The Rise of the Hybrid Power Plant

Will Gorman

Lawrence Berkeley National Laboratory

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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

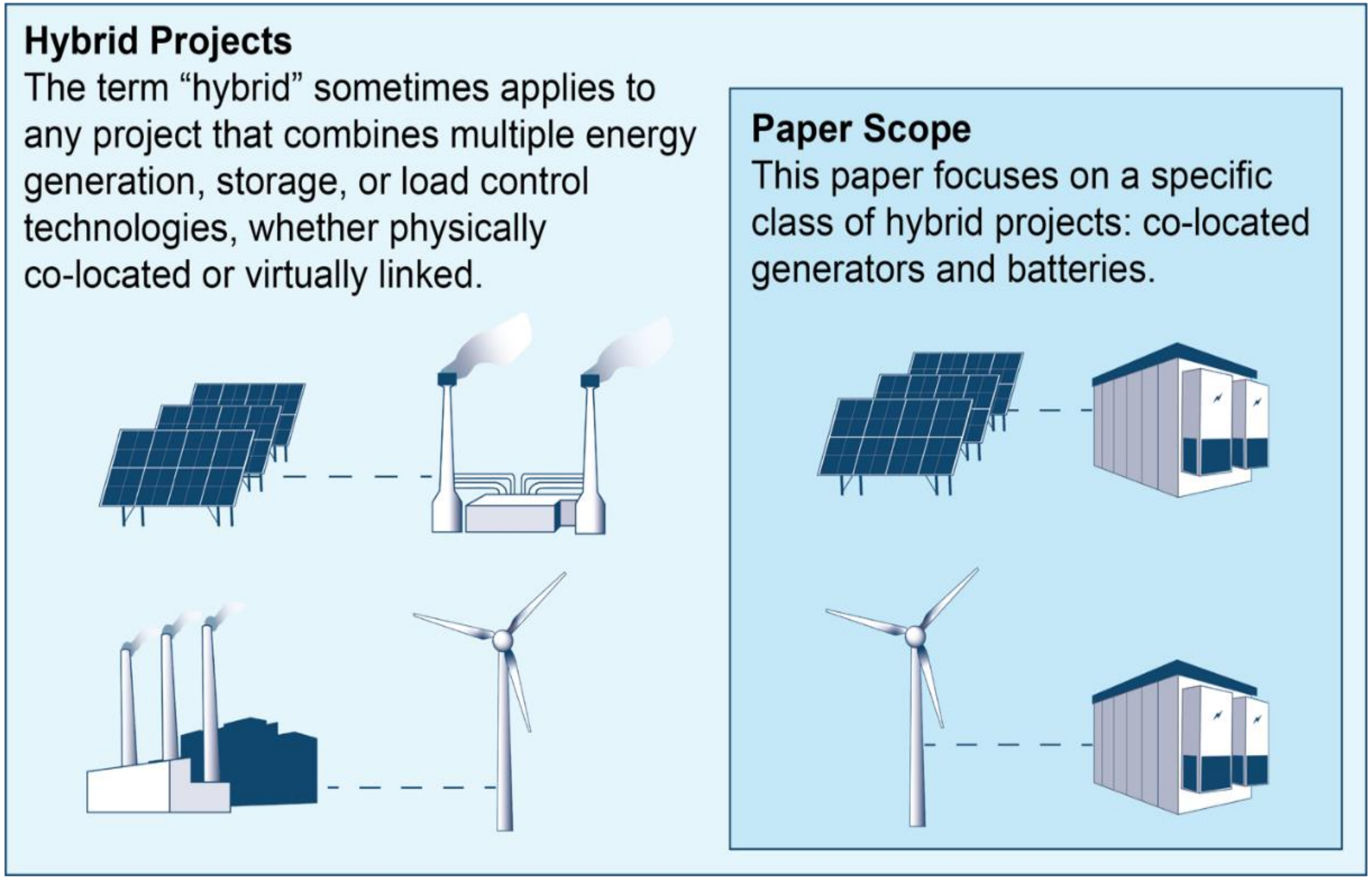
- ***Siting choice*** depends on multiple considerations…
- …which can also impact ***effective renewable integration***

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

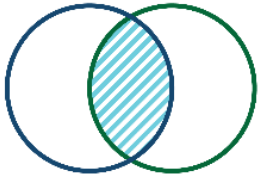
FERC Order 841

We have focused on battery-plus-generator hybrids due to current commercial interest in these applications



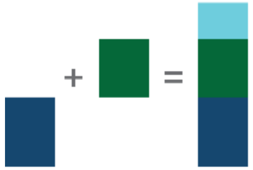
Out of scope examples:
(1) Multiple generation types (e.g. PV + wind)
(2) Alternative storage types (e.g. wind + pumped storage, concentrating solar power)
(3) Virtual hybrids with distributed technologies

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



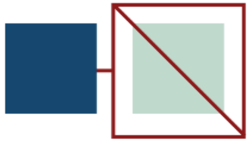
+ Cost Synergies

- 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

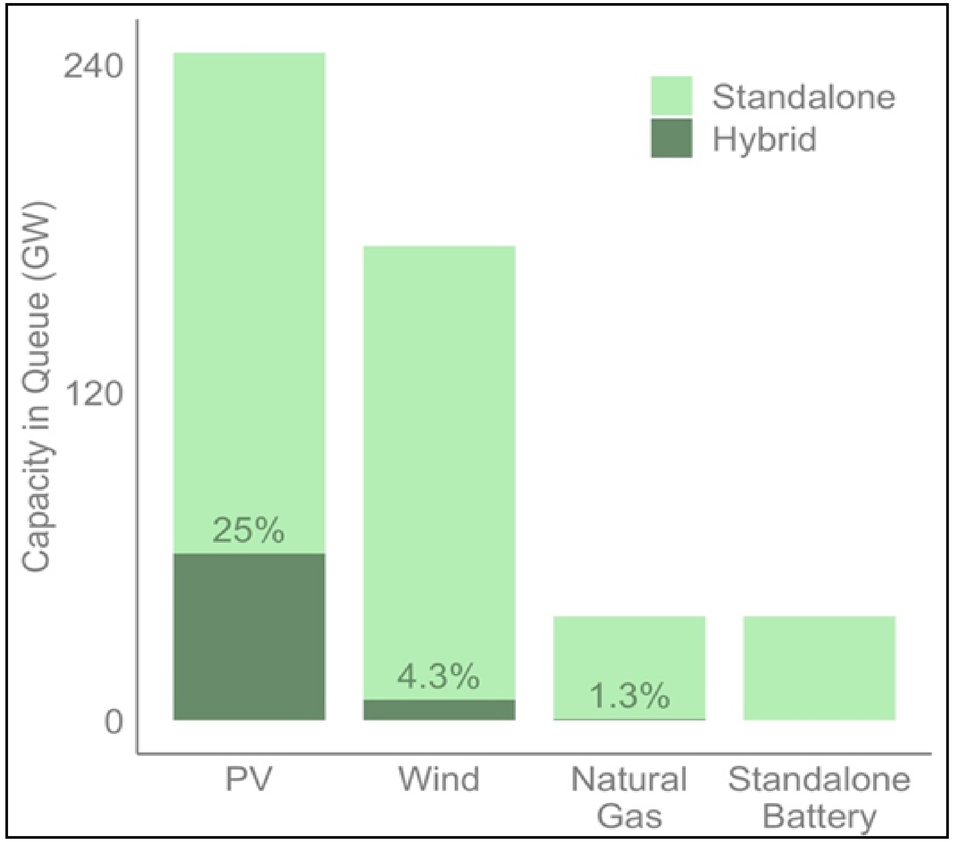
Not all of these drivers reflect true system-level economic advantages, e.g., the federal ITC and some market design rules that may inefficiently favor hybridization over standalone plants

