Energy Storage Panel

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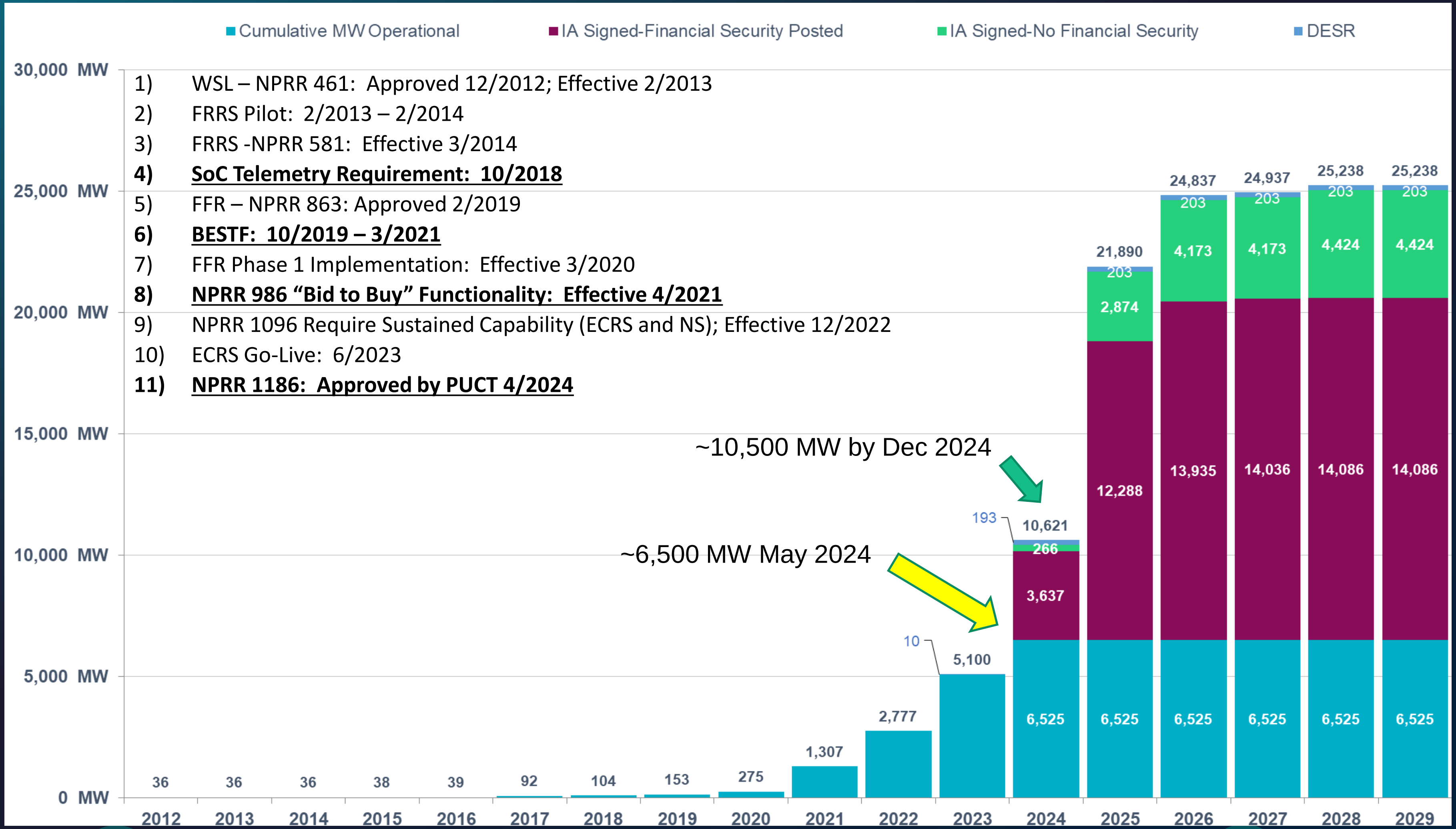
Battery Additions by Year (as of April 30, 2024)



MORA June 2024: 59 DESRs total = 568 MW
September 2019 DGR moratorium lifted 1-4-22

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Battery Additions by Year (as of April 30, 2024)

