Planning for energy storage and microgrids

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Integrated Distribution System Planning Training
for Midwest/MISO Region
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Agenda

- Technology Overview
- Services and Valuation
- Energy Storage in Regional Markets
- Storage in Microgrids
- Integration
- Hybrid Power Plants

Technologies, Services and Valuation, Regional Markets, and Microgrids

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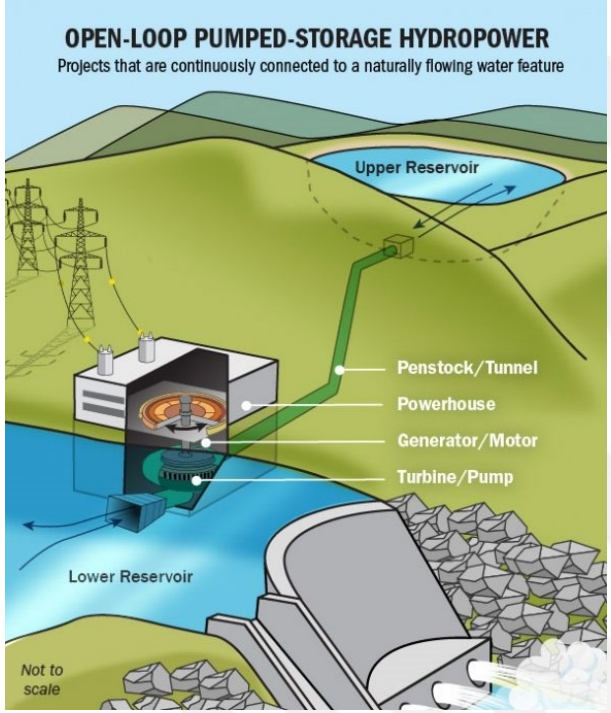
Pacific Northwest National Laboratory

Technology Overview

Storage Technologies: Mechanical

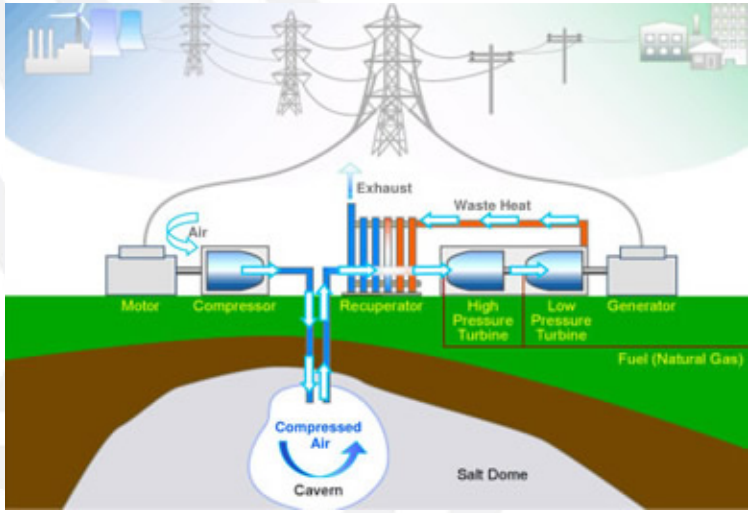
Electricity is stored as potential energy that is later used to generate electricity.

Pumped-Storage Hydro (PSH)



- Long duration (8+ hours)
- Good round-trip efficiency (RTE) – 80%
- Cycle life: 15,000 (40+ years)
- Limited flexibility

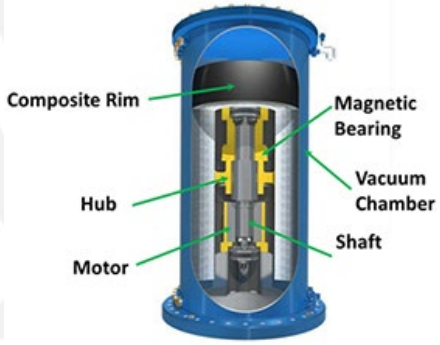
Compressed Air Energy Storage



Ridge Energy Storage & Grid Services LP

- Long duration (8+ hours)
- Low RTE (~50%)
- Cycle life: 10,000 (~25 years)
- Limited flexibility

Flywheels



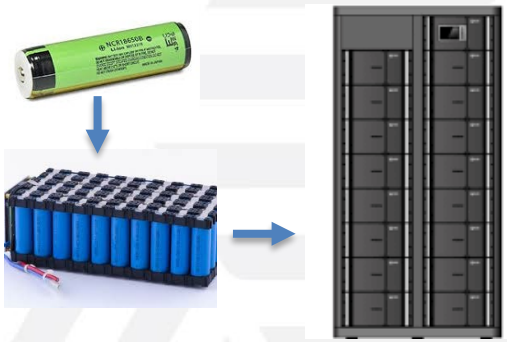
Source: Beacon Power, LLC

- Short duration (~15 min)
- Very good RTE (~85%)
- Cycle life: 200,000 (~20 years)
- Highly flexible

Storage Technologies: Electrochemical

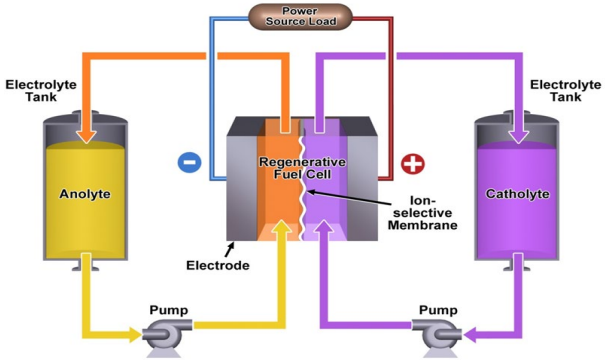
Electricity is stored in chemical bonds and later released.

Lithium-ion Batteries



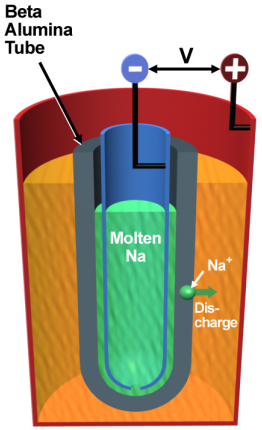
- Short to mid-range duration (0.5 - 4 hours)
- Very good round-trip efficiency (RTE) – 86%
- Cycle life: 3,500 (7-10 years)
- Highly flexible
- Developed supply chain
- Safety concerns
- Recycling challenges

Flow Batteries



- Moderate durations (4-8 hours)
- Moderate round-trip efficiency (RTE) – 70%
- Cycle life: 10,000 (15-20 years)
- Highly flexible
- Improved safety
- Highly recyclable
- Mechanical challenges

Sodium Batteries

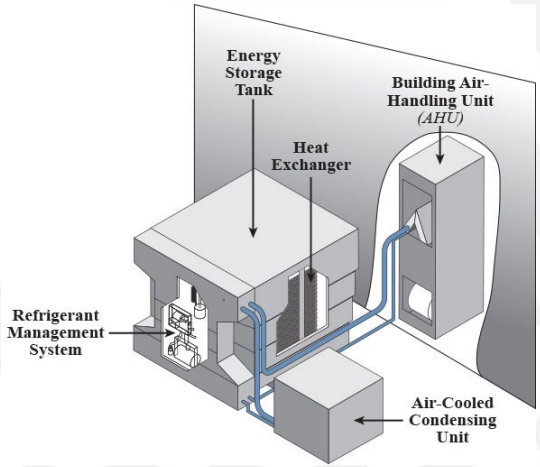


- Moderate durations (4-6 hours)
- Good round-trip efficiency (RTE) – 75%
- Cycle life: 4,000 (10-13 years)
- Highly flexible
- High-temperature ops

Storage Technologies: Thermal

Electricity is stored by heating/cooling air or another medium for energy management or electricity production.

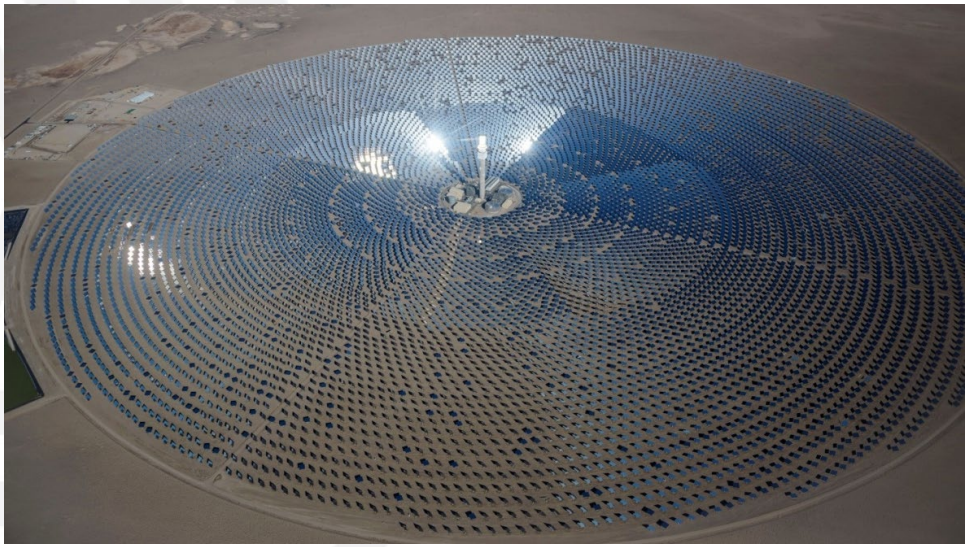
Ice thermal storage



Ice Energy, Inc.

- Moves energy through time, but does not inject electricity into the grid
- Moderate duration (4-6 hours)
- Can shift up to 95% of HVAC loads to off-peak

Concentrating Solar

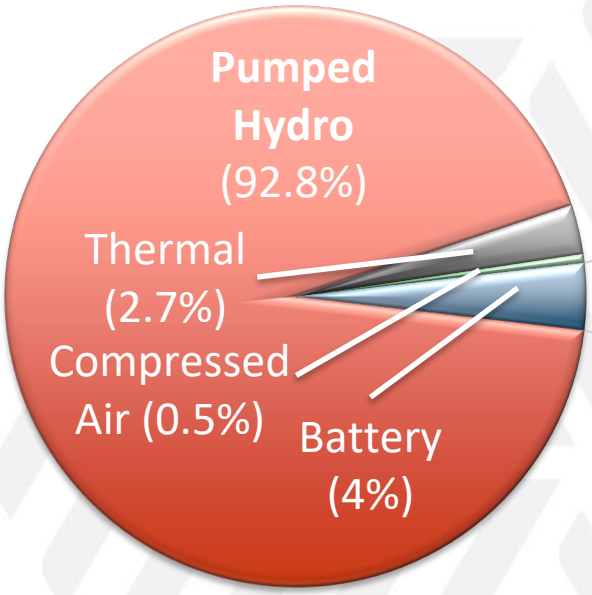


U.S. DOE

- Longer duration (6-12 hours)
- Very good RTE – 86% (Hameer and Van Niekerk 2016)
- Moderate life (20-30 years)
- Moderately flexible (turbine generator)

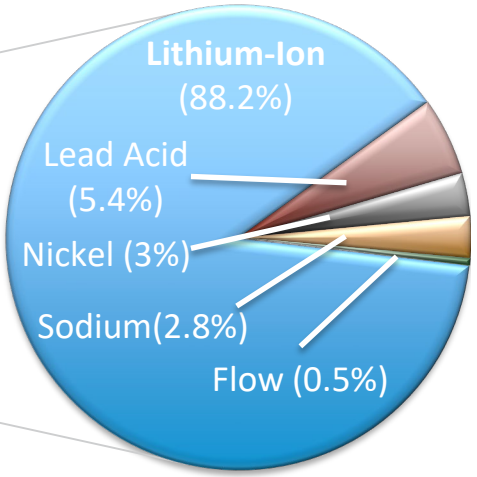
Current Installed Capacity – U.S.

Total Energy Storage Capacity



Pumped Hydro	22.6 GW
Battery	0.9 GW
Thermal	0.7 GW
Compressed Air	0.1 GW
Total	**24.3 GW**

Total Battery Capacity



Lithium-Ion	792 MW
Lead Acid	49 MW
Nickel	40 MW
Sodium	26 MW
Flow	4 MW
Flywheel	58 MW
Capacitor	2 MW

Sources:
DOE Global Energy Storage Database (https://www.sandia.gov/ess-ssl/global-energy-storage-database-home/);
EIA Form 860 Data (https://www.eia.gov/electricity/data/eia860/)

Storage Technologies: Additional Information

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Table 4.3. Summary of Compiled Findings by Technology Type – BESS[(a)]

Parameter	Sodium Sulfur	Li-Ion	Lead Acid	Sodium Metal Halide	Zinc-Hybrid Cathode	Redox Flow
Capital Cost – Energy Capacity ($/kWh)	661 (465)	271 (189)	260 (220)	700 (482)	265 (192)	555 (393)
Power Conversion System ($/kW)	350 (211)	288 (211)	350 (211)	350 (211)	350 (211)	350 (211)
Balance of Plant ($/kW)	100 (95)	100 (95)	100 (95)	100 (95)	100 (95)	100 (95)
Construction and Commission Cost ($/kWh)	133 (127)	101 (96)	176 (167)	115 (110)	173 (164)	190 (180)
Total Project Cost ($/kW)	3,626 (2,674)	1,876 (1,446)	2,194 (1,854)	3,710 (2,674)	2,202 (1,730)	3,430 (2,598)
Total Project Cost ($/kWh)	907 (669)	469 (362)	549 (464)	928 (669)	551 (433)	858 (650)
O&M Fixed ($/kW-yr)	10 (8)	10 (8)	10 (8)	10 (8)	10 (8)	10 (8)
O&M Variable Cents/kWh	0.03	0.03	0.03	0.03	0.03	0.03
System Round-Trip Efficiency (RTE)	0.75	0.86	0.72	0.83	0.72	0.675 (0.7)
Annual RTE Degradation Factor	0.34%	0.50%	5.40%	0.35%	1.50%	0.40%
Response Time (limited by PCS)	1 sec	1 sec	1 sec	1 sec	1 sec	1 sec
Cycles at 80% Depth of Discharge	4,000	3,500	900	3,500	3,500	10,000
Life (Years)	13.5	10	2.6 (3)	12.5	10	15
MRL	9 (10)	9 (10)	9 (10)	7 (9)	6 (8)	8 (9)
TRL	8 (9)	8 (9)	8 (9)	6 (8)	5 (7)	7 (8)

(a) An E/P ratio of 4 hours was used for battery technologies when calculating total costs.
MRL = manufacturing readiness level; O&M = operations and maintenance; TRL = technology readiness level.