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

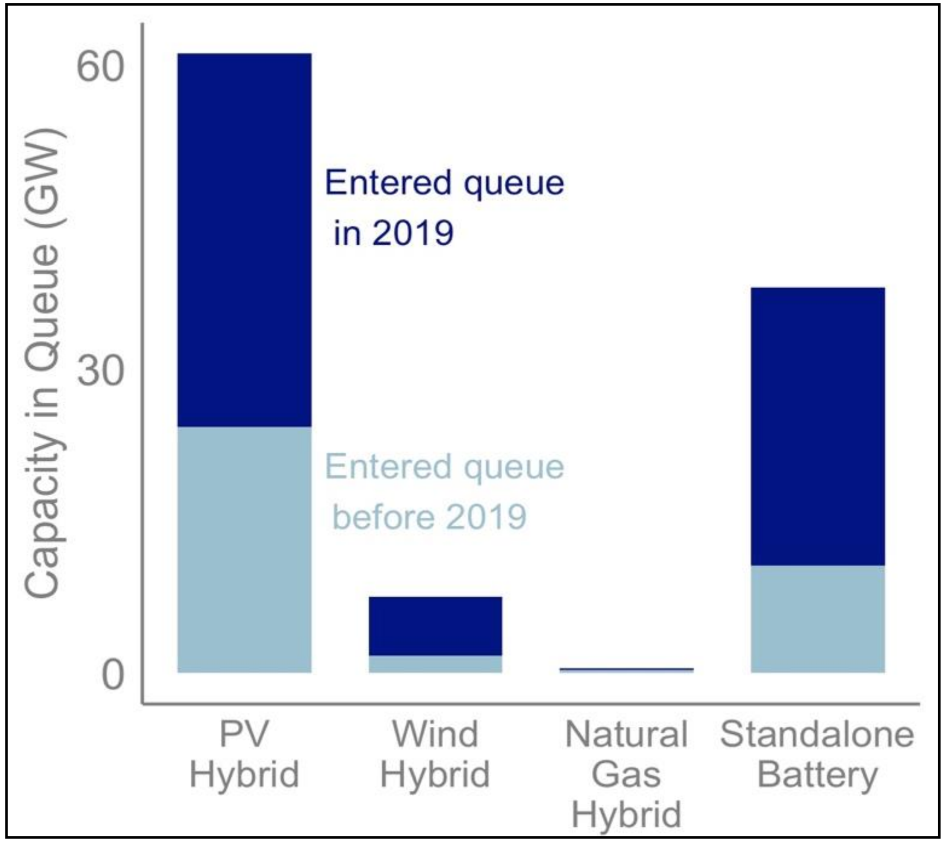
PV hybrids dominate the 7 ISO/RTO interconnection queues, but there are a number of wind and natural gas hybrids too

25% of the PV capacity in the seven ISO queues at the end of 2019 includes batteries



69 GW of total hybrid generator capacity in 7 ISO/RTO queues

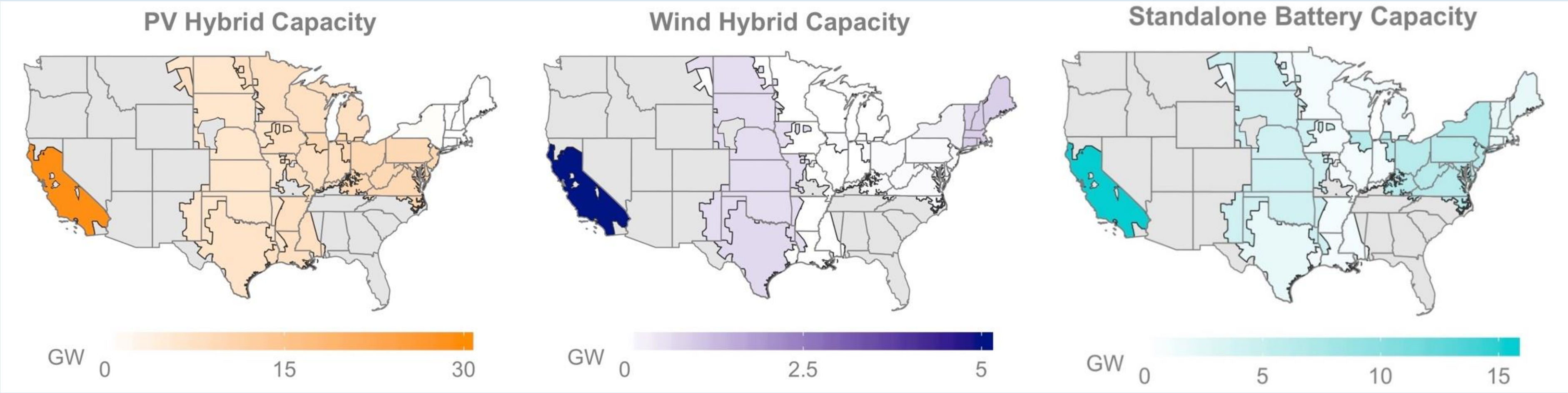
A majority of the proposed hybrid projects entered the queues very recently, in 2019



CAISO is the leading market among ISOs in terms of PV and wind hybrids and standalone storage in queues

- In CAISO for 2019 applications, ***96% of PV and 75% of wind*** are paired with batteries
- Over ***all application years*** in CAISO, 67% of PV and 50% of wind paired with batteries