Fuel Type/ Technology Type	SS and FIS Completed IA (MW)	Grand Total In Progress (MW)
Combined Cycle	146	3,568
Combustion Turbine	732	10,755
Steam Turbine	14	694
ICE (Internal Combustion Engine)	368	556
Wind	6,036	**32,956**
Solar	26,878	**152,917**
Compressed Air Storage	0	0
Battery	11,742	**145,000**
Other (Includes Pumped Hydro 1,232 MW)	0	2,332
Total	45,916	348,778

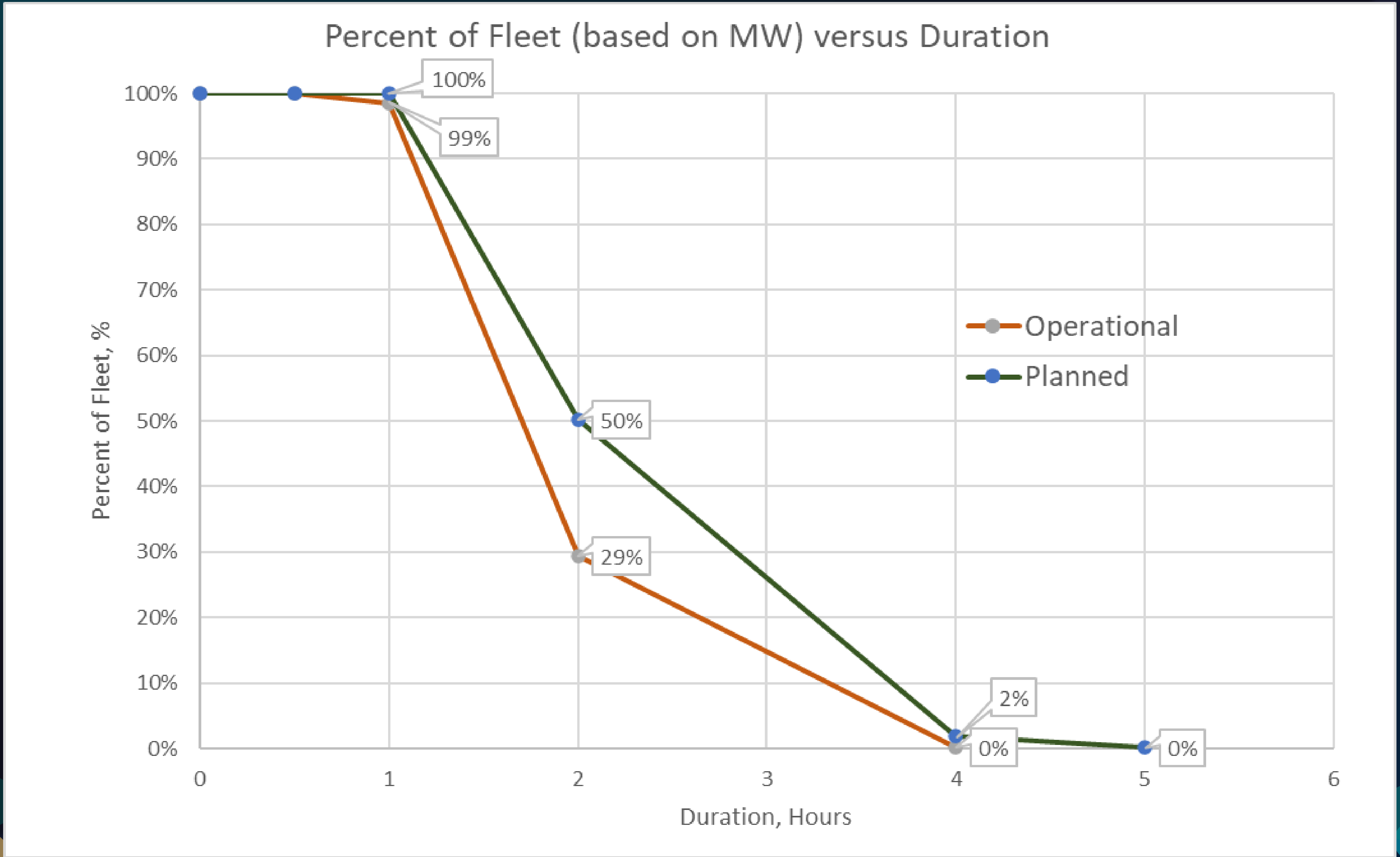
The battery total of 145,000 MW includes requests of 630 MW of distribution connected.