Mongird et al, *Energy Storage Technology and Cost Characterization Report*.
http://energystorage.pnnl.gov/pdf/PNNL-28866.pdf.

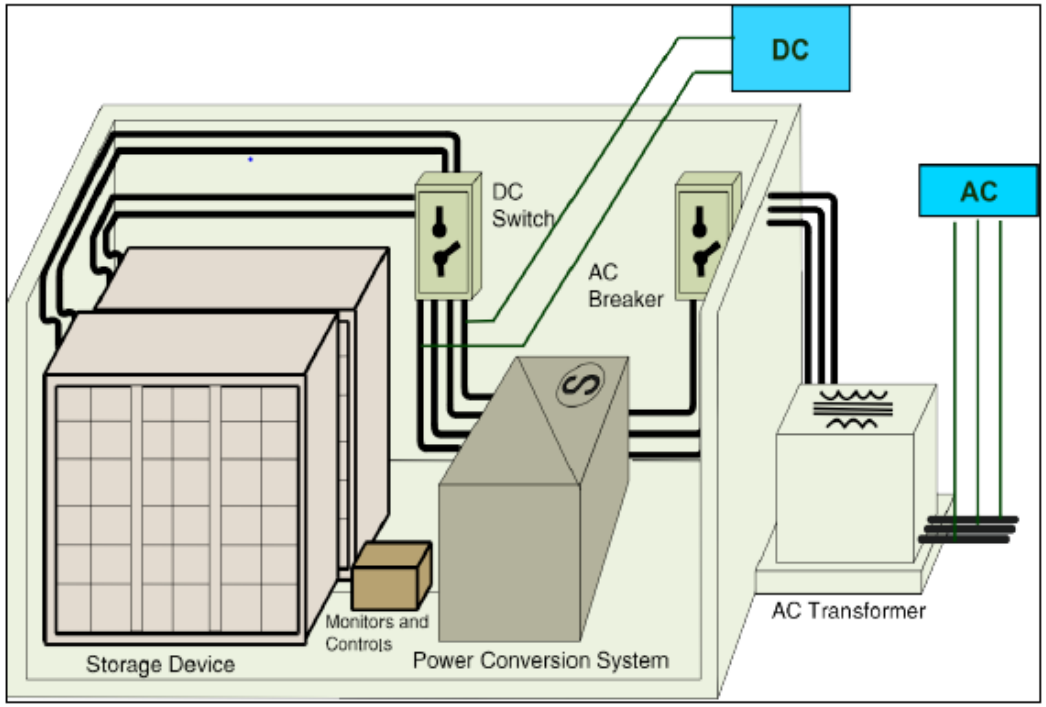
Interconnection and Control Infrastructure

Battery storage prices are generally given based on the battery itself, but interconnecting the device to the grid and allowing for control and interoperability requires additional infrastructure (and cost):

Example 4-hour lithium-ion project

Balance of Plant (controls, switches, HVAC, etc.): $100/kW ($25/kWh)

Battery capacity: $271/kWh ($1,084/kW)



DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA

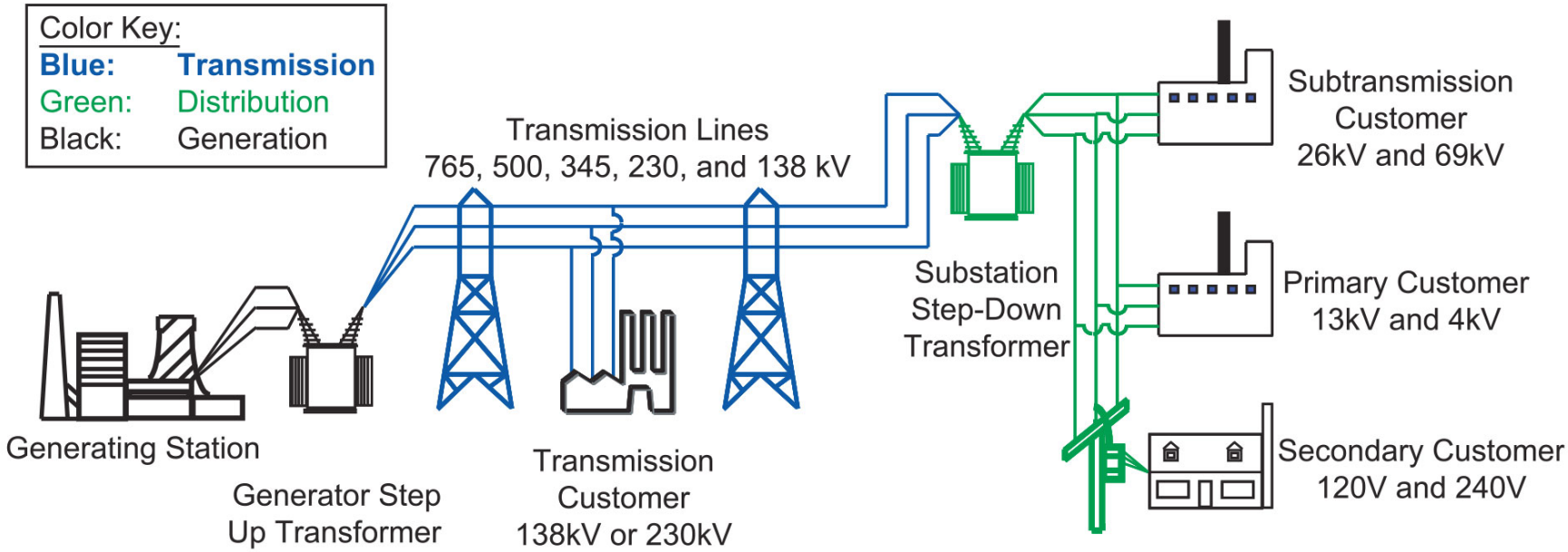
Construction & Commissioning: $101/kW ($25/kWh)

Power Conversion: $288/kW ($72/kWh)

Total all-in cost for a 4-hour li-ion battery: $469/kWh, $1,876/kW

Services and Valuation

Energy Storage Services



Generation Services
- Capacity
- Energy
- Ancillary services
  - Regulation
  - Frequency response
  - Spin/non-spin reserve
  - Etc. …

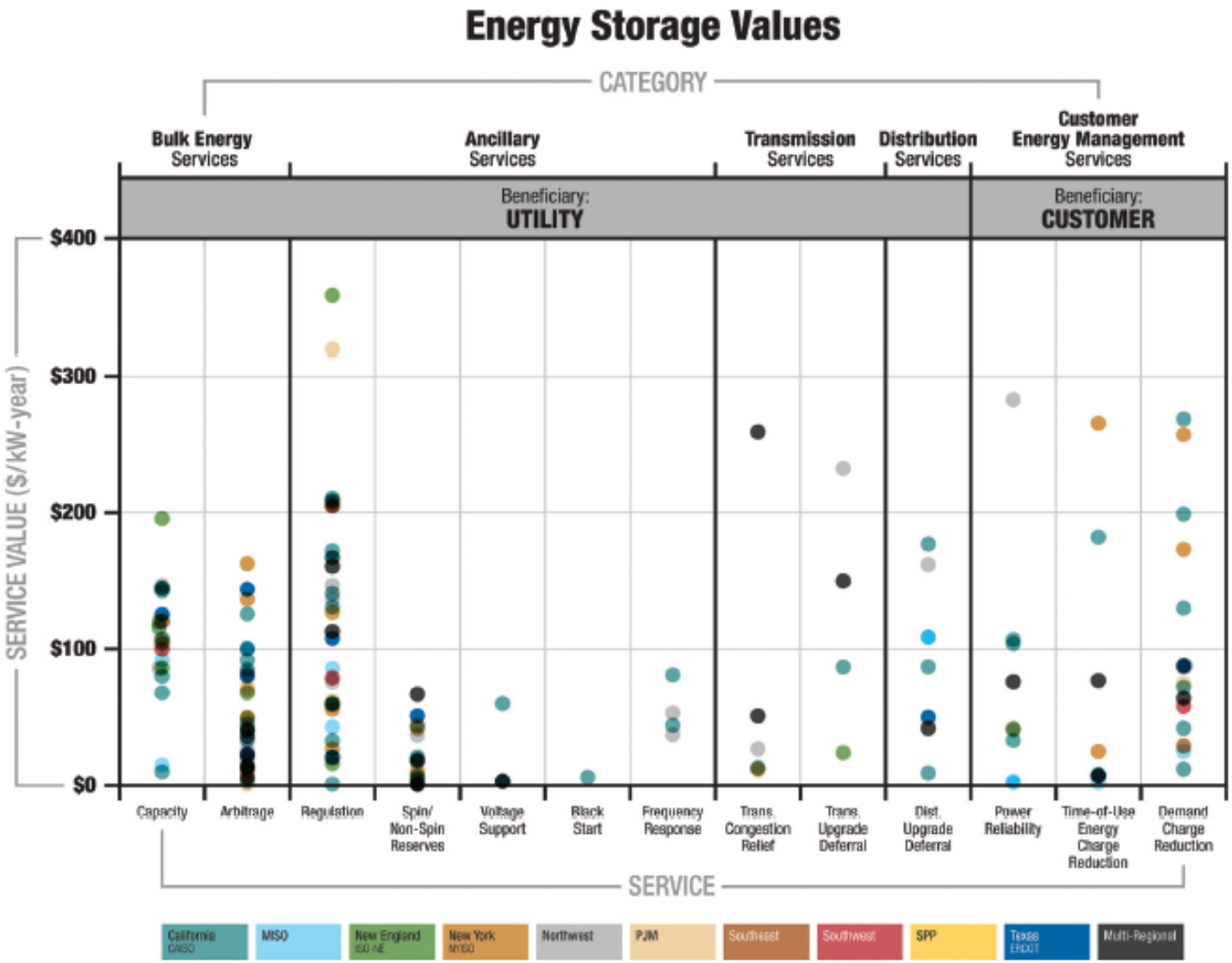
Transmission Services
- Thermal management
- Congestion relief
- Infrastructure deferral

Distribution Services
- Voltage support
- Conservation voltage reduction
- DG integration/hosting capacity
- Flow management
- Infrastructure deferral

Customer Services
- TOU rate management
- Demand charge reduction
- Power quality
- Resilience

Image: U.S. Department of Energy, "Grid Modernization Multi-Year Program Plan"

Energy Storage Values



Storage values are locational, subject to:

- Resource mix
- Local infrastructure
- Contingency conditions
- Utility tariffs
- Market structure

Balducci et al, "Assigning Value to Energy Storage Systems at Multiple Points in an Electric Grid."

A Different Paradigm: Embedded Energy Storage

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Electricity is unique among commodities in that its "supply chain" was developed without a storage component.

- Every other commodity has the ability to store excess quantities built into its supply chain – warehouses, granaries, reservoirs, etc.
- Embedded storage creates a buffer between mismatches in supply and demand, stabilizing prices and protecting customers.

Question: Now that we have the technology to store electricity, should we retrofit the grid with it?

- To date, energy storage has been added "on the margins" to impart flexibility to the grid.
- If storage were embedded infrastructure, similar to a substation or a transformer, it could act as a natural buffer between mismatches in supply and demand and the grid would *be* flexible.

First report available here; watch PNNL's Grid Architecture site for additional reports in the series

Embedded Storage in the Natural Gas System

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A simple comparison: Natural gas and electricity

- Simple assumptions: City has average daily demand of 1 million cubic feet (CF) of natural gas, peaking to 1.5 million CF; average electricity demand of 100 MW, peaking to 125 MW

Adapted from Aspen Environmental Group

Result: Embedded storage on the natural gas system means that pipelines upstream of the storage facility can be sized based on average demand, and only downstream pipelines need to be sized based on peak.

- On the electric side, the entire system (generation, transmission, and distribution) serving the city must be designed based on peak demand.

Interesting Idea, Lots of Questions

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Theoretically, embedded storage could facilitate more efficient design and use of the electric grid and reduce costs by managing volatility (no daily price swings, reduced need for ancillary services, etc.).

Several regulatory barriers exist:

- Lack of underlying standards (not contemplated in reliability standards; no resilience standards)
- Inclusion in planning processes (regional transmission planning processes are generally slow to integrate new technologies)
- Ownership models (security and control issues complicate third-party ownership)
- Compensation structure (current market structures not designed to value this kind of service; lack of standards means it's difficult to make a case for it as a regulated asset)
- Metrics (how do you measure a buffer?)

Valuing this type of asset is something we're just starting to think about:

- How would you quantify its impacts on the grid and compensate them?
- Valuation will be the focus of a forthcoming paper.