Hybrid capacity compared to standalone battery capacity in each ISO queue



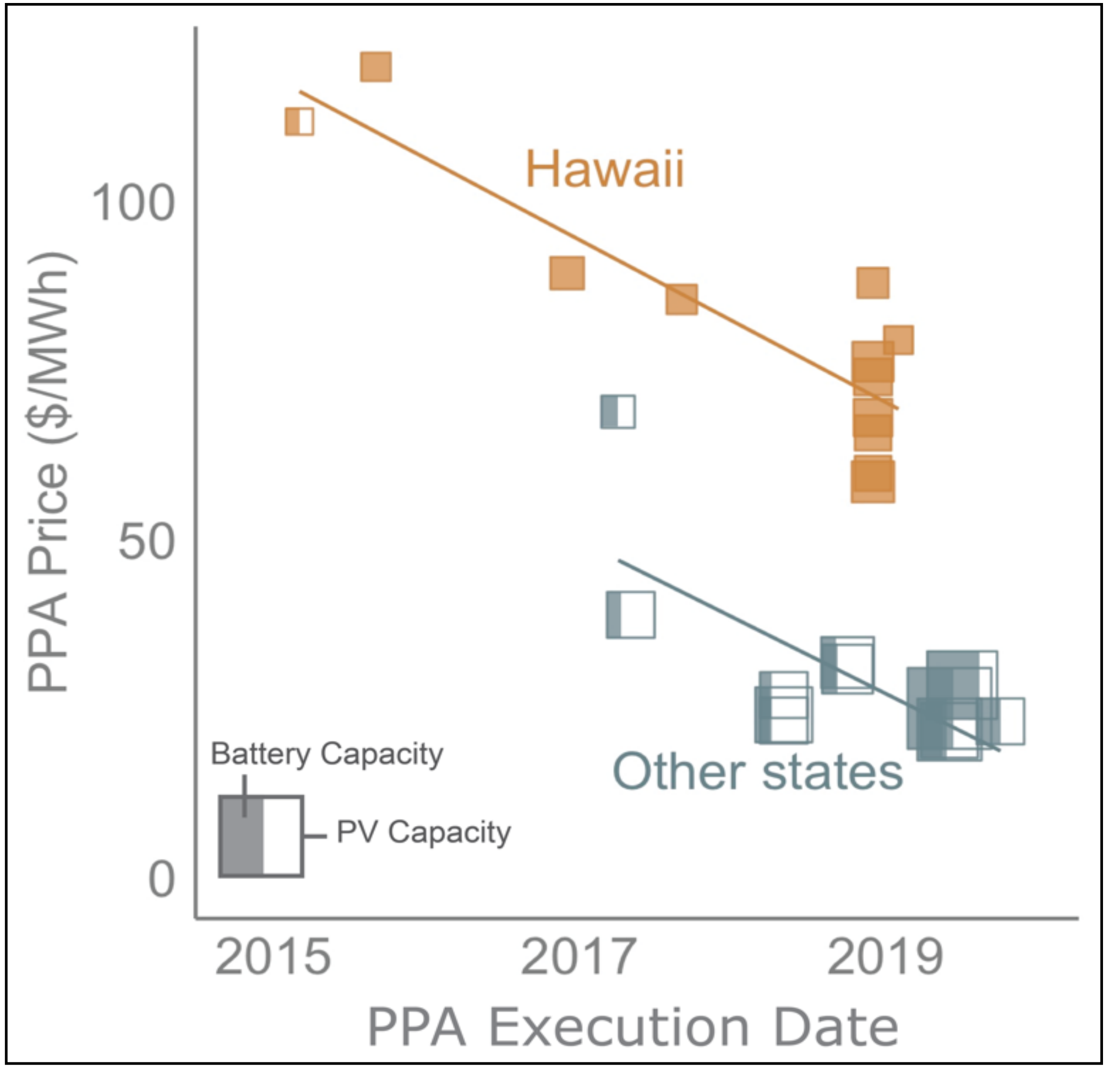
Percentage of generators hybridizing in each queue

ISO/RTO	PV	Wind
CAISO	67%	50%
ERCOT	13%	3%
SPP	22%	1%
MISO	16%	0%
PJM	17%	0%
NYISO	5%	1%
ISO-NE	0%	6%

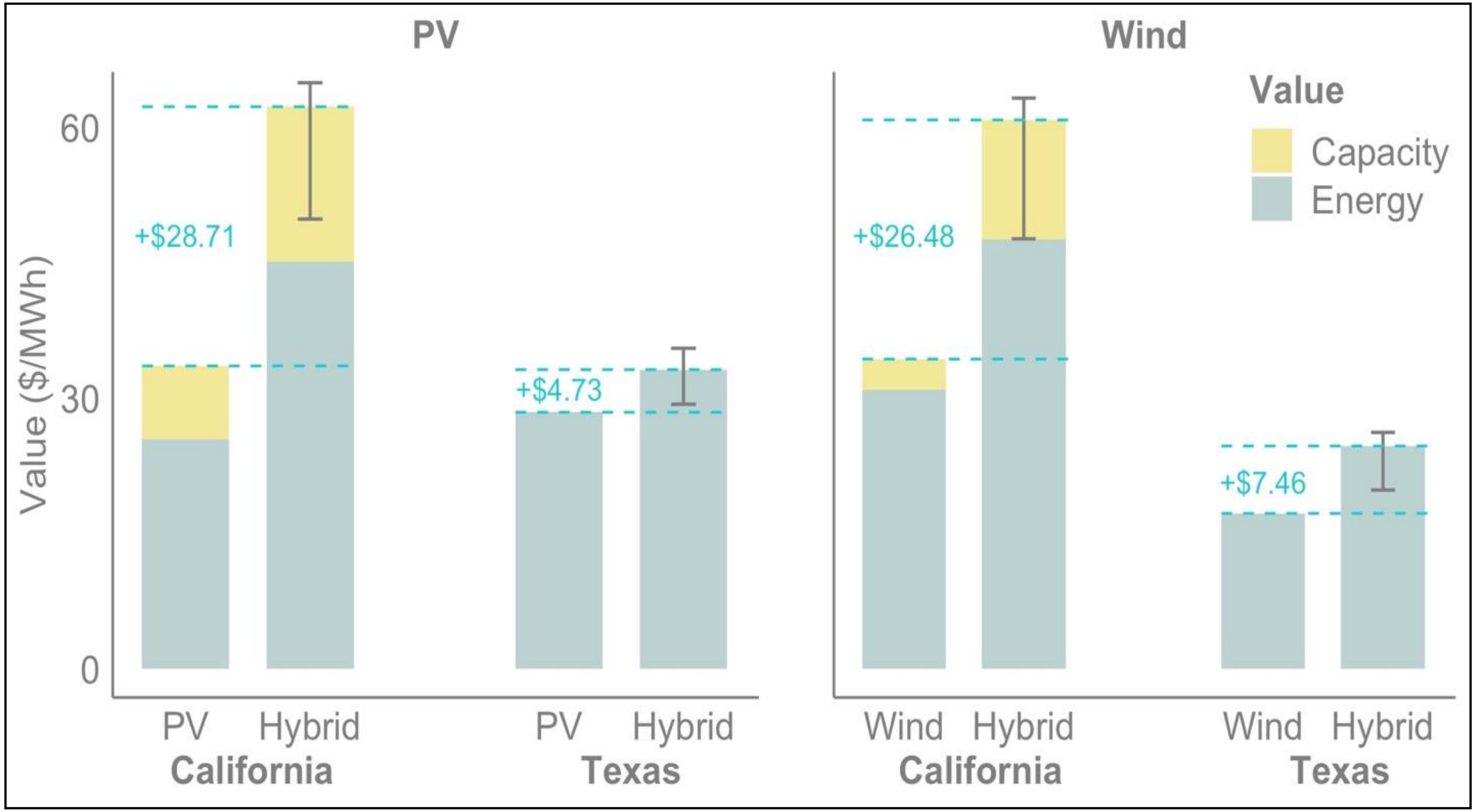
- As shown later, wholesale pricing patterns in CAISO (impacted by solar growth & ‘duck curve’) already deliver substantial value for hybridization, at least compared to TX

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



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



- ***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

(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

Conclusions

- ***Commercial interest*** in generator-battery hybrid plants is growing rapidly

- Co-locating batteries with renewables offers ***significant potential value in some regions,*** assuming historical prices for energy and capacity services (and no AS)
  - ***Energy & capacity value*** boost ***exceeds costs*** in some regions
    - Future work: *predict hybrid capabilities* to maximize value under evolving market designs
  - ***Independently sited*** batteries could capture ***even-more value, but lose cost synergies***
    - Future work: better understand the *total cost savings* from hybrids vs. standalone projects

Questions?

