



California ISO

Limited Energy Storage Resources Opportunity Cost in CAISO