Energy Storage in Regional Markets

Energy Storage and Regional Markets

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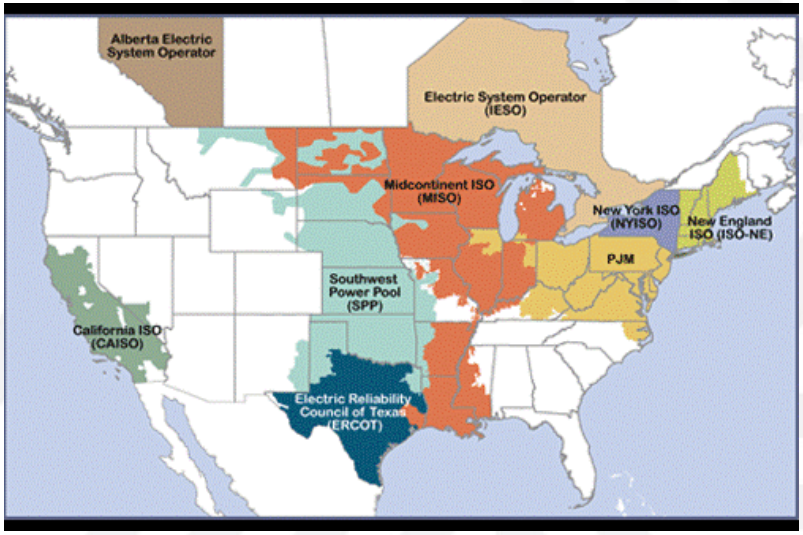
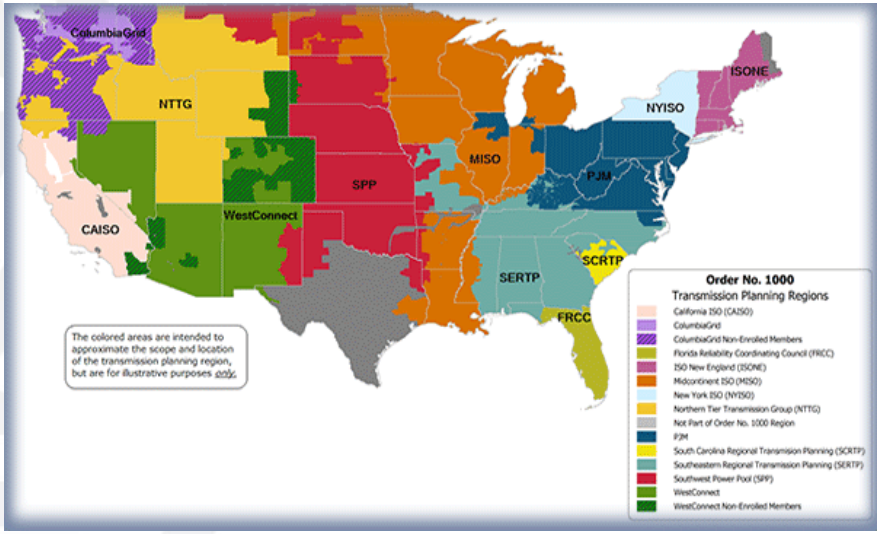
The Federal Energy Regulatory Commission (FERC) has two primary areas of regulatory authority over the electric grid:





Market design and operations in the deregulated market footprints (minus ERCOT)

Transmission system planning, operations, and ratemaking in all regions with interstate transmission

In recent years, FERC has sought to improve access for energy storage in both areas.

Market Access: FERC Order 841

In February 2018, FERC issued Order 841 to "remove barriers to the participation of electric storage resources in the capacity, energy, and ancillary service markets operated by Regional Transmission Organizations (RTO) and Independent System Operators (ISO)."

Filings must meet seven criteria:

- Create a participation model;
- Make storage eligible to participate in all applicable markets;
- Account for the physical and operational characteristics of storage resources;
- Allow storage owners to self-manage their state of charge;
- Establish a minimum size requirement no greater than 100 kW;
- Accurately meter and charge storage devices when charging (wholesale rates, no transmission charges when directed to charge by ISO); and
- Have an effective date within one year of FERC acceptance unless more time is reasonably necessary.

Order 841 in MISO

Midcontinent ISO (MISO), Docket ER19-465: Provisionally approved Nov. 2019, effective June 2022

- Electric Storage Resource :
  - "A Resource capable of receiving Energy from the Transmission System and storing it for later injection of Energy back to the Transmission System."
  - Resource may self-schedule for energy and operational reserves
  - Must be able to respond to 5-minute dispatch signal
  - Submit 35-part bids, including charging energy bid, discharge energy bids, ancillary service bids, start-up bids, technological considerations, etc.
  - Storage resources not selected in day-ahead energy market may participate in the Reliability Assessment Commitment (RAC) if needed

Order 841 in MISO (cont.)

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FERC accepted MISO's initial filing, but directed an additional compliance filing to:

- Remove a cap on very small participating resources
- Omit storage resources from paying transmission charges when directed to charge by the ISO (regulation down, ramp down, etc.)
- Provide more specificity about how distribution-connected storage will be metered, billed and compensated

FERC accepted MISO's compliance filing, but directed an additional compliance filing to clarify the process by which distribution-connected storage will be metered and billed when it is also paying retail rates for some of its charging energy.

Transmission Access: FERC Policy Statement

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Prompted by two proceedings involving PSH facilities

- Nevada Hydro (2008): FERC **rejects** developer's petition to build a pumped storage hydro (PSH) project and require California Independent System Operator (CAISO) to assume operational control and operate it as a transmission asset; bid in market at $0
- Western Grid (2010): FERC **approves** developer's petition to build a PSH project that will be operated as a transmission asset at CAISO's direction, no market bids

Policy Statement: Storage can be a dual-use (transmission and generation) asset, subject to three clarifying principles:

- Avoid double recovery of costs
- Minimize adverse impacts on markets
- ISO/RTO independence must not be compromised

A policy statement is a nonbinding document; no action required

- CAISO and MISO were the only entities to initiate a direct response to statement

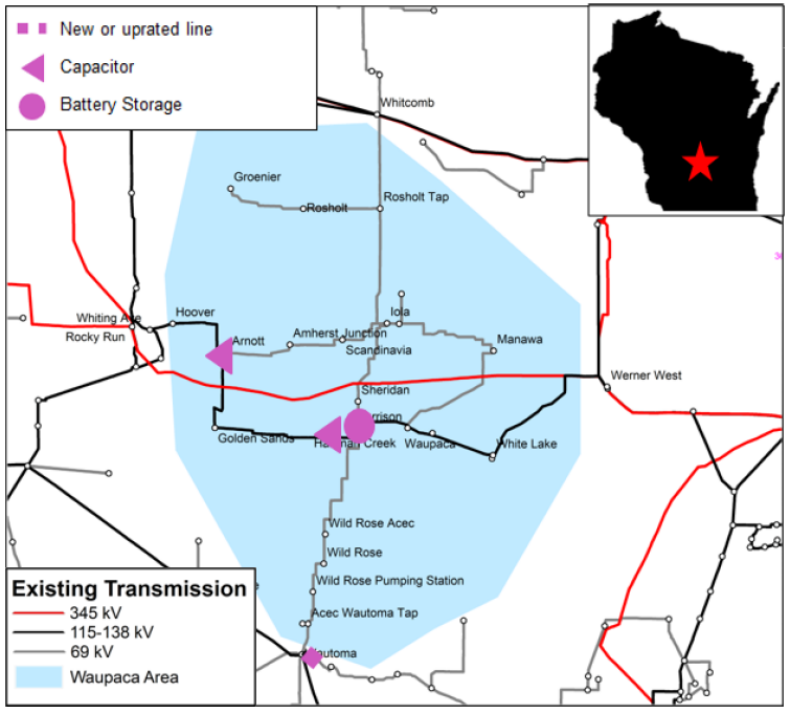
Storage as Transmission in MISO

MISO initiated a proceeding, Energy Storage as a Transmission Reliability Asset, in Q2 2018. FERC's policy statement was identified as one of the driving factors.

- Where CAISO focused on the details of enabling dual-use storage and set aside the question of transmission planning, MISO ultimately focused on transmission planning and set aside the question of dual-use storage.
- MISO Filing: Storage as a Transmission Asset Only (SATOA); dual-use storage should be a market resource
  - To be included in the MISO Transmission Expansion Plan, a SATOA device must demonstrate "a need to resolve the Transmission Issue(s) through the storage facility's function as a SATOA *instead of* as a resource that participates in the Transmission Provider's markets." (Emphasis added)
  - "SATOA may only participate in the Transmission Provider's markets to the extent necessary to receive Energy from the Transmission System and to inject Energy into the Transmission System to provide the services for which the SATOA was included in the MTEP. *SATOA may not otherwise participate in the Energy and Operating Reserve Markets and/or the Planning Resource Auction*." (Emphasis added)

Storage as Transmission: Case Study

- **The 2019 MISO Transmission Expansion Plan (MTEP) was the second regional transmission plan to select energy storage as a transmission asset**
- **Storage as Transmission: Waupaca, WI**
  - Under certain N-1 contingency scenarios, the Waupaca area would be cut off
  - At $12.2 million over 40 years, a 2.5 MW/5 MWh energy storage system, coupled with line sectionalization, was selected over a $13.1 million project to install an additional circuit
  - Expected in-service date: Dec. 2021



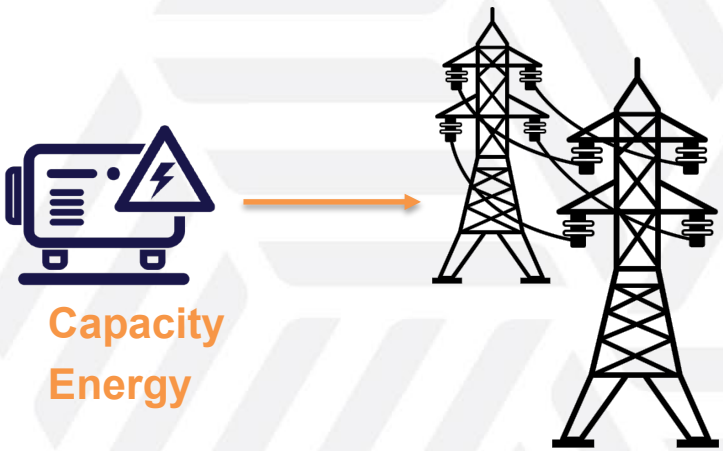
- As a transmission asset, the storage system's costs will be recovered through MISO's FERC-approved transmission system rates, and it will not participate in energy markets.

Storage in Microgrids

Storage and Microgrids: A New Resilience Paradigm

The advent of cost-competitive energy storage options has enabled us to go from:

Mission-critical Resilience



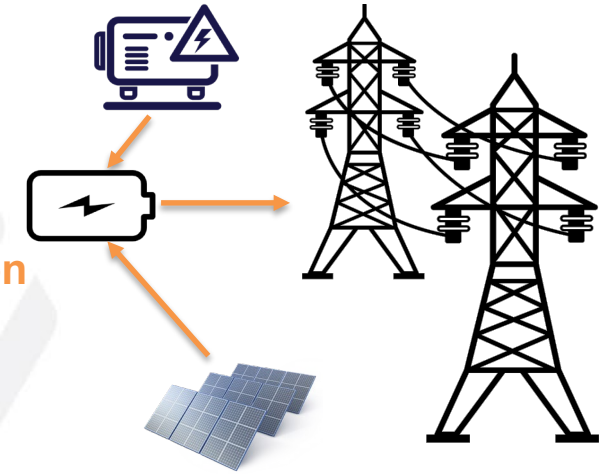
- Capacity
- Energy

- Limited opportunities for grid participation
- High cost
- Limited to facilities in which resilience is mission critical

to

Economic Resilience

- Capacity
- Energy
- Regulation
- Reserves
- Arbitrage
- …



- Increased opportunities for grid participation
- Offsetting revenues reduce system costs
- Viable resilience for broader range of facilities

Questions States Can Ask

- Are planning tools accounting for the granular values and operational characteristics of energy storage technologies?
- Are tariffs and rates in place to incent customers who deploy storage and other distributed energy resources to use those assets in a way that benefits the grid and reduces system costs?
- Can tariffs be used to incent development and grid-beneficial use of microgrids?
- What plans are in place for end-of-life disposal of battery assets?
- Absent resilience metrics, how can planning processes be adapted to meet resilience goals in a cost-effective manner?
- Are there opportunities for furthering state goals through increased engagement in RTO/ISO processes?