- Contact the presenters
  - Will Gorman (wgorman@lbl.gov)

- Additional project team at Lawrence Berkeley National Laboratory:
  - Andrew Mills
  - Ryan Wiser
  - Mark Bolinger

Download all of our work at:

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

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Extra Slides

Next Steps

- These results are from the ***first year*** of a three year collaboration with NREL

- Current work underway to calculate a more ***comprehensive valuation*** of hybrids
  - Led by LBNL
  - Exploring the ***key factors:*** storage duration, storage to generation ratio, sizing of storage relative to inverter, inverter loading ratios, grid charging constraints
  - Expand value analysis to cover ***substantially more wholesale pricing nodes***

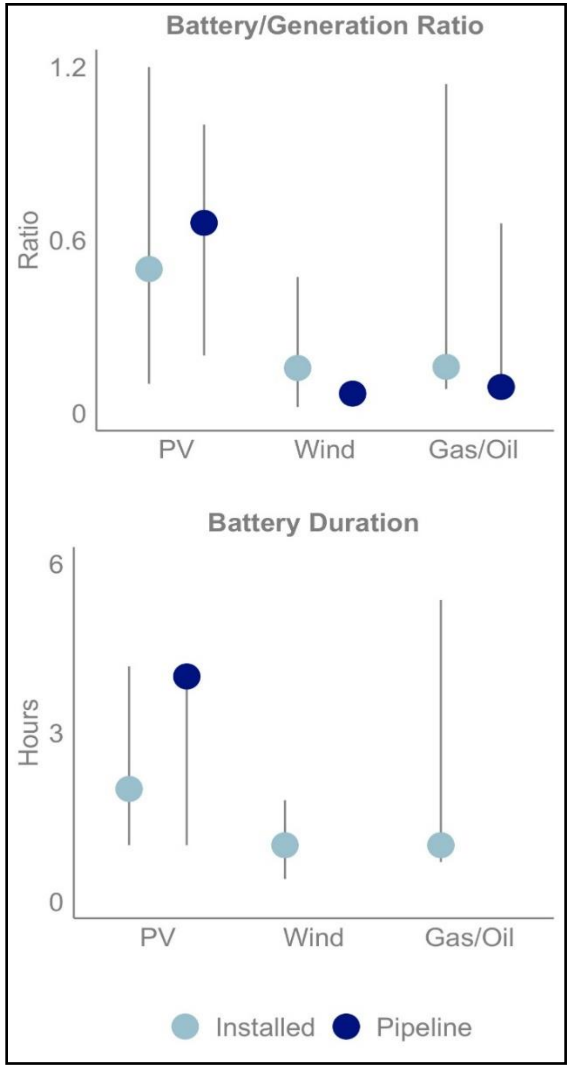
- Year 3 work aims to understand future value and deployment of hybrids
  - Led by NREL
  - Develop methods to represent ***future expansion*** of hybrid systems using ReEDS and PLEXOS

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

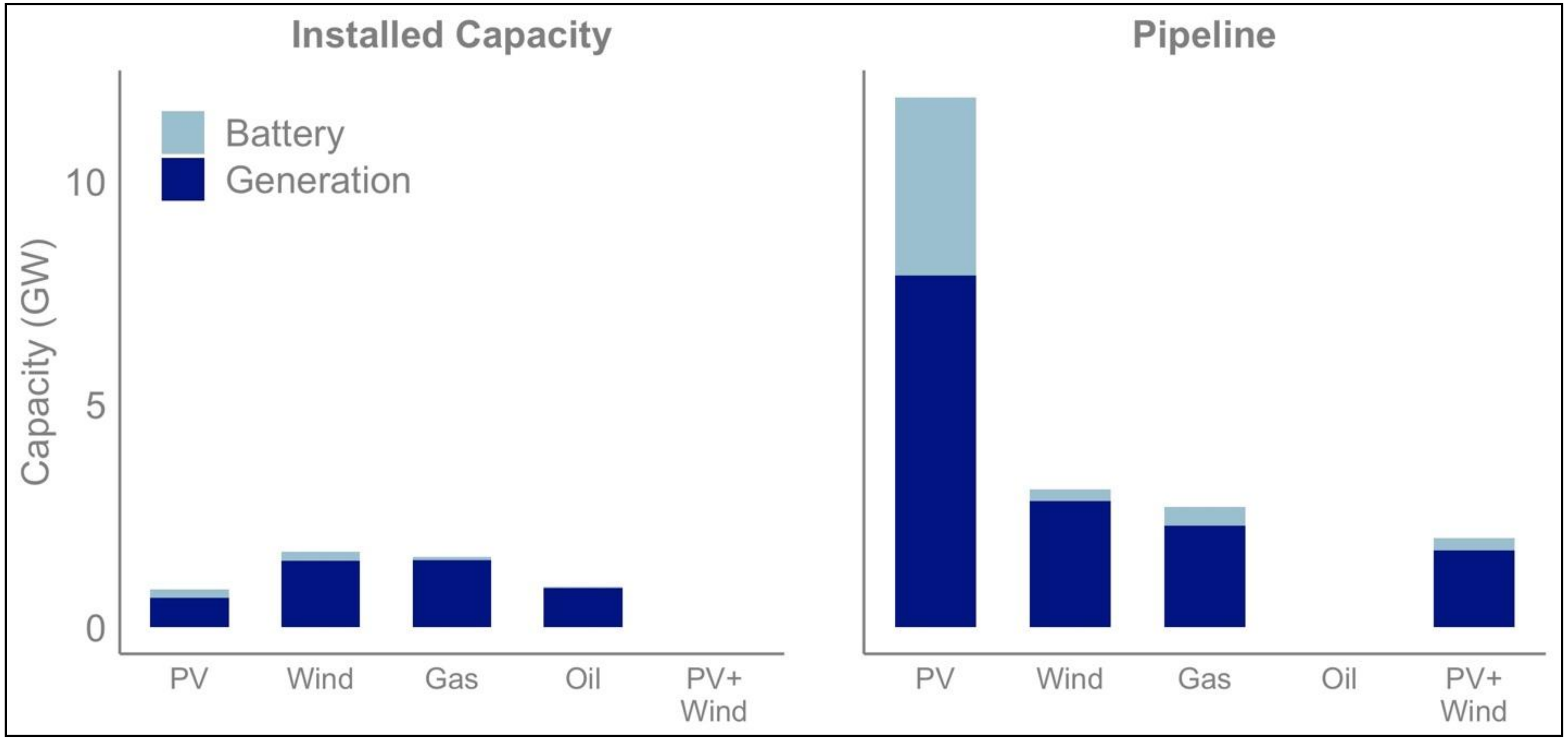
- ***Battery durations*** and ***battery-to-generation ratios*** appear to be on the rise for PV hybrids: higher in near-term pipeline than those currently online

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



Today’s 4.6 GW of hybrid generator capacity is accompanied by 14.7 GW in the immediate development pipeline

- 61 hybrid (or co-located) > 1 MW projects ***currently online;*** more wind, gas & oil capacity than PV
- 88 projects in ***near-term pipeline***
- PV dominates pipeline, but wind, fossil, and PV+wind also present