It does not include requests of approximately 11,000 MW of "Self-Limiting Facility" batteries.

SS = Security Screening Study
FIS = Full Interconnection Study
IA = Interconnection Agreement

Report Run Date	Battery Qty
Dec 1, 2023:	124,941 MW
Dec 1, 2022:	78,746 MW
Dec 1, 2021:	46,946 MW
Dec 1, 2020:	21,404 MW
Dec 1, 2019:	7,214 MW
Dec 1, 2018:	2,048 MW
Dec 1, 2017:	0 MW

Duration Information (as of March 31, 2024)



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Operating Day May 8, 2024

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Energy Storage Integration in Electricity Markets

Challenges and opportunities for operating energy storage in electricity markets

Erik Ela
Program Manager,
EPRI

Outstanding challenges to better integrating electric storage resources into wholesale electricity markets

Day-ahead market

- Computational advances to simplify SoCM
- ESR use and SoCM in RUC
- Enhanced energy representation for adequate SoC calculation

Real-time market

- Approaches to augment incentive compatibility of multi-interval RTSCED problems
- Re-optimizing the day-ahead with shorter horizon

Ancillary services market

- Impact and feasibility of A/S on SoCM
- Price formation impacts of sustained duration performance requirements for A/S with storage

Miscellaneous

- Representation of degradation
- Market power mitigation
- Participation models for LDES
- Price formation in high VRE systems with storage

FERC Order No. 841: Summary

- ISOs must include a **participation model** for electric storage resources (ESRs) that allows them to participate in energy, ancillary service, and capacity markets when technically capable of doing so.
- ESRs must be eligible to **set the wholesale price** as both a buyer and seller when the marginal resource.
- ISOs must allow a minimum size requirement that is at most **100 kW.**
- Sale of energy that is stored from purchases in the wholesale market must be **sold at wholesale nodal prices.**
- ISOs must allow **self-management** of state of charge (SOC).
- ISOs must **account for physical parameters** of ESRs through bidding or otherwise – these include SOC parameters.

Electric Storage Participation in Markets Operated by Regional Transmission Organizations and Independent System Operators, FERC Order 841, Final Rule, 162 FERC 61, 127 (February 15, 2018) ("Order No. 841").

SoC Management: Options

Self-Schedule

- ESR self-dispatches its output and is insensitive to price.

Allowed by all ISOs/RTOs

Self-SOC-Management

- ESR provides an offer curve analogous to traditional resources.
- ESRs can set offers to ensure desired and feasible SOC.
- ISO schedules without SOC consideration

CAISO, NYISO ESR/PSH

SOC-Management-Lite

- ESR provides an offer curve.
- ISO does not schedule ESR if it would lead to infeasible SOC.
- Schedules are not optimized across time to optimize ESR schedules.

SPP, ISO-NE, MISO, PJM

ISO-SOC-Management

- ESR may or may not provide an offer curve.
- SO ensures SOC feasibility and optimizes ESR schedules across time to minimize cost.

CAISO, NYISO ESR, PJM PSH

ISO scheduling responsibility / theoretical economic efficiency and reliability benefits / complexity →

← **ESR asset owner participation responsibility and flexibility / computational efficiency**

The Storage Forecast Dilemma

Lots of data. Potentially "bad data" vs. good data, but not much of it…

Storage Price Formation Game

ISO-directed vs. self-directed

When should the ISO get involved?

Holding back capacity is called "reserve"

What is holding back energy called?

What does a reserve offer mean?

Does a high offer mean:

"I know there is a high offer later, so I don't want to operate prematurely"

"I know I can set the price for this interval, so I better set it high"

Multi-interval real-time markets conundrum

Advisory prices vs. binding prices

Pricing based on binding decision

Price Formation becomes key for future decision-making with ESRs

An Analogy

The way that storage impacts price formation, especially with large amounts of storage, and a dominant zero-fuel-cost resources, is analogous to how transmission impacts on locational prices. There are important differences, however. The conceptual view below can be used for either case. Because of the unique way in which power flows as defined by Kirchhoff's laws, we encourage readers to instead think of zonal, transportation-based flow with a radial network structure.