Resources for More Information

- Y Xu, CC Liu, KP Schneider, FK Tuffner, DT Ton: Microgrids for Service Restoration to Critical Load in a Resilient Distribution System
- Schneider et al., Preliminary Design Process for Networked Microgrids
- M Armendariz et al., Coordinated Microgrid Investment and Planning Processes Considering the System Operator
- JB Twitchell, RS O'Neil, MT McDonnell, Planning Considerations for Energy Storage in Resilience Applications
- B Ward et al., The Advanced Microgrid: Integration and Operability

- PNNL energy storage site: https://www.pnnl.gov/energy-storage
- Sandia National Laboratories energy storage site: https://www.sandia.gov/ess-ssl/
- Storage resources from Berkeley Lab's Electricity Markets and Policy Department: https://emp.lbl.gov/publications?f%5Bsearch%5D=storage
- U.S. DOE's grid-interactive efficient buildings website: https://www.energy.gov/eere/buildings/grid-interactive-efficient-buildings

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Storage for Integration and Hybrid Power Plants

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Integration

Integration Challenges Include Variability and Contribution to Resource Adequacy

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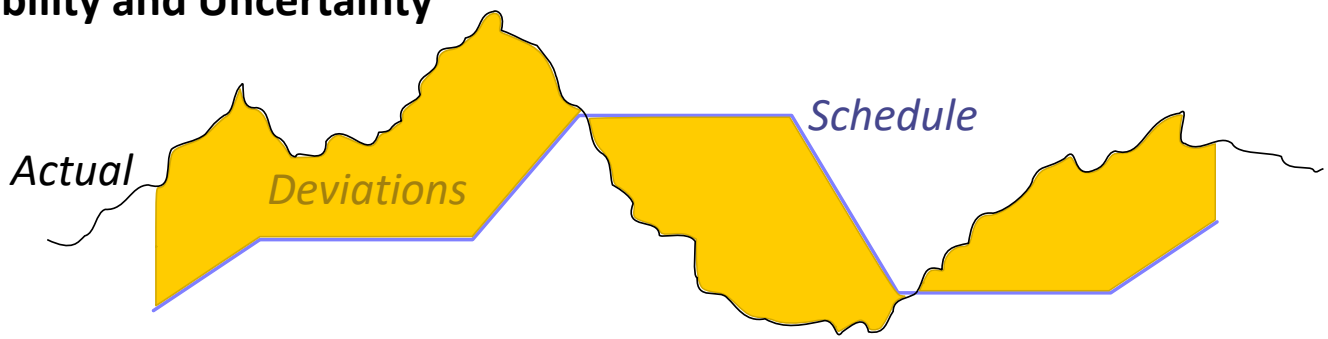
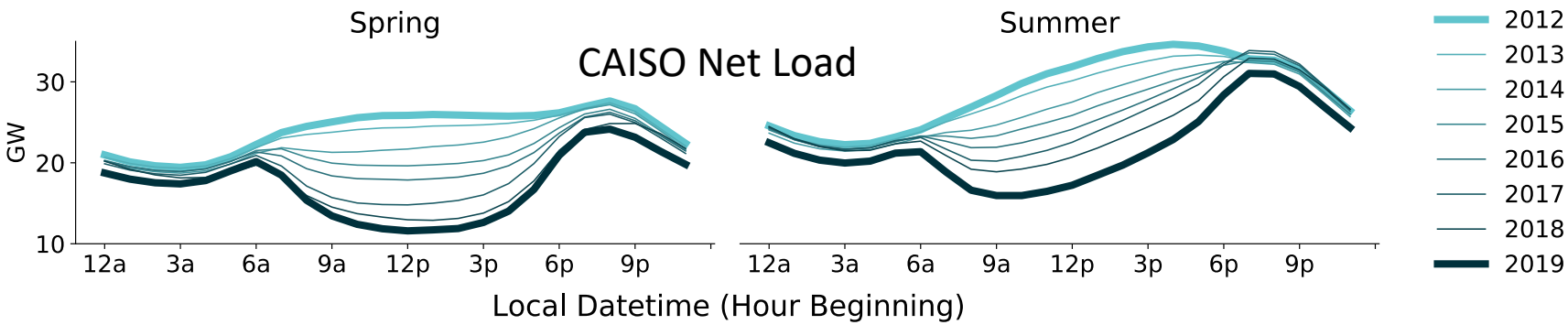
Variability and Uncertainty



Because of increased variability and uncertainty, addition of variable renewable resources increases deviations between schedules and actuals.

Contribution to Resource Adequacy



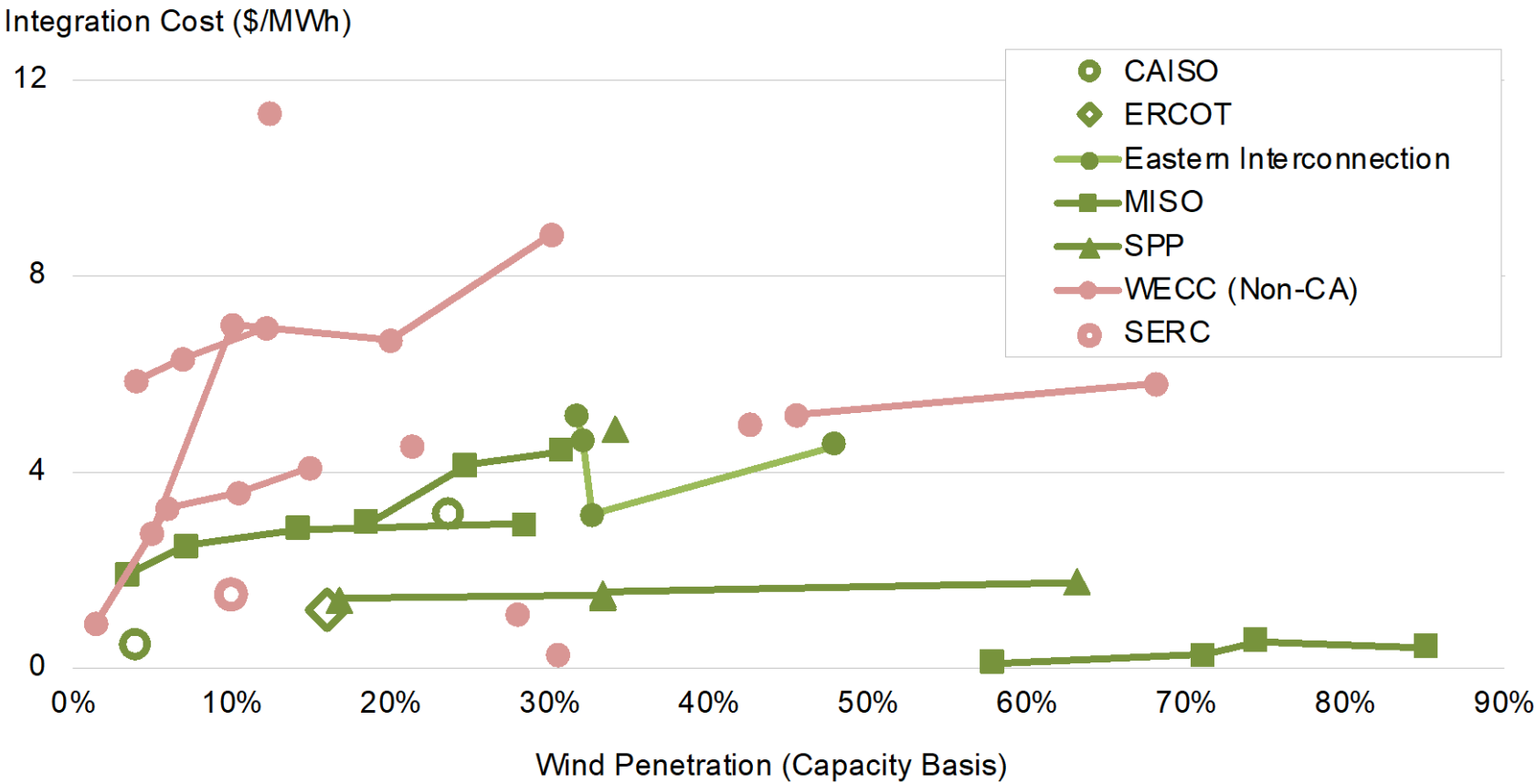
Resource adequacy contribution of solar declines as peak net load periods shift from mid-afternoon to early evening after sunset.

Integration: Variability and Uncertainty

Survey of Integration Cost Studies

- Numerous entities conduct studies to estimate integration costs of wind and solar.
- Integration cost estimates vary from study to study, due in part to differences in:
  - Resource mix
  - Institutional setting
  - Definitions of integration costs and calculation methodology
- Some methods are better suited to the context of an Integrated Resource Plan than others:
  - What aspects of variable renewables are already captured in standard grid planning tools, and what aspects need to be separately estimated via an integration cost?

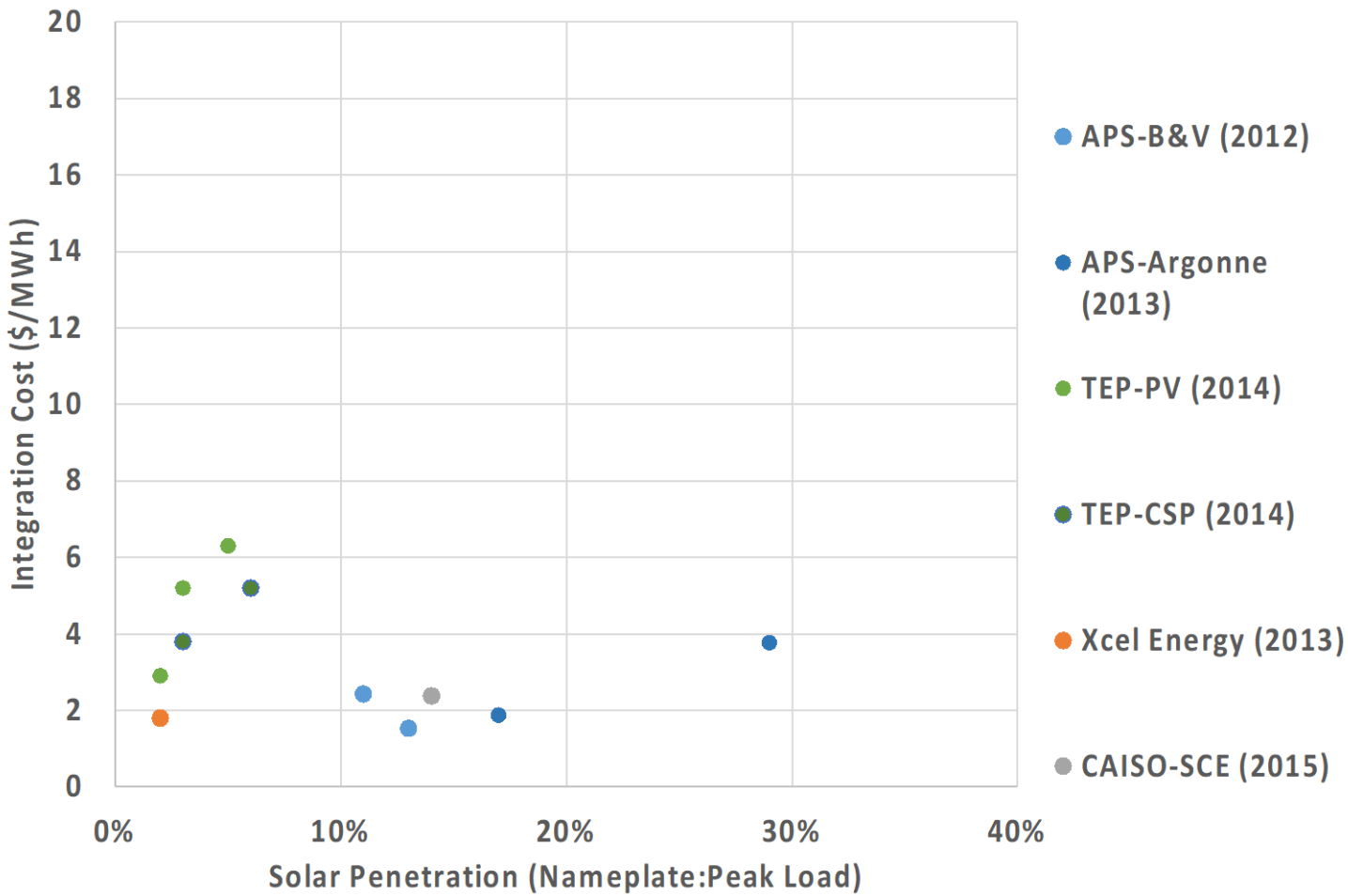
US Wind Integration Cost Estimates



For more see: Wiser et al. "Wind Technologies Market Report"(2020)

US Solar Integration Cost Estimates

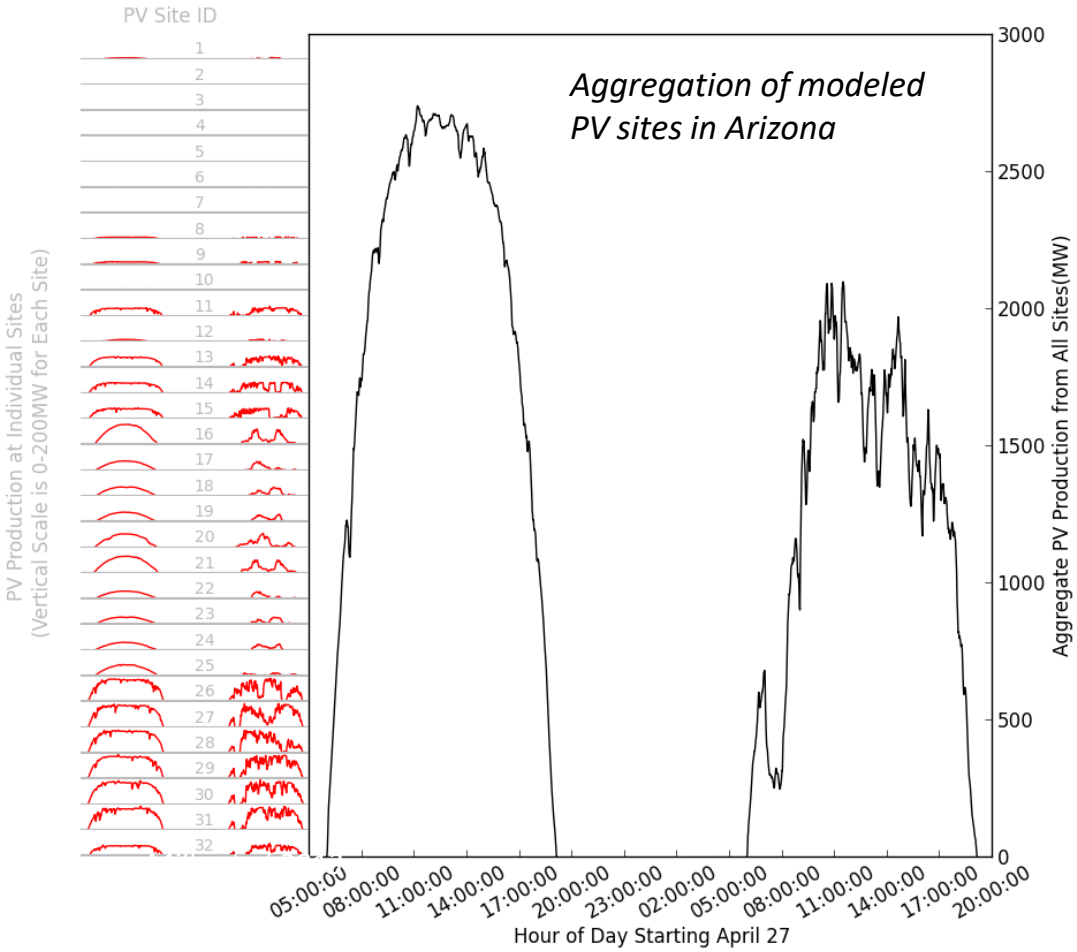
Figure 5. Solar integration costs by level of penetration