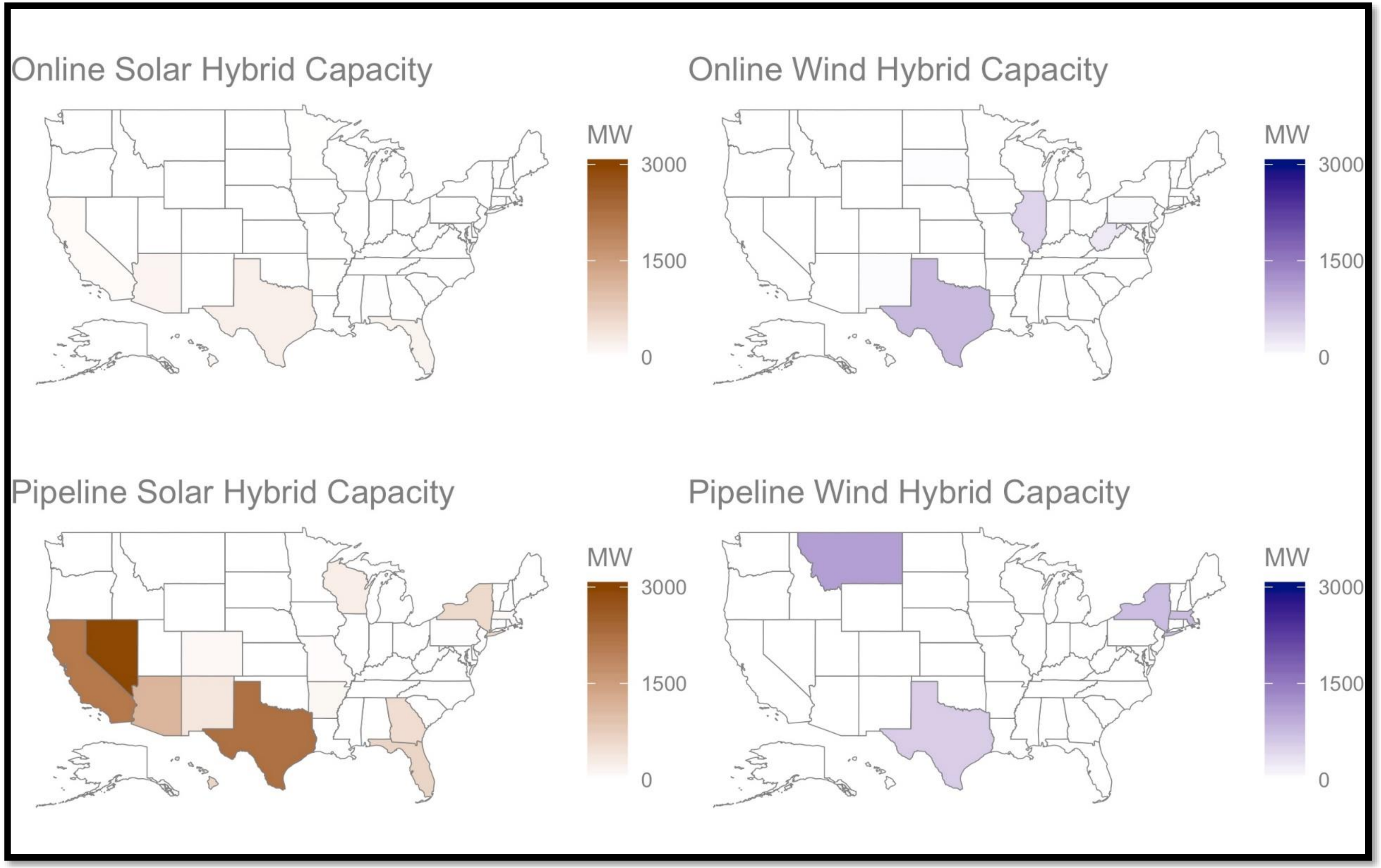


Online and pipeline hybrids focused in a few states

The limited online hybrid capacity for solar is in the south

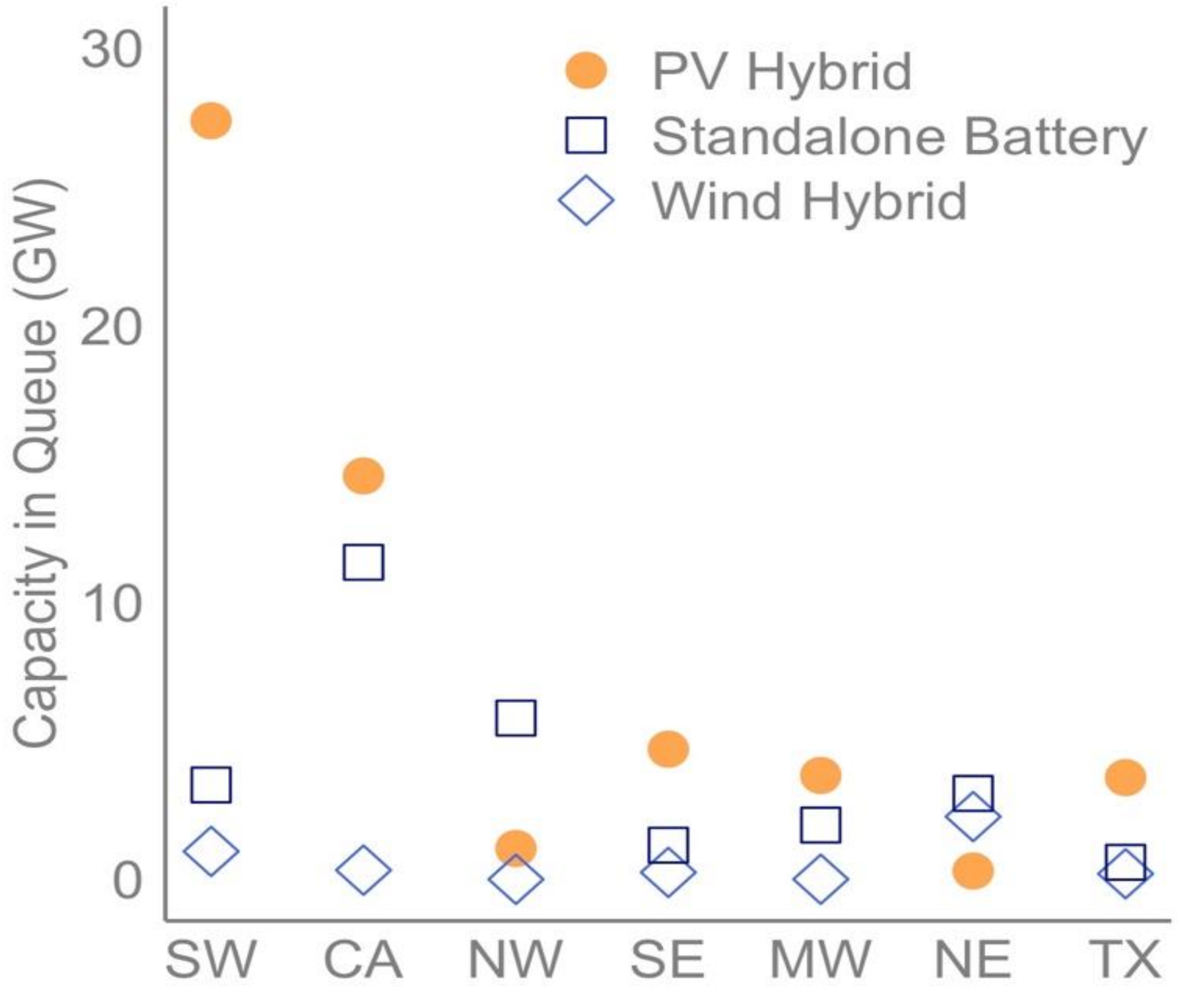
The pipeline of wind hybrids is not much larger than the wind projects already online

The pipeline for solar hybrids shows focused growth in the Southwest region of the United States



