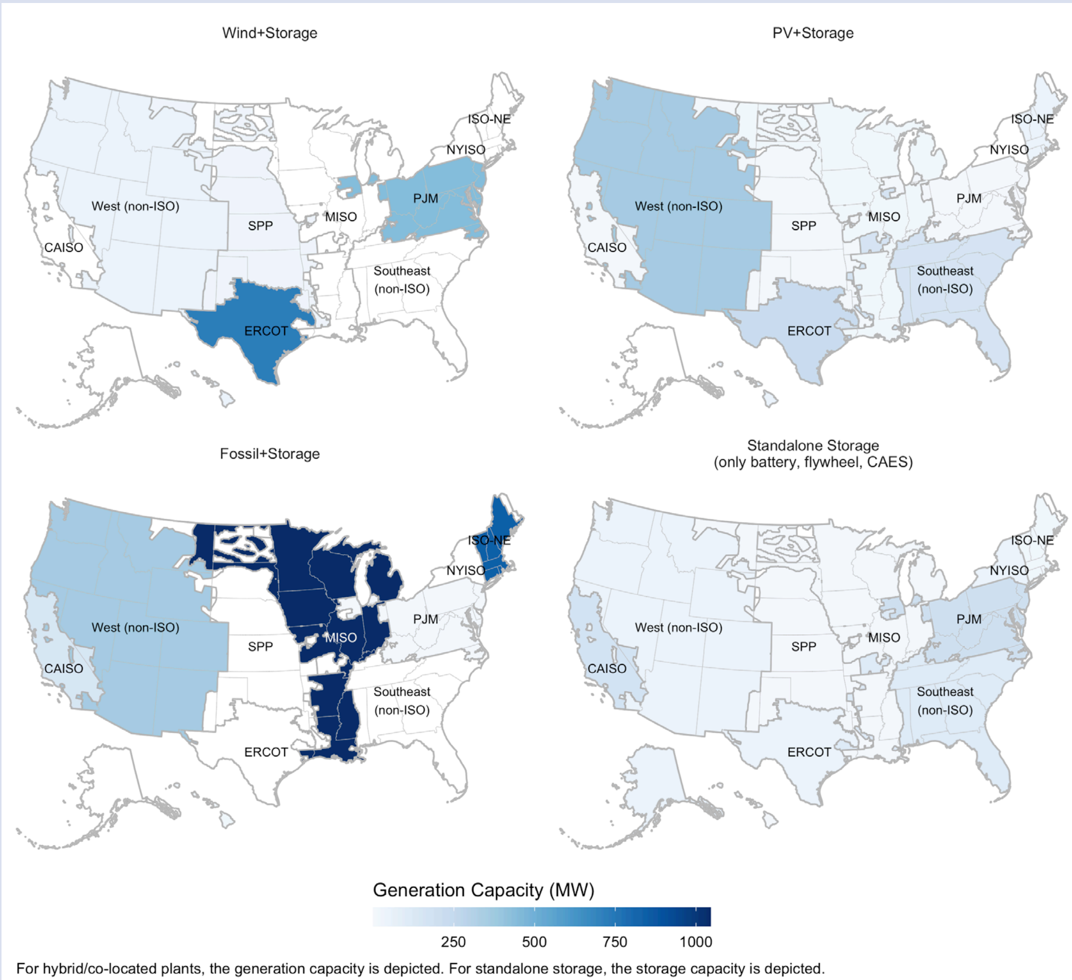
- ***Battery-to-generation ratios*** *and* ***battery durations*** are ***larger*** for PV-battery projects than for wind and gas hybrids

- ***Battery durations*** and ***battery-to-generation ratios*** appear to be on the rise for PV hybrids: higher in near-term pipeline than those currently online

- Majority of these projects rely on ***lithium-ion***, as opposed to lead acid or sodium-based battery technologies



Generator + storage hybrid / co-located projects at end of 2019, compared to subset of standalone storage technologies



Sources: EIA 860 2019 Early Release, Berkeley Lab

- Wind+storage plants located primarily in ERCOT and PJM so far
- PV+storage plants located primarily in non-ISO West, ERCOT, and Southeast
- Fossil+storage plants located primarily in MISO and ISO-NE
- Standalone storage (ex. pumped hydro) largely in PJM, CAISO, Southeast

Methods and Data Sources: Interconnection Queues

- Data from **generator interconnection queues** for 7 ISOs and 30 utilities, representing ~80% of all U.S. electricity load
  - Projects that connect to the bulk power system: not behind-the-meter or virtual
  - Includes all projects in queues through the end of 2019
  - Filtered to include only “active” projects: removed “online,” “withdrawn,” “suspended”
- Hybrid / co-located projects identified via either of these two methods:
  - “Generator Type” field includes **multiple types for a single queue entry** (row)
  - Two or more queue entries (of different gen. types) that share the **same point of interconnection** and sponsor, queue date, ID number, and/or COD
    - Emphasis was placed on identification of wind+storage and solar+storage
    - Other hybrid configurations are likely undercounted
- Storage capacity for hybrids (i.e., broken out from generator capacity) was **only available for 4 of 7 ISOs**, and not collected for the utilities
  - Available for: CAISO, ERCOT, SPP, and NYISO
- Note that being in an interconnection queue does not guarantee ultimate construction: majority of plants are not subsequently built

BERKELEY LAB