Source: Synapse (2015)

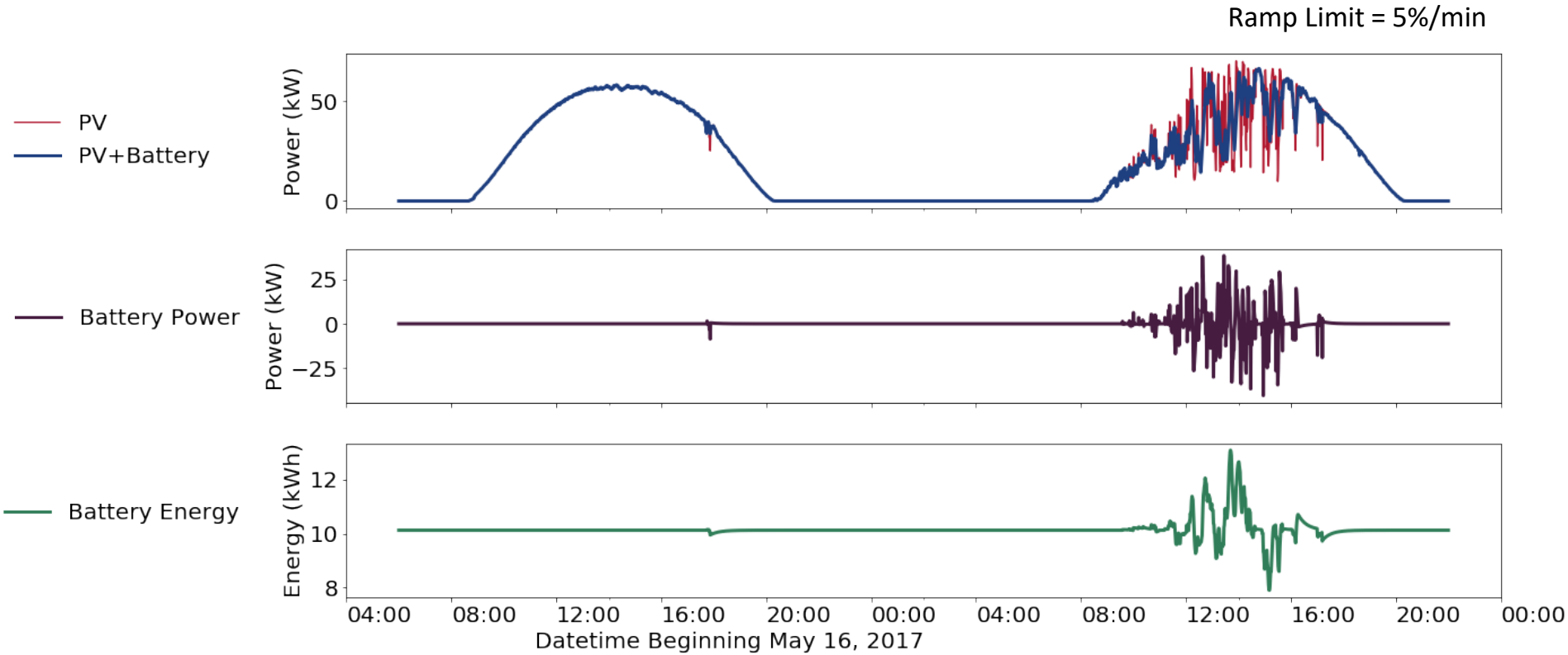
Aggregation of PV Smooths Production

- Aggregate output of multiple sites is smoother than individual sites
- Degree of smoothing depends on the time-scale of variability (e.g., minutes to hours) and the distance between sites
- Costs of managing short-term variability are considerably lower with aggregation



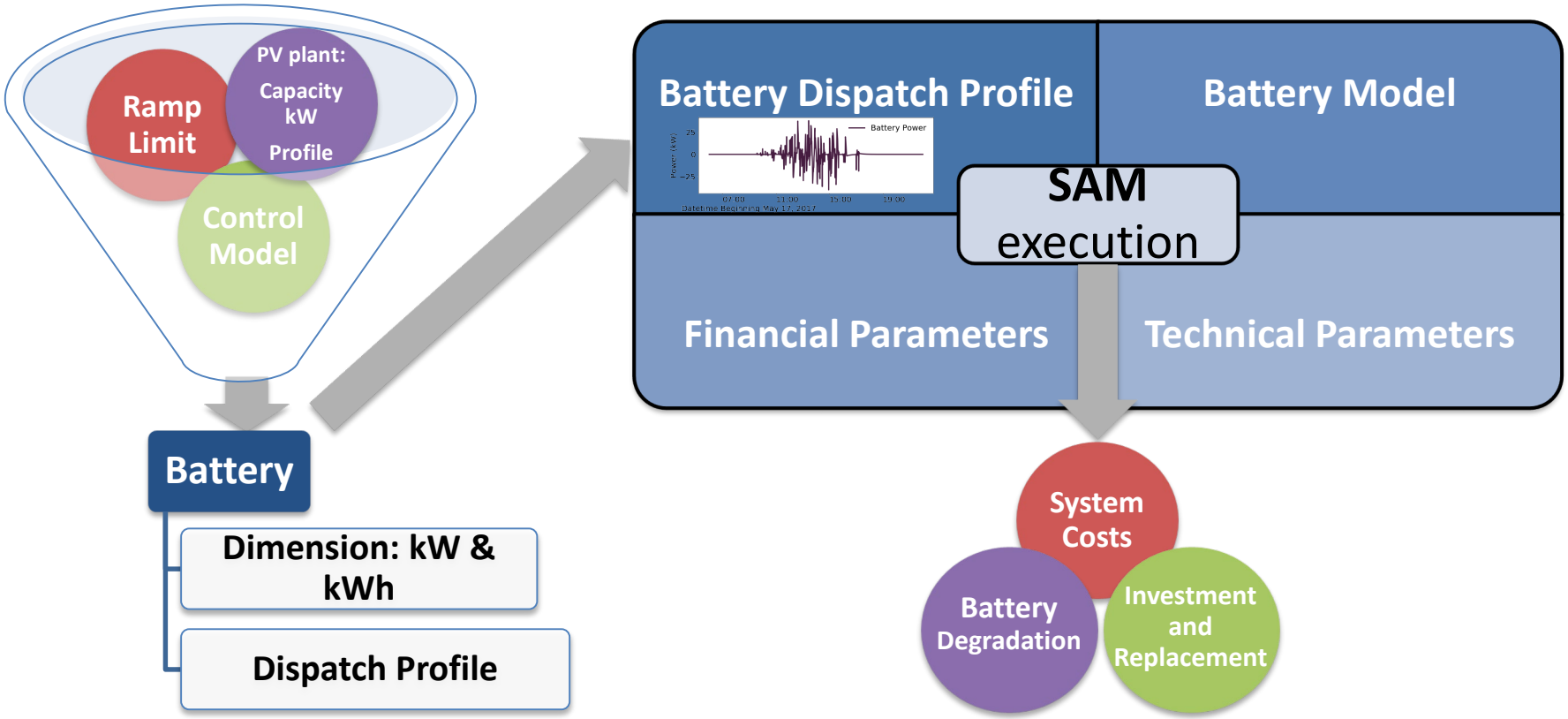
For more see: Mills et al. (2013)

Could Storage Be Used to Smooth PV Output Instead?

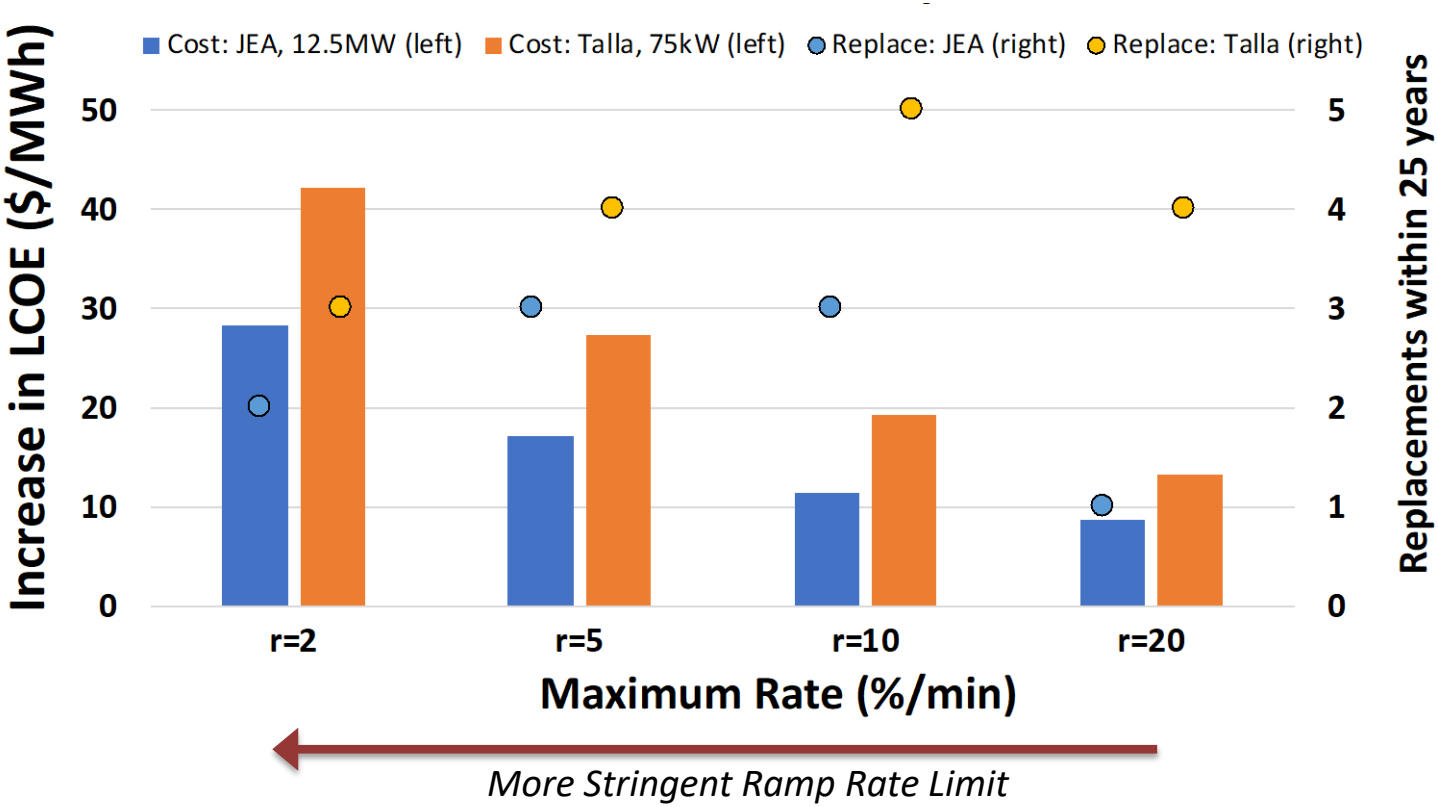


- Size the battery for worst fluctuation: ~15 min duration battery to meet 5% ramp limit
- Dispatch battery using a simple daytime charging ramp control model

Use NREL's SAM to Analyze Battery Degradation and Costs for Different Ramp Rate Limits