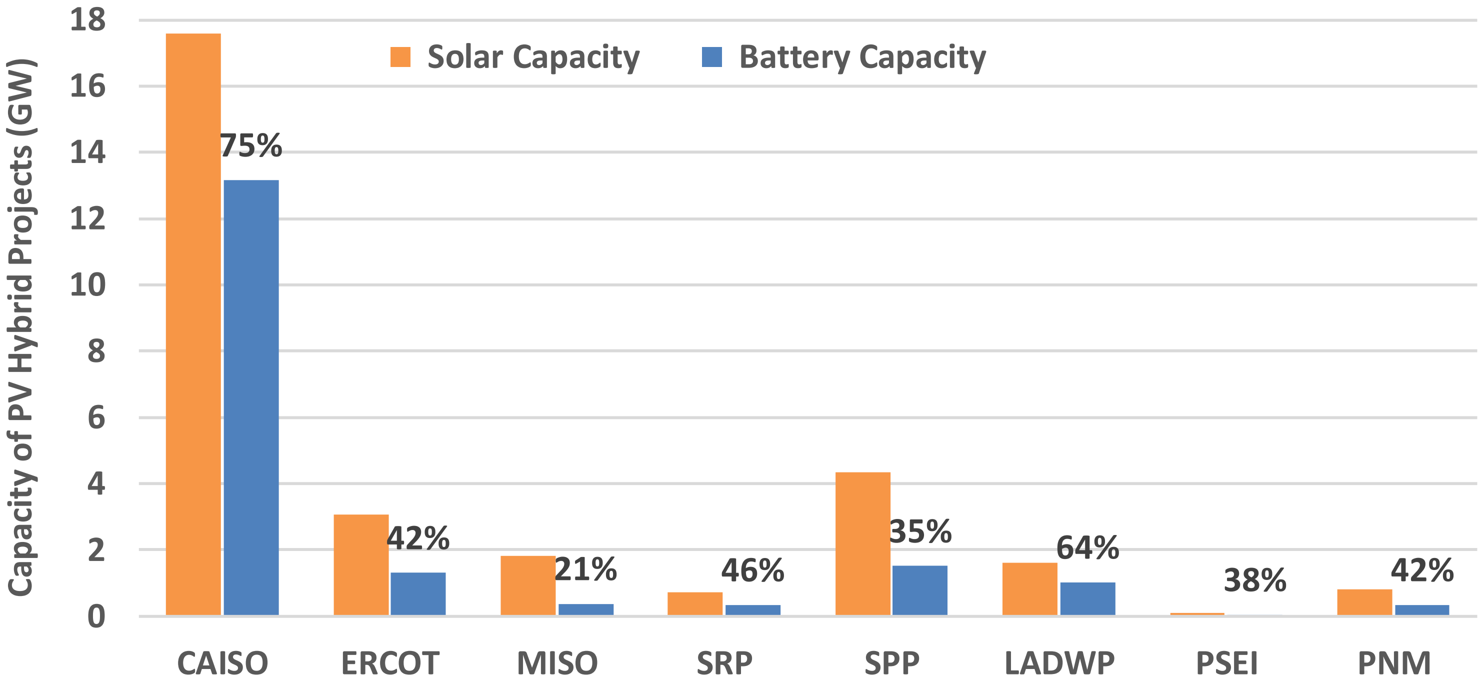
At end of 2018, most PV hybrids in interconnection queues (considering ISOs/RTOs & many utilities) were in Southwest

- PV hybrids most-popular in regions already experiencing solar-induced ‘duck curve’
- The northeast had the largest amount of wind hybrids
- The northwest saw more interconnection requests for standalone batteries than hybrid projects



At end of 2018, considering a portion of these queues, 30 GW of PV were paired with 18 GW of batteries

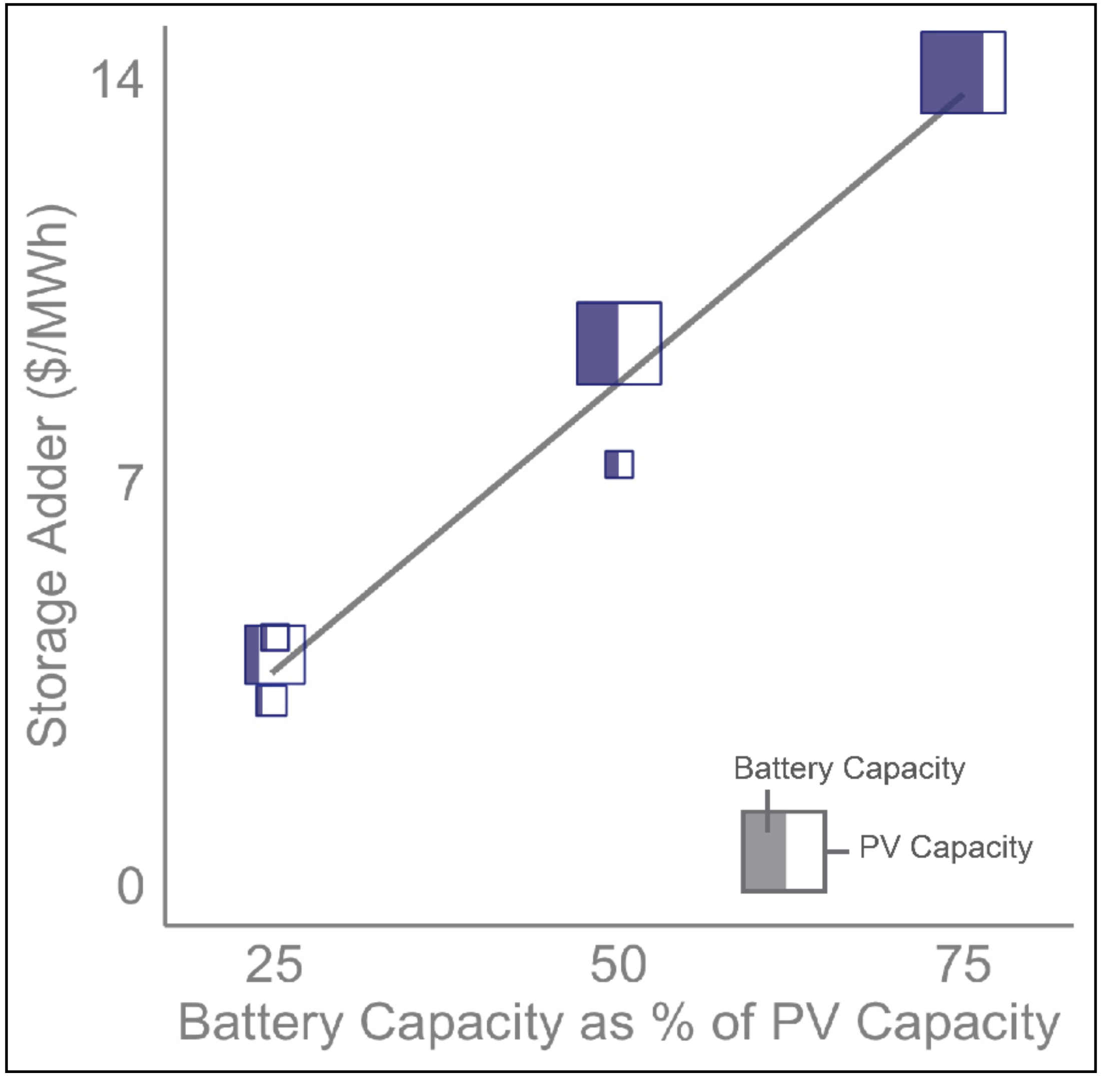
- Only 8 of these queues, accounting for 30 GW (of the 55 GW in total) of PV hybrid projects, break out the battery capacity
- CAISO (75%) and LADWP (64%) had the highest ratio of battery:PV capacity—which makes sense in light of “the duck curve”