Concept	X	Y	If all Yn are limitless (ignoring losses)	Other price differences
Locational Pricing	Zones	Transmission Interface Constraints	All locations have the same price (based on marginal resource across all zones)	Transmission losses
Temporal Pricing	Intervals	Energy Storage SOC constraints	All intervals have the same price (based on marginal resource across all intervals)	Storage round-trip efficiency losses

$0/MWh prices when there is no curtailment, shortage pricing when there is no shortage

How do Energy Storage Resources Impact Wholesale Electricity Prices in Future Systems with 100% Zero Fuel Cost (ZFC) Resources? EPRI, Palo Alto, CA: 2022. 3002024549.

Breakthrough Low-cost, Multi-day Energy Storage

Jason Houck
Senior Manager of Policy Strategy,
Form Energy

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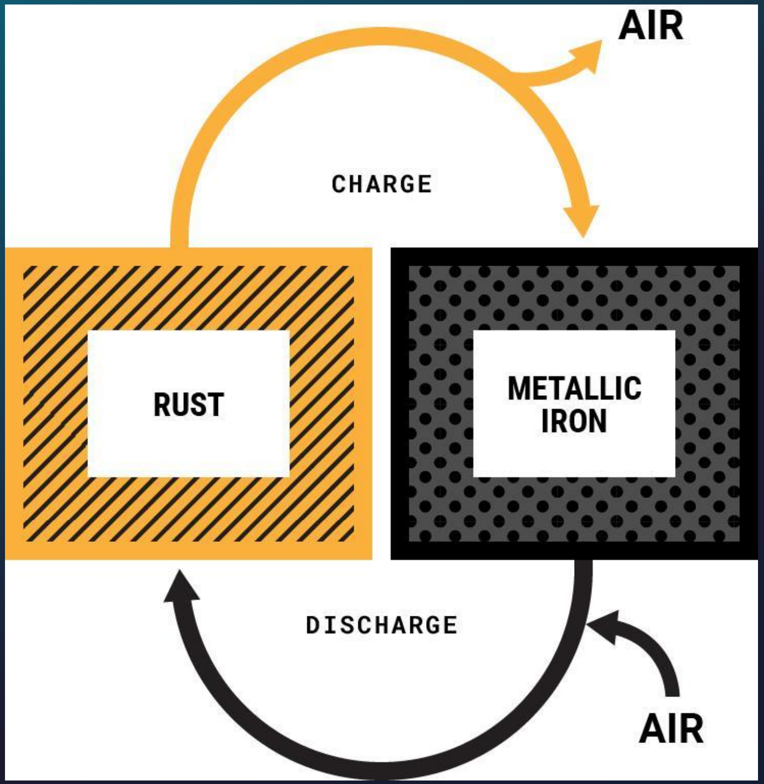
Rechargeable iron-air batteries are the best technology for multi-day storage

Form's 100-Hour Reversible Rust Battery



COST

Lowest cost rechargeable battery chemistry.
Chemistry entitlement <$1.00/kWh

SAFETY

No thermal runaway (unlike li-ion)
Non-flammable aqueous electrolyte

SCALE

Iron is the most globally abundant metal
Easily scalable to meet TW demand for storage

DURABILITY

Iron electrode durability proven through decades of life and 1000's of cycles (Fe-Ni)