Incremental Battery Costs Increase with Stringency of Ramp Rate Limits



Battery Costs (Fu 2018):
= $285/kWh + $106/kW

Battery nameplate equal to solar nameplate

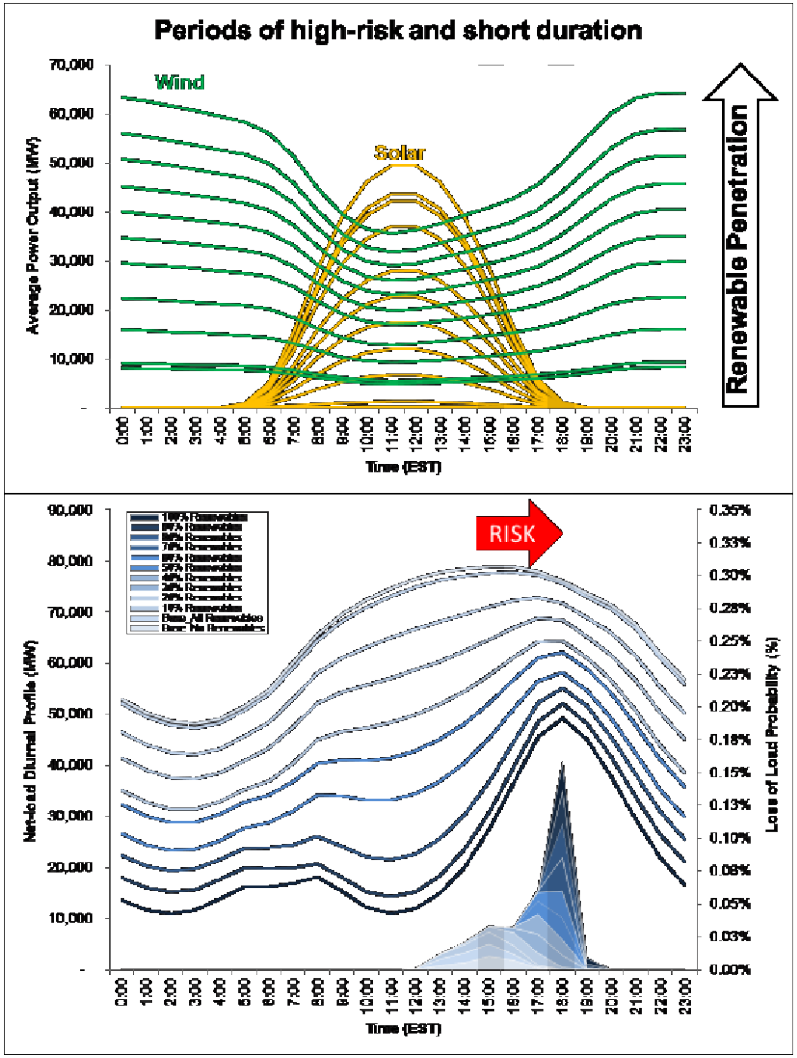
Discount rate of 6.4%

Replacement when battery degrades to 80% of energy capacity

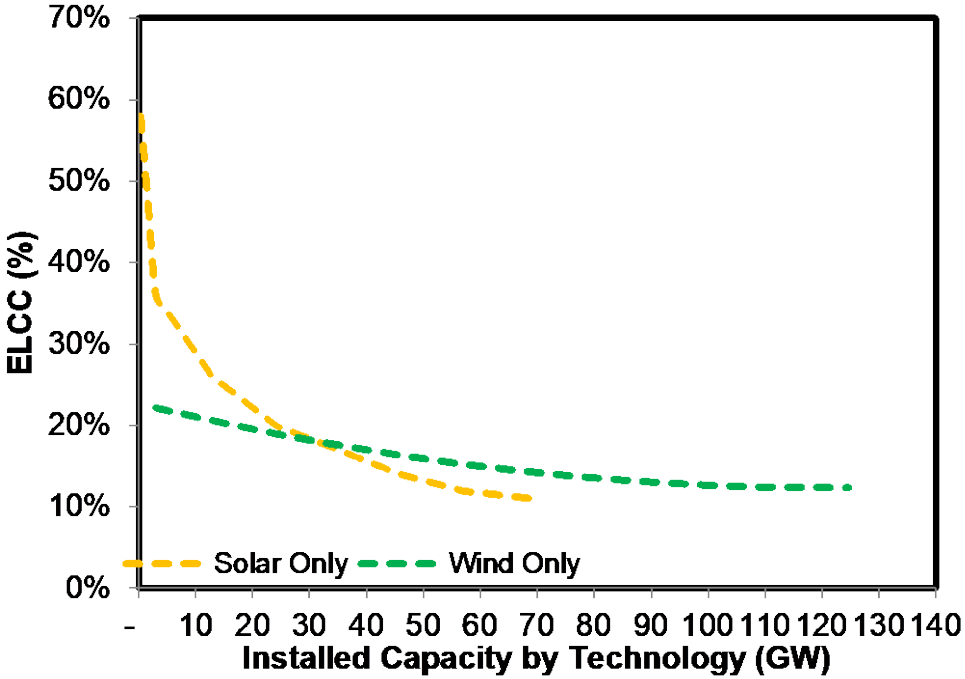
Increase in LCOE represents incremental cost per unit of solar energy to meet ramp limit

Integration: Resource Adequacy

Contribution of Wind and Solar to Resource Adequacy Declines with Increasing Penetration

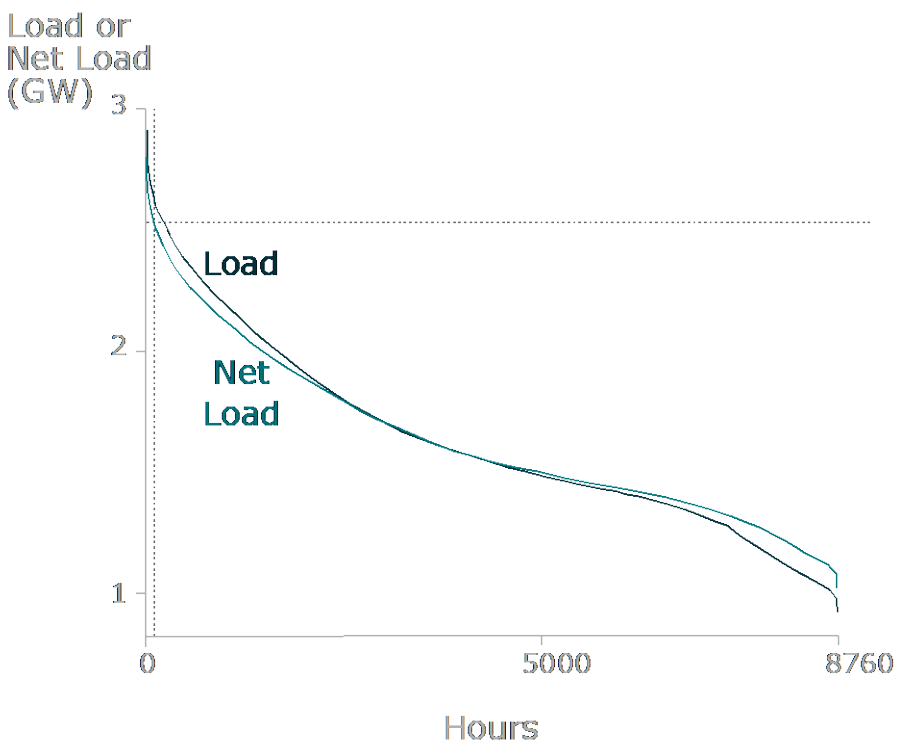


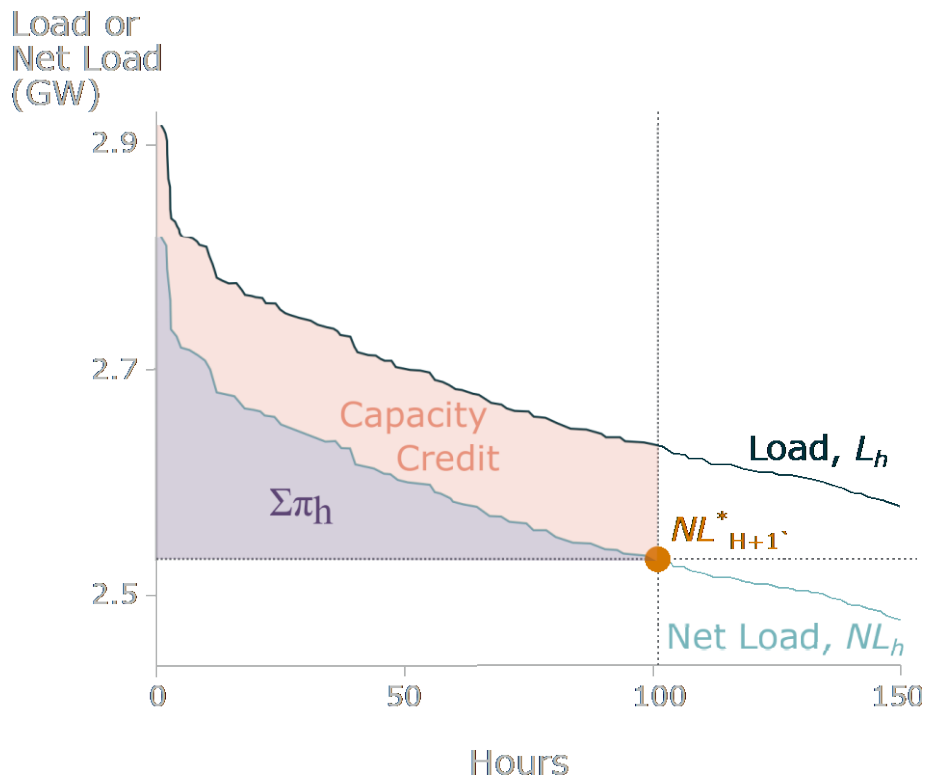
MISO Resource Adequacy Analysis



Source: Aditya Jayam Prabhakar, MISO

Storage Dispatch to Maximize Capacity Credit of Storage

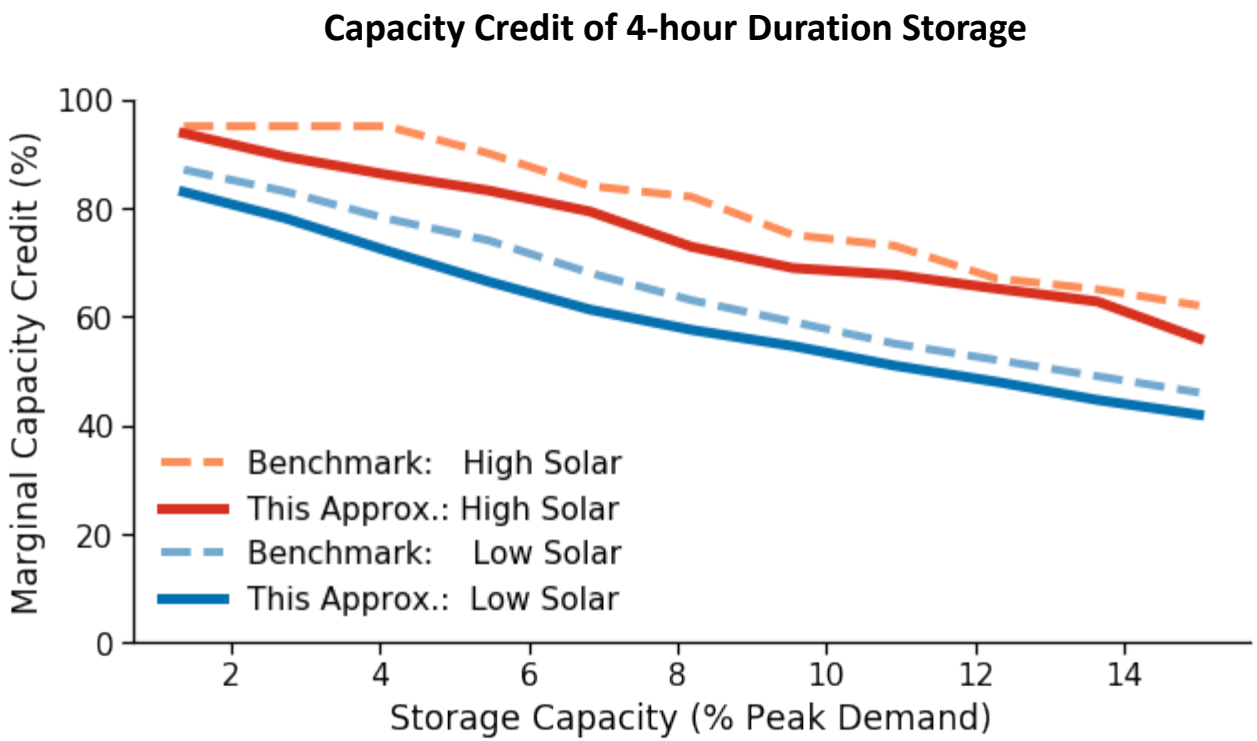




Define capacity credit similar to NREL's "Resource Planning Model": difference of the highest peak load hours and highest peak net load hours. Use a simple linear model to find the storage dispatch that maximizes this capacity credit.

For more see: Mills et al. (2020)

Approximation Validated With a Probabilistic Benchmark from a Utility in the Western US



Probabilistic benchmark is a detailed Loss of Load Probability model used by the utility for planning.

The Benchmark shows the utility's estimated ELCC of 4-hour duration storage with a reliability criteria of 2.4 LOLH/yr.

Approximation method uses the utility's net load data to calculate the capacity credit of storage.

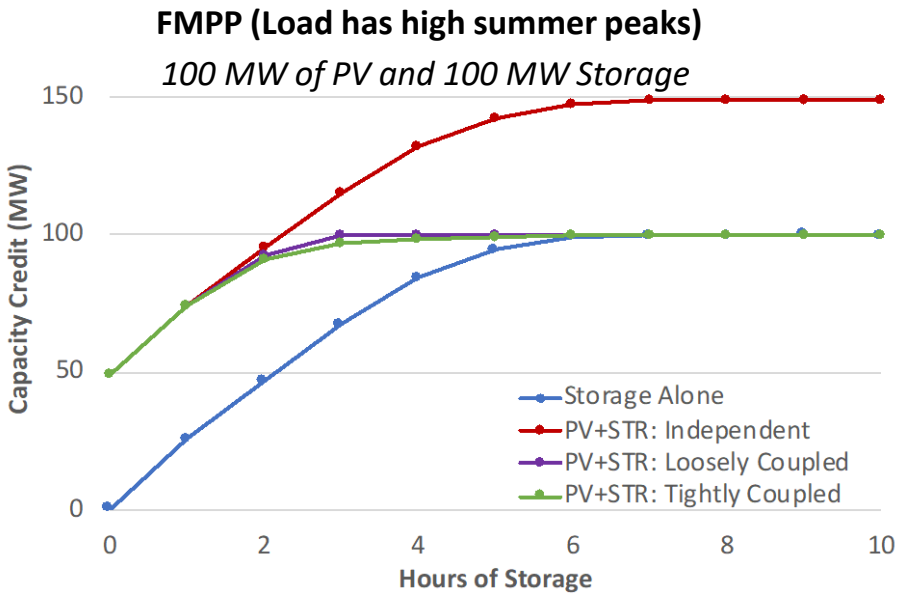
Both approaches show a declining capacity credit of 4-hour duration storage, and increase in capacity credit with high system-wide solar.

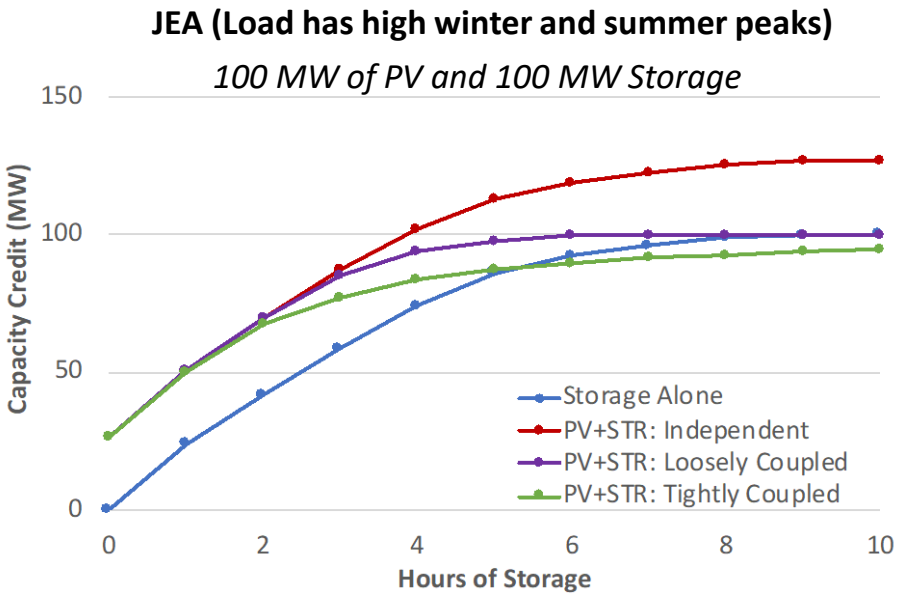
For more see: Mills et al. (2020)

PV + Storage Configurations

Configuration	Description	Share Equipment?	Source of Electricity for Storage
Independent	PV and storage do not share equipment and storage is charged from the grid	No	Grid
Loosely Coupled	PV and storage both connect on the DC side of shared inverters, but storage can charge from storage or the grid	Shared Inverter	Grid or PV
Tightly Coupled	PV and storage connect on DC side of shared inverters, and storage can only charge from PV	Shared Inverter	Only PV

Capacity Credit of Solar+Storage Systems With Large Batteries Depends on Configuration





- Capacity credit of PV+Storage can be limited by the shared inverter when DC coupled
- No significant difference for loosely vs. tightly coupled

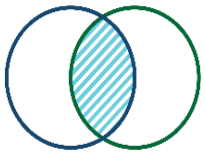
- For a load with high winter peaks, differences between loosely and tightly coupled are more important
- Restricting storage to charge only from solar can lead to a lower capacity credit than storage alone

For more see: Mills et al. (2020)

Hybrid Power Plants

Pros and Cons of Hybridization vs. Developing Standalone Battery and Generator Plants

GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy



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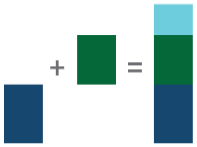
Cost Synergies

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



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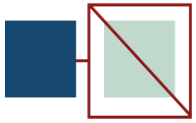
Market Value Synergies

- 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.



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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 Investment Tax Credit (ITC), and some market design rules that may inefficiently favor hybridization over standalone plants

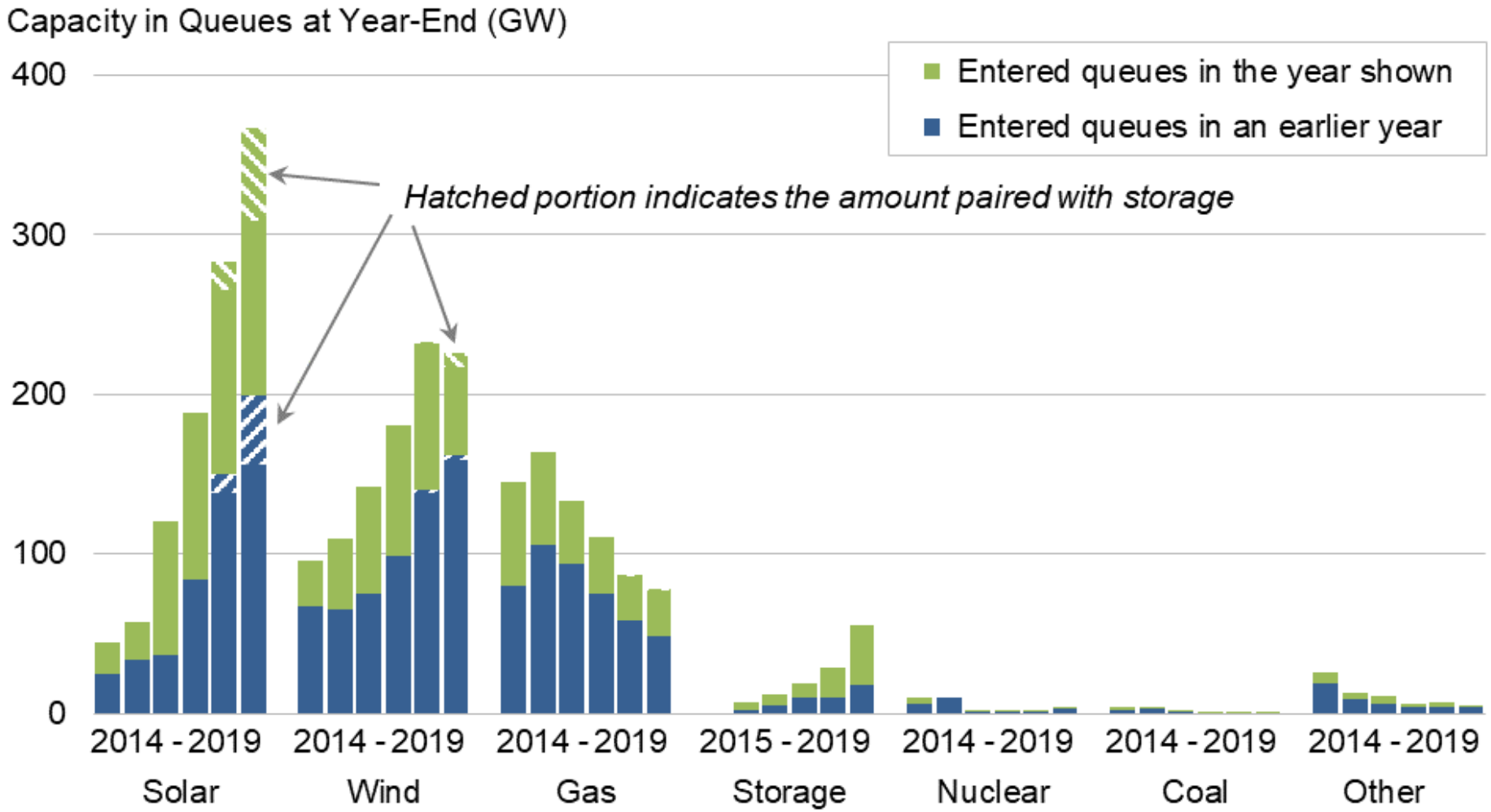
Possible disadvantages of hybridization include operational and siting constraints

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

For more see: Gorman et al. (2020)

Hybrid Power Plants: Longer-term Pipeline Interconnection Queues at end of 2019

Commercial Interest in Solar, Wind and Storage Has Grown, Including Via Hybridization

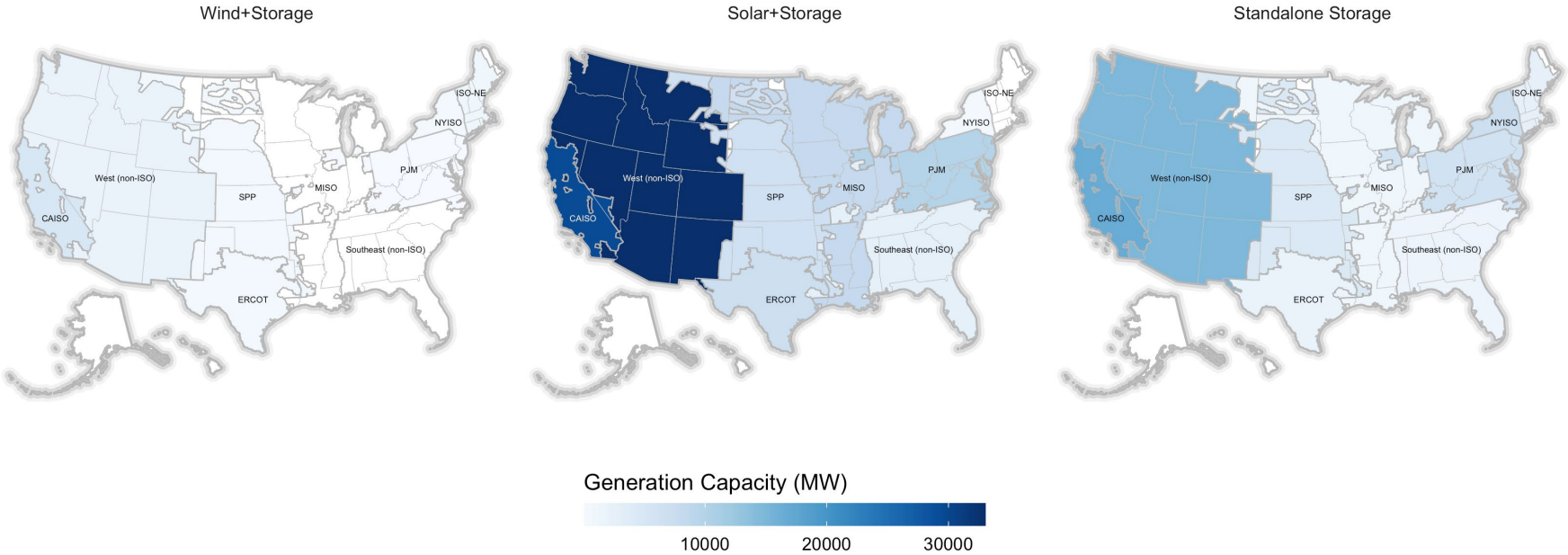


Source: Berkeley Lab review of 37 ISO and utility interconnection queues

Note: Not all of this capacity will be built

For more see: Wiser et al. (2020)

Solar+Storage is Dominant Hybrid Type in Queues; CAISO & West of Greatest Interest So Far



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

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

For more see: Wiser et al. (2020)

Hybrids Comprise a Sizable Fraction of all Proposed Solar Plants in Multiple Regions

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

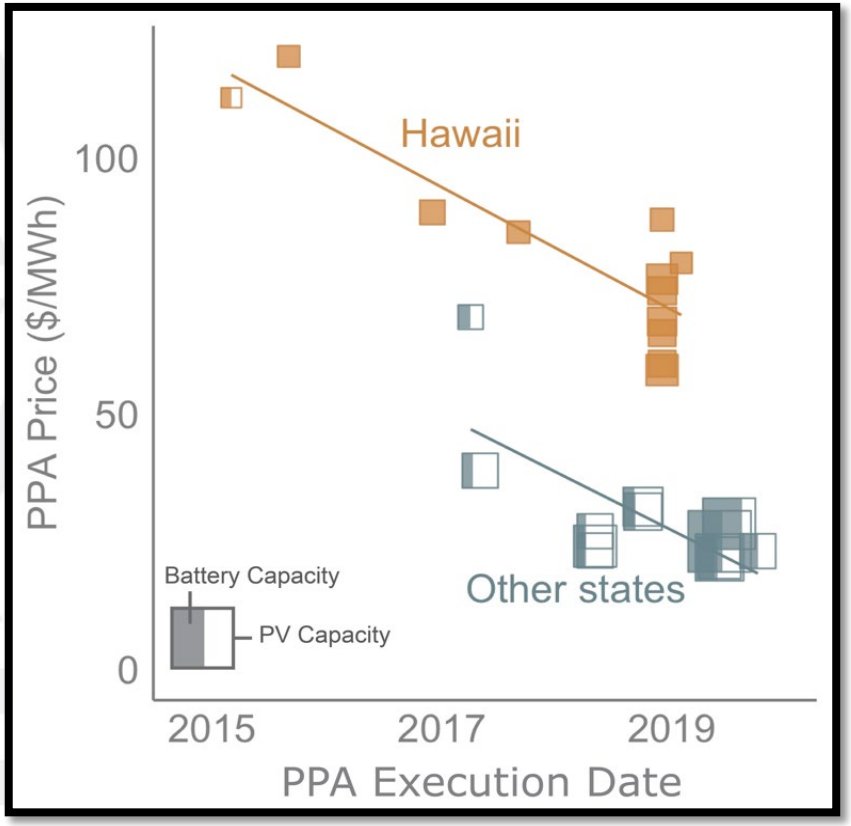
- **Solar** hybridization relative to total amount of solar in each queue is highest in CAISO (67%) and non-ISO West (50%), and is above 10% in PJM, MISO, ERCOT
- **Wind** hybridization relative to total amount of wind in each queue is highest in CAISO (50%), and is less than 7% in all other regions

For more see: Wiser et al. (2020)

Hybrid Power Plants: Cost and Valuation of Hybrid Projects

Levelized Power Purchase Agreement (PPA) Prices for PV-Battery Projects are Declining