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

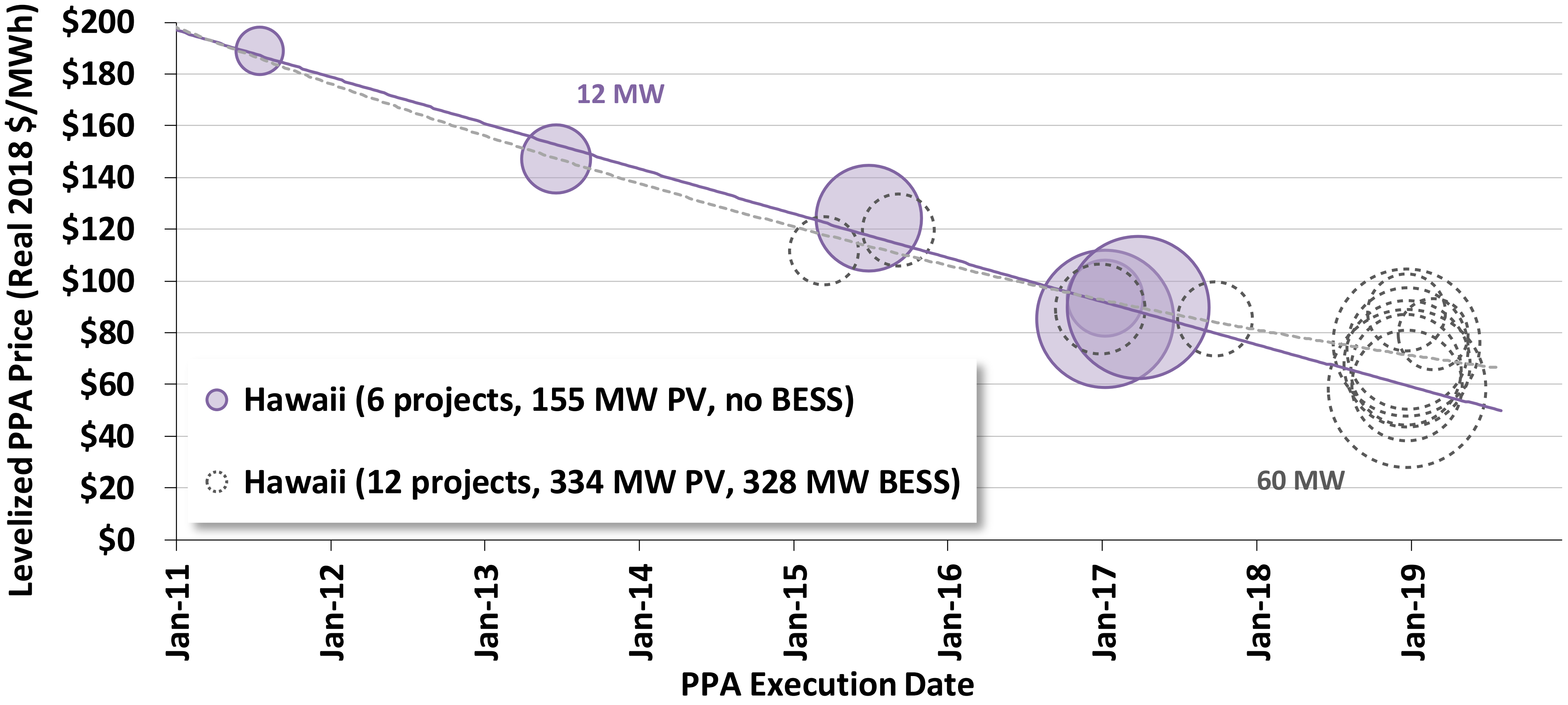
- ***Six of the 23*** PV-battery PPAs provide information to enable calculation of a ***battery adder*** (e.g., through separate capacity payments for battery component)

- 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



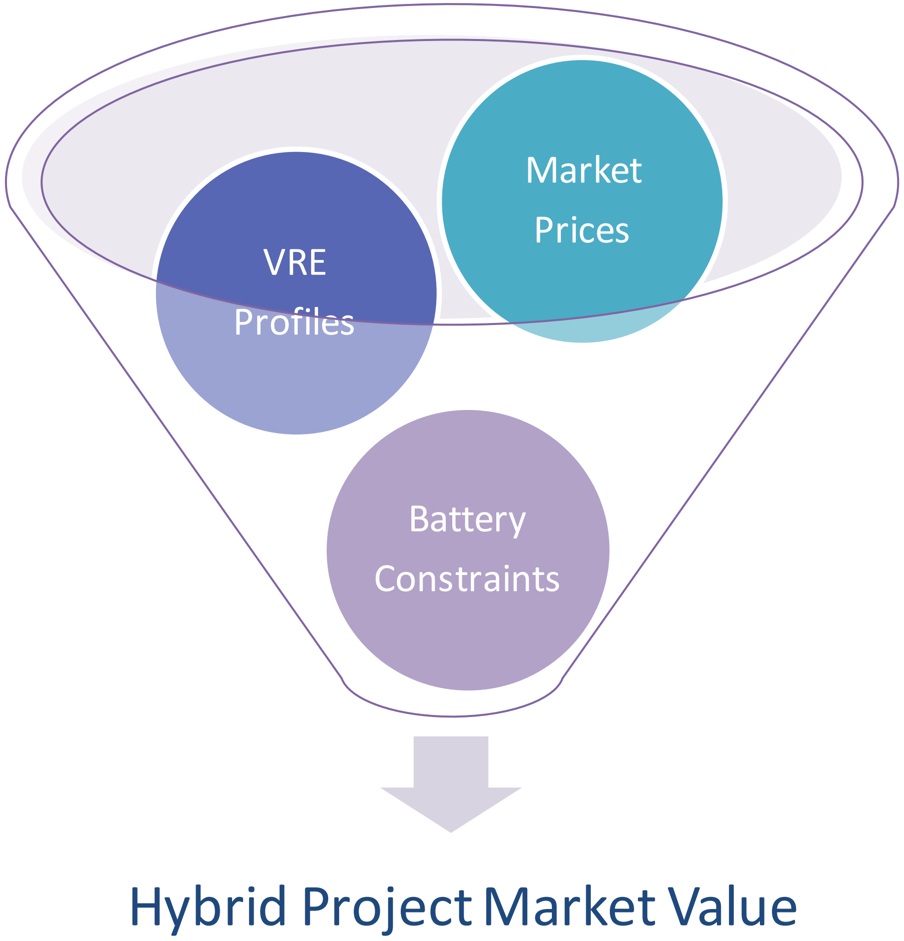
PPA prices for hybrids are dropping

- The apparent lack of a storage price adder in Hawaii is surprising given the high battery:PV capacity ratio (often 1:1), which should increase the storage price adder