What makes up a Form Energy system

Modular design enables easy scaling to GWh systems

Cell

Electrodes + Electrolyte

Smallest **Electrochemical** Functional Unit

Battery Module

~50 **Cells**

Smallest Building Block of **DC** Power

Enclosure

~5 **Modules**

Product Building Block with **integrated module auxiliary systems**

Power Block

~3.5 MW / 350 MWh

<2 acres

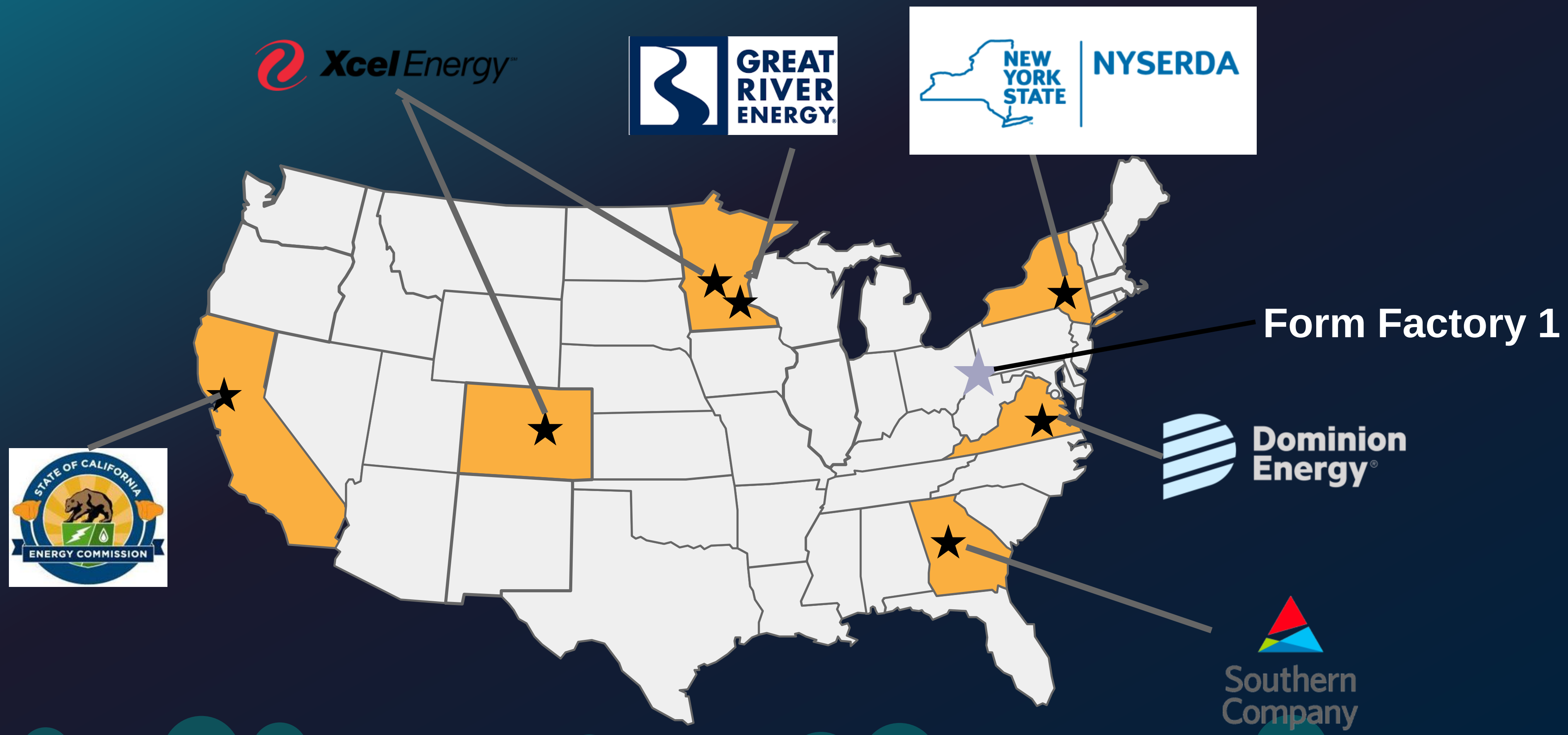
Smallest independent system and **AC Power** building block

System

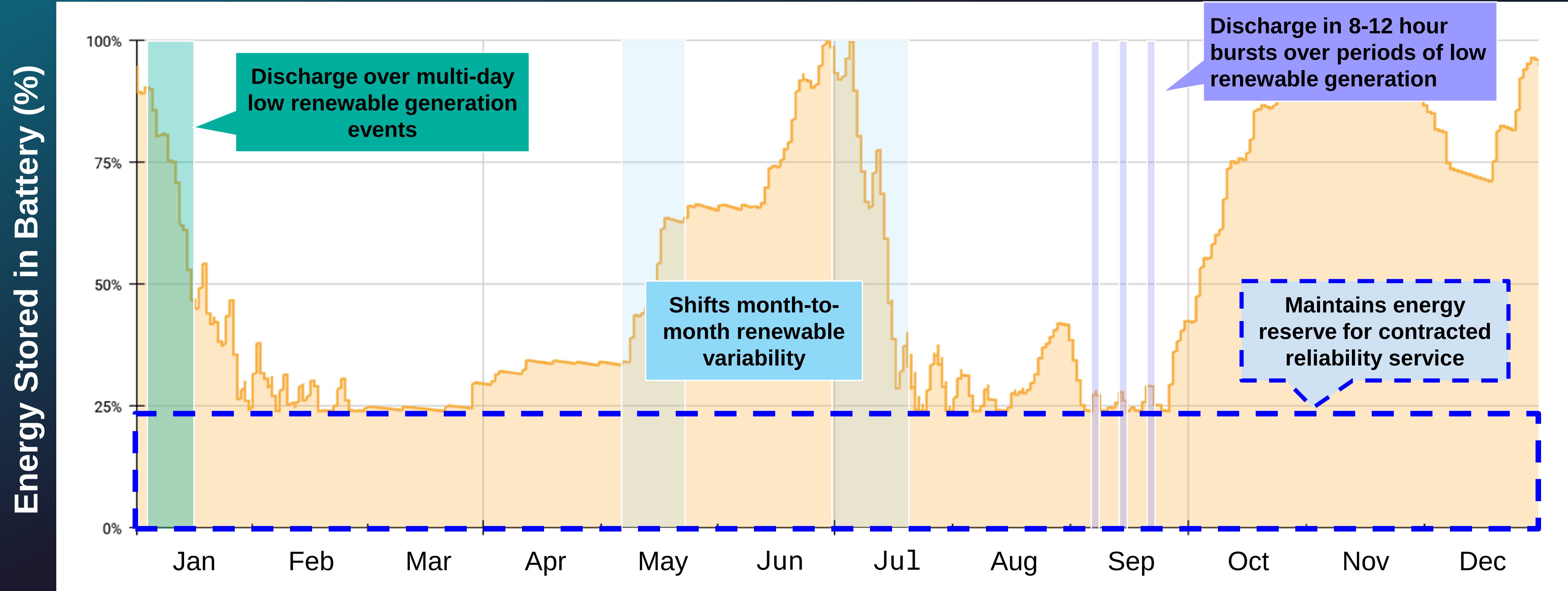
10s - 100s of Power Blocks

Commercial Intent System

Form energy has announced over 5 GWh of multi-day storage projects coming online by 2026



Multi-day storage operates year-round to balance seasonal, multi-day, and intra-day variability



Multi-Day

Seasonal Up
(net charge with excess renewables)

Seasonal Down
(net discharge during peak load season)

Intra-Day

24 hr reliability reserve

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Near-term multi-day energy storage investments provide additional hedging and portfolio diversification benefits

	Supports grid reliability and saves customers money during **extreme weather**
	Can scale deployment **independently of fuel or geographic constraints** located value is highest
	Provides a **diversified technology portfolio**, reducing technology and timeline risk
	Hedges against volatile and difficult to predict **commodity prices**
	Lowers total system costs by maximizing the use of generation and transmission assets

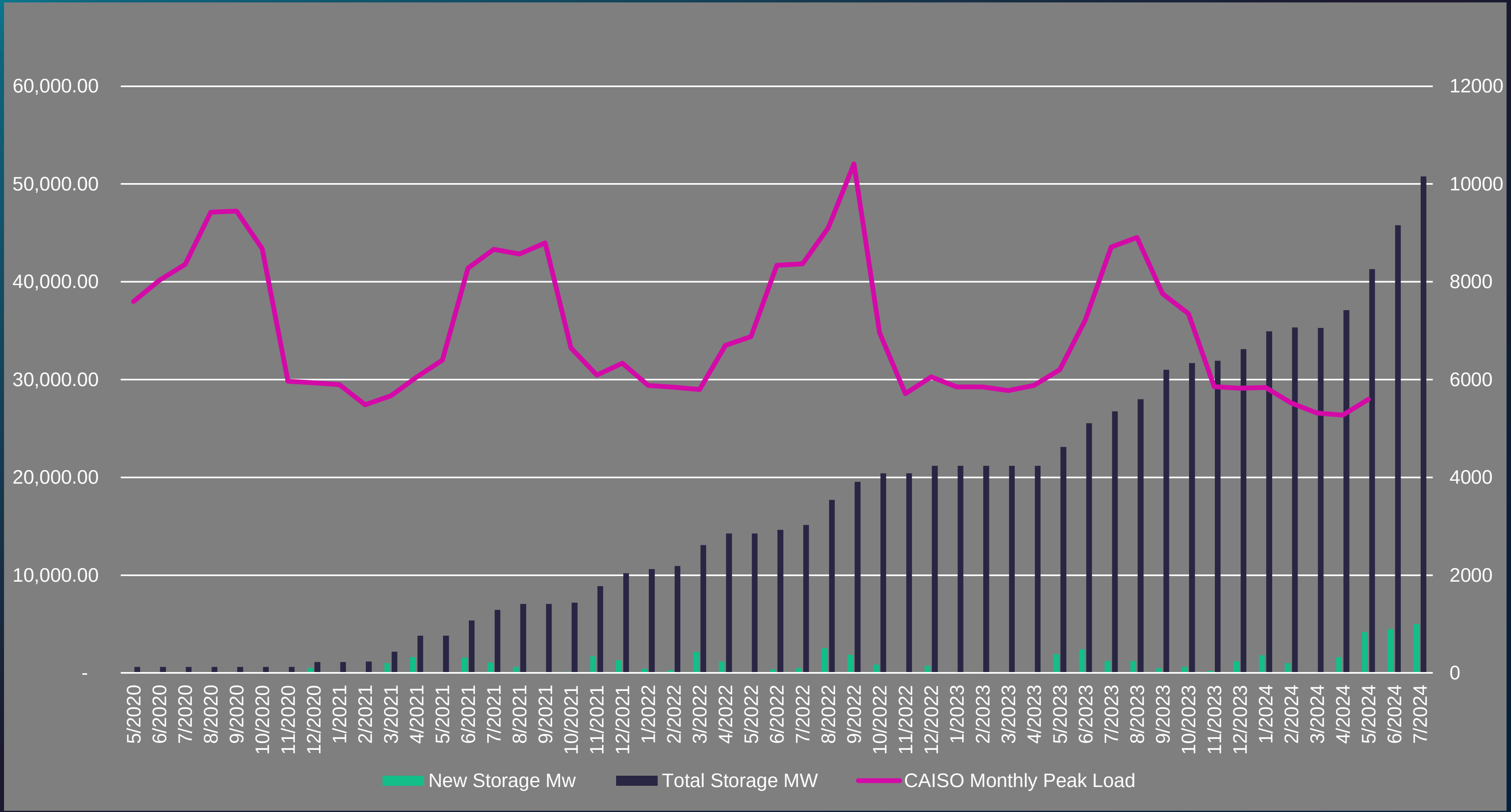
Storage resource participation in the CAISO

Danny Johnson, Market Design Sector Manager
Market Policy Development – California ISO

Storage is a significant and growing technology within CAISO's resource fleet

- Approximately 8,900 MW of installed capacity; ~900 MW are part of hybrid registered resources. +10,000MW projected by July 1
  - Primarily 4-hour lithium ion
- CAISO interconnection que projects significant additional development of storage resources
  - Hundreds of applications totaling +115 GW of dispatchable energy
- CAISO all-time peak load is ~52000MW

CAISO Monthly Peak Load & Battery Storage



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The CAISO offers 3 different market models storage resources can use to participate

- Non-Generator Model: Full +/- biddable range, no transition times
- Hybrid Model: Single modeled resource behind a point of interconnection, comprised of variable energy resource (VER) and storage resources; CAISO market optimizes project
- Co-located Model: Multiple VER and storage resources behind single point of interconnection; scheduling coordinators separately manage bid submission for both resources

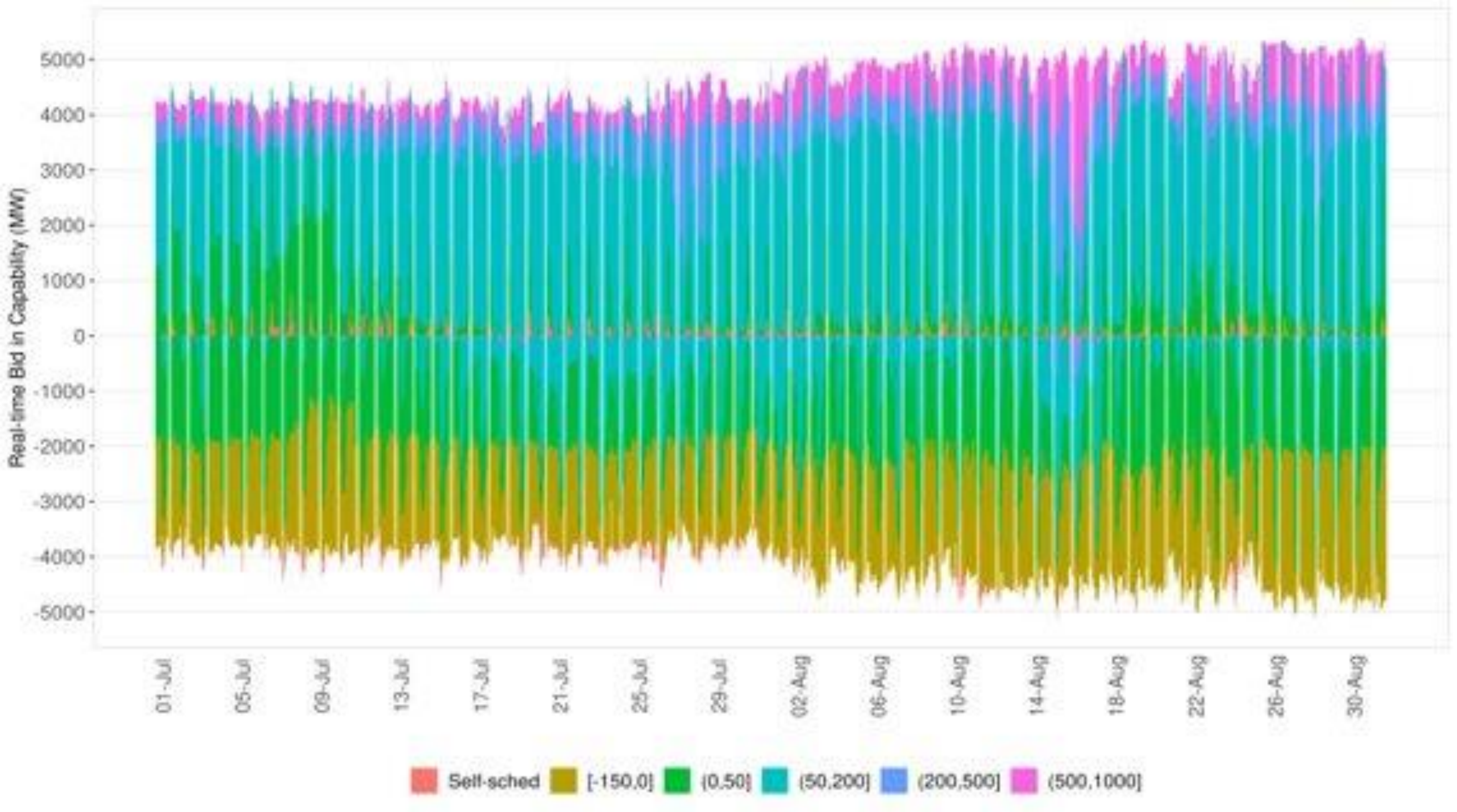
Storage Resource Participation in the CAISO

- Storage resources are able to sell all CAISO market products; including energy, ancillary services and flexibility/uncertainty products
  - Extensive participation in energy arbitrage
  - Largely saturated ancillary service markets

- State-of-Charge **(SOC)** parameter tracks how much energy the battery has available; is modeled as a constraint and optimized within the day-ahead and real-time markets. MWh units

- CAISO utilizes a multi-interval optimization allowing the market to implicitly dispatch storage based on buy/sell spreads

Recent economic participation of storage resources is robust in the CAISO's markets in summer of 2023



The CAISO is planning near-term market enhancements to further refine storage resource participation

- Potential to explicitly value state-of-charge
  - SOC as a biddable market product
  - Conversion of ancillary service or flexibility product awards into SOC
  - Accurate representation of SOC limited opportunity costs in bid limits and default energy bids
  - Ensuring accurate initial SOC within the day-ahead market run
- Address non-linear operational properties of storage resources
- Interplay between energy market and capacity revenues for storage resources
  - Ensuring planned capacity is able to be operationalized within energy markets