- ***Hawaiian*** project 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

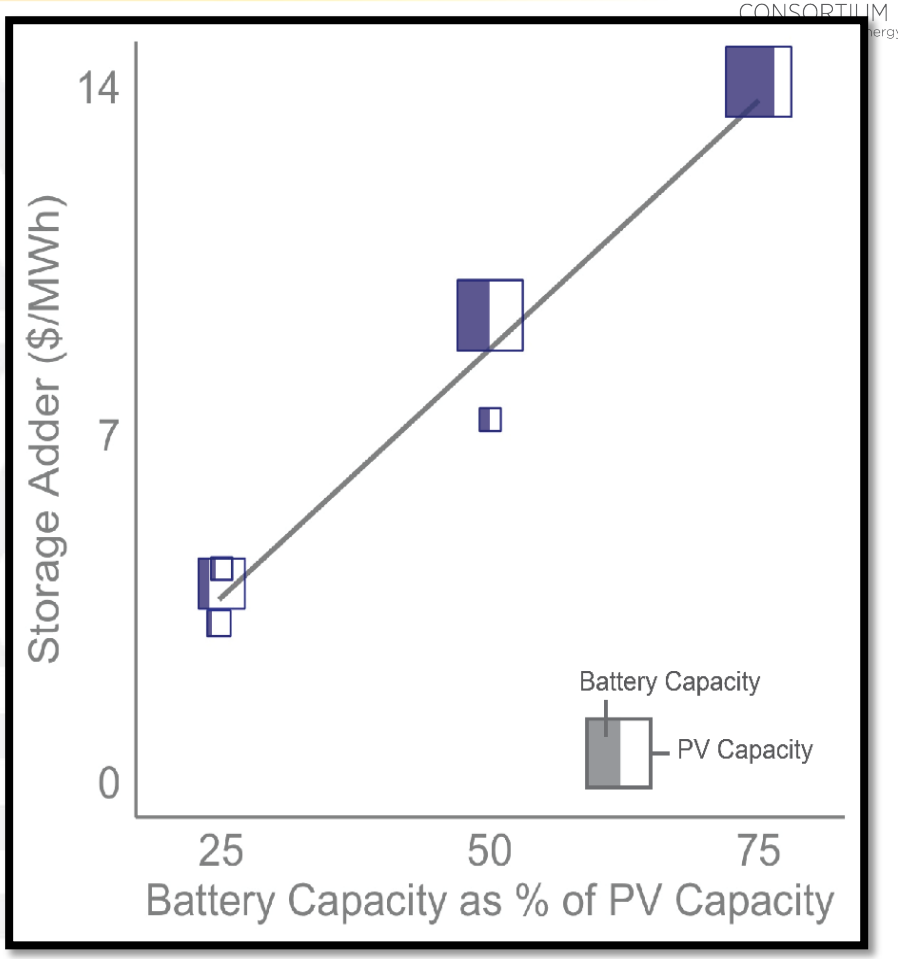


For more see: Gorman et al. (2020)

Battery PPA Premium for 4-hr Duration Storage Is ~$4-14/MWh Depending on Battery Size Relative to PV Capacity

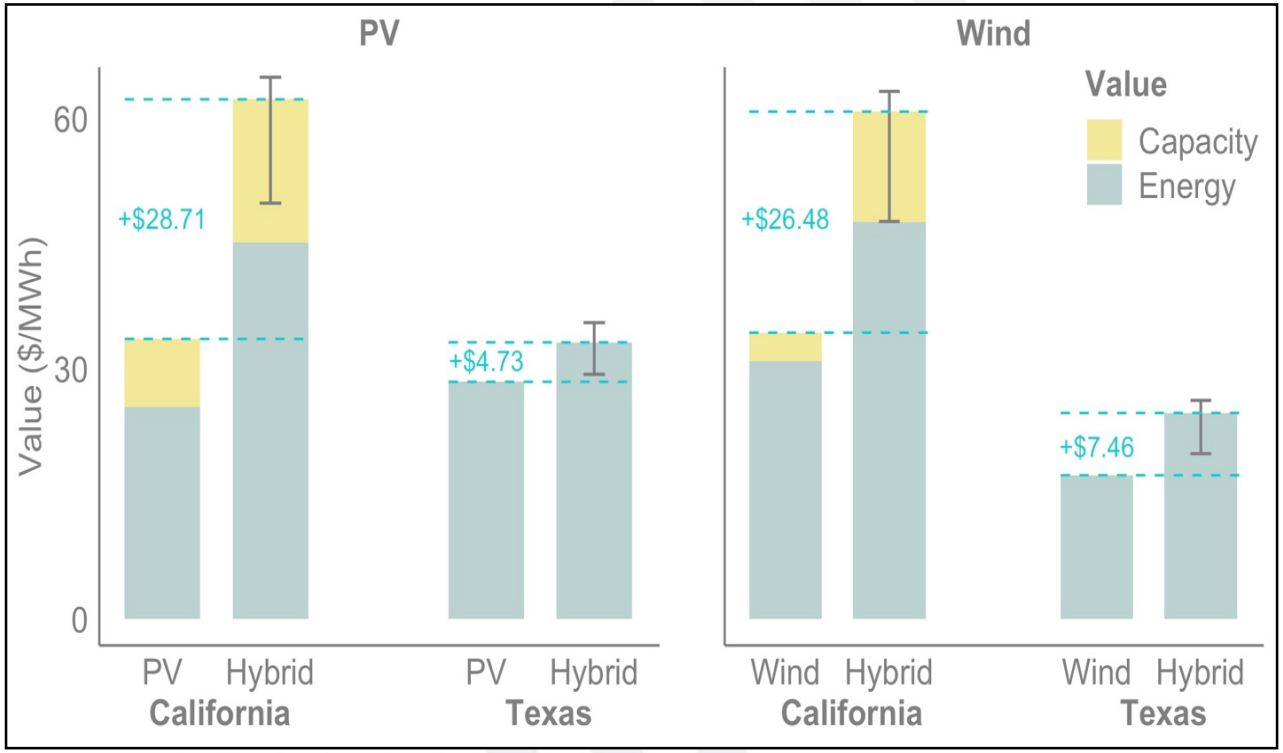
- ***Six of the 23*** PV-battery PPAs provide information to enable calculation of a ***battery adder*** (e.g., through separate capacity payments for battery component)

- 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



For more see: Gorman et al. (2020)

Hybrid Projects in CA Would Have Added More Value Than in TX, Considering Energy & Capacity Prices from 2016-2018

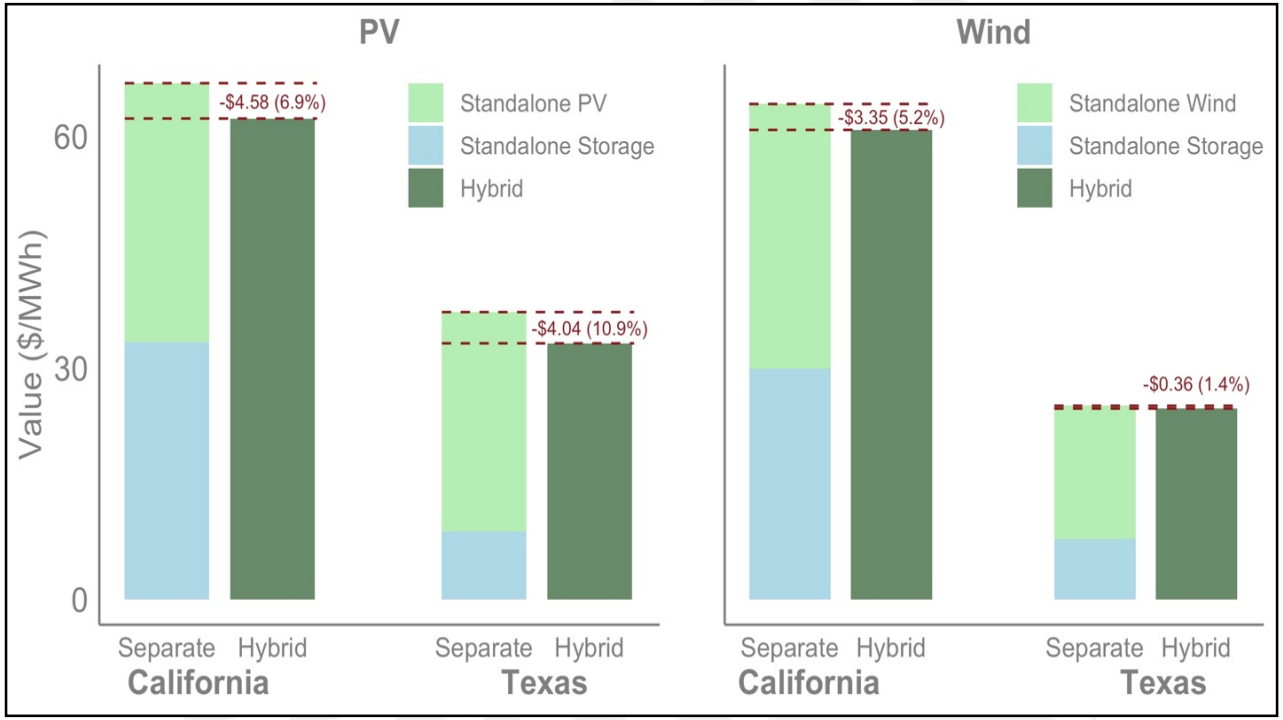


(1) Upper gray bar represents 15-minute perfect foresight dispatch case
(2) Lower gray bar represents day ahead persistence case, where storage is dispatched based on previous day's optimal schedule

- ***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

For more see: Gorman et al. (2020)

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

For more see: Gorman et al. (2020)

Key Questions States Can Ask

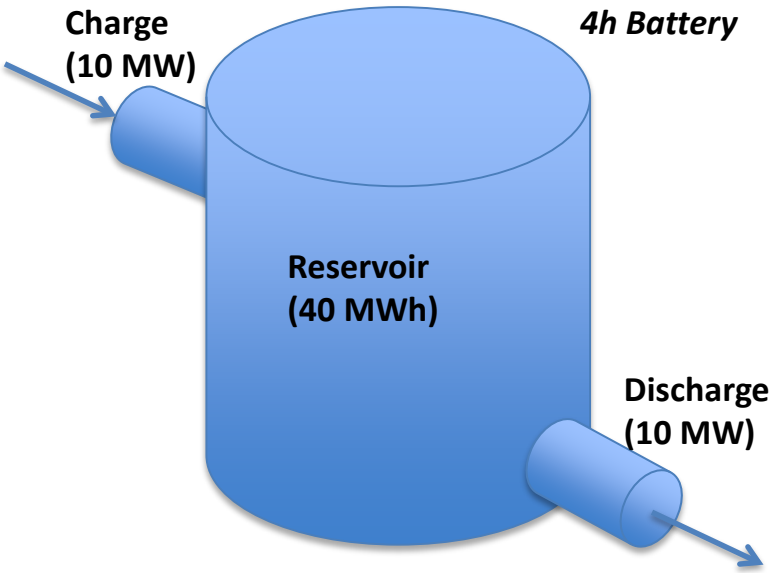
- How do you take advantage of geographic diversity to manage challenges with variability and uncertainty?
- How much storage is needed to manage aggregate variability and uncertainty compared to managing it at each individual plant?
- How does your resource adequacy assessment account for potential changes in the contribution of resources with increased deployment?
- How do the costs and benefits of hybrid configurations compare to standalone configurations?
- What potential cost or value synergies of hybrids do you account for in planning and procurement?
- What are the consequences of allowing or preventing grid charging with hybrids? Does grid charging affect eligibility for state policies (e.g., Renewable Portfolio Standards, Clean Energy Standards)?

Resources for More Information

- Mills, A., Botterud, A., Wu, J., Zhou, Z., Hodge, B-M., and Heany, M. "Integrating Solar PV in Utility System Operations." Berkeley, CA: Lawrence Berkeley National Laboratory, 2013. https://dx.doi.org/10.2172/1164898
- Wiser, R.H., Bolinger, M. et al. "Wind Technologies Market Report: 2020 Briefing" Berkeley, CA: Lawrence Berkeley National Laboratory, August 2020. https://emp.lbl.gov/wind-technologies-market-report
- Synapse "A Solved Problem: Existing measures provide low-cost wind and solar integration", August 2015. http://www.synapse-energy.com/sites/default/files/A-Solved-Problem-15-088.pdf
- Wiser, R. H., M. Bolinger, Will G., J. Rand, S. Jeong, J. Seel, C. Warner, and B. Paulos. "Hybrid Power Plants: Status of Installed and Proposed Projects." Berkeley, CA: Lawrence Berkeley National Laboratory, July 30, 2020. https://escholarship.org/uc/item/9979w72n.
- Gorman, W., A. Mills, M. Bolinger, R. Wiser, N. G. Singhal, E. Ela, and E. O'Shaughnessy. "Motivations and Options for Deploying Hybrid Generator-plus-Battery Projects within the Bulk Power System." The Electricity Journal 33, no. 5 (June 1, 2020): 106739. https://doi.org/10.1016/j.tej.2020.106739.
- Mills, A. D., and P. Rodriguez. "A Simple and Fast Algorithm for Estimating the Capacity Credit of Solar and Storage." Energy, August 15, 2020, 118587. https://doi.org/10.1016/j.energy.2020.118587.

A Note on Storage Sizes

- Batteries have a maximum rate of charge or discharge (the MW nameplate rating).
- And they have a limited amount of energy that can be stored in a reservoir (MWh rating).
- We refer to the size of the battery based on the number of hours that it can be discharged at its full rate of discharge.
- Here a 10 MW battery can provide 10 MW of power or consume 10 MW of load.
- If the 10 MW battery can store 40 MWh of electricity then we call it a 4-hour battery.



Real batteries may not be able to fully charge and discharge (i.e. may not achieve 100% depth of discharge). We use the* ***accessible energy**, which may be less than the rated energy.*