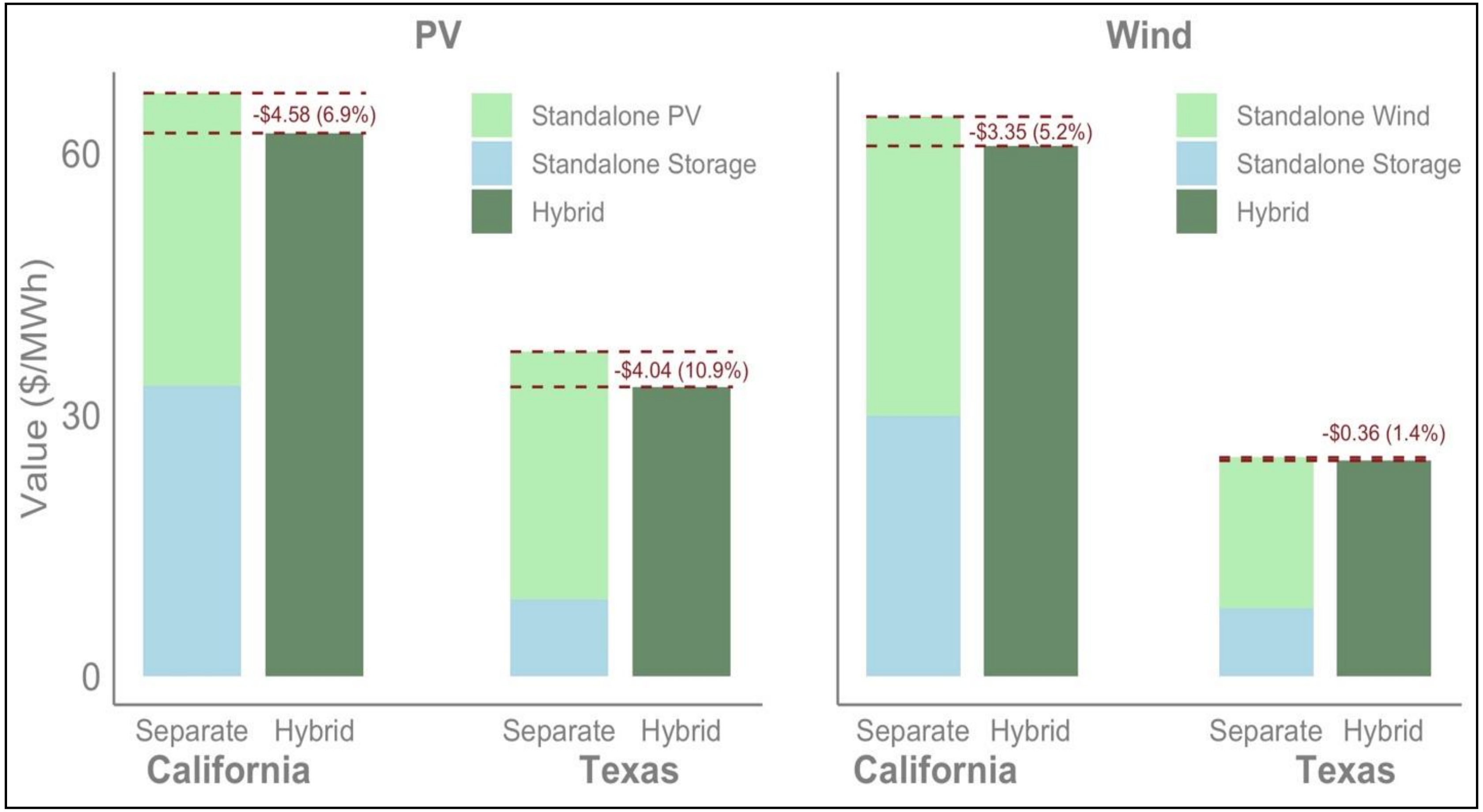


Simple optimization model used to provide preliminary insights into value of hybridization, vs. standalone

- **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)



Constraints on hybrid projects lead to 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***

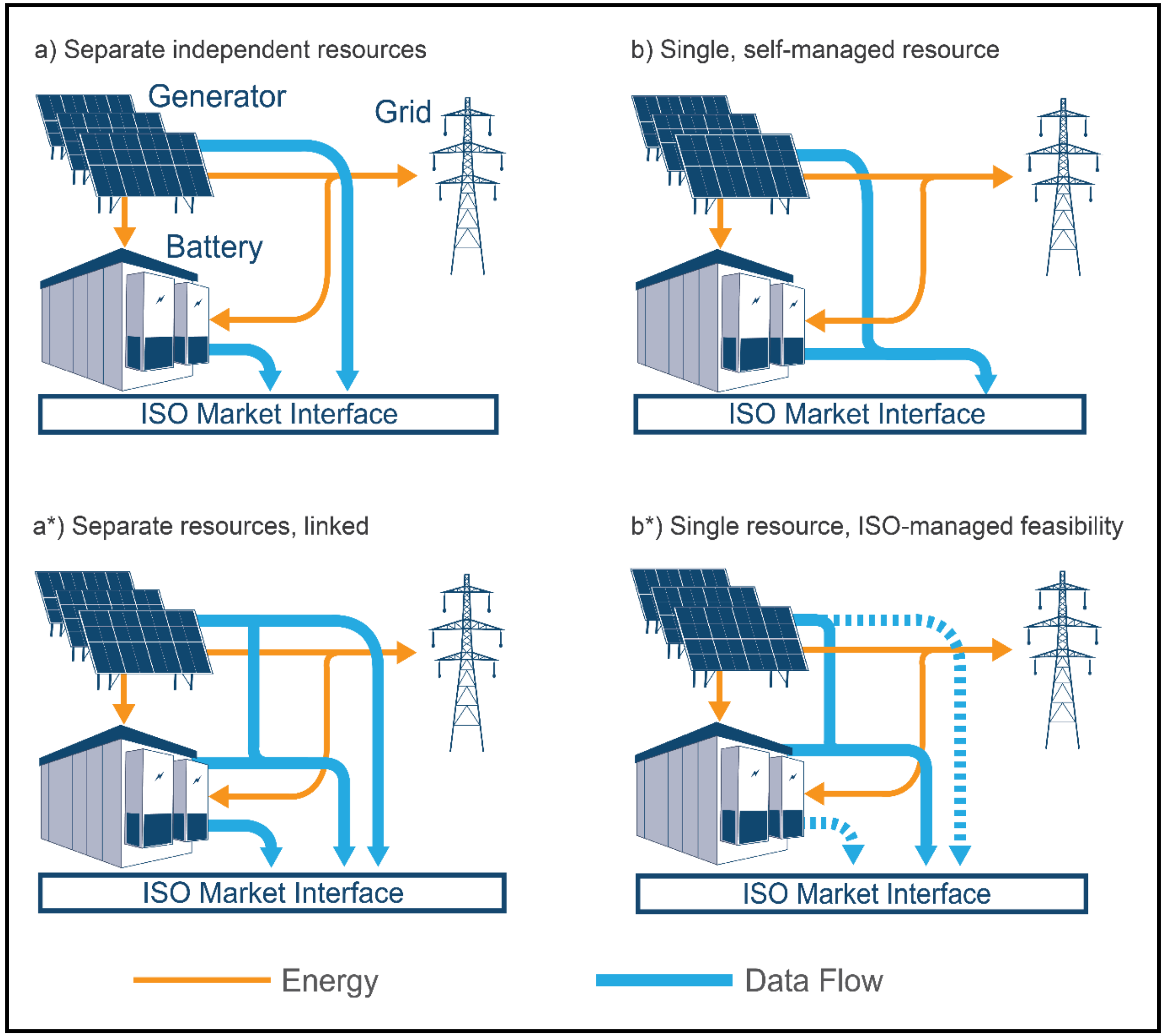
NOTE: Analysis assumes standalone battery delivers to same pricing node as hybrid; as such, analysis likely understates value of standalone storage and so also understates value-reduction due to hybridization

Benefits of hybridization from receiving the investment tax credit and reducing interconnection costs may need to be > 2%–11% to offset this value loss from hybridization

Realizing hybrid projects’ full value depends on nascent wholesale-market participation models

a) Separately represent each resource, with ***minimal changes*** to existing market designs

a*) Add linking constraint to increase ability to operate resource in ***flexible manner***



b) Single offers and operating parameters allows participant ***bidding strategy flexibility***

b*) Add telemetry/forecasts to allow ISO to ***limit infeasible schedules***

New technical challenges must be addressed to enhance market participation: impacted by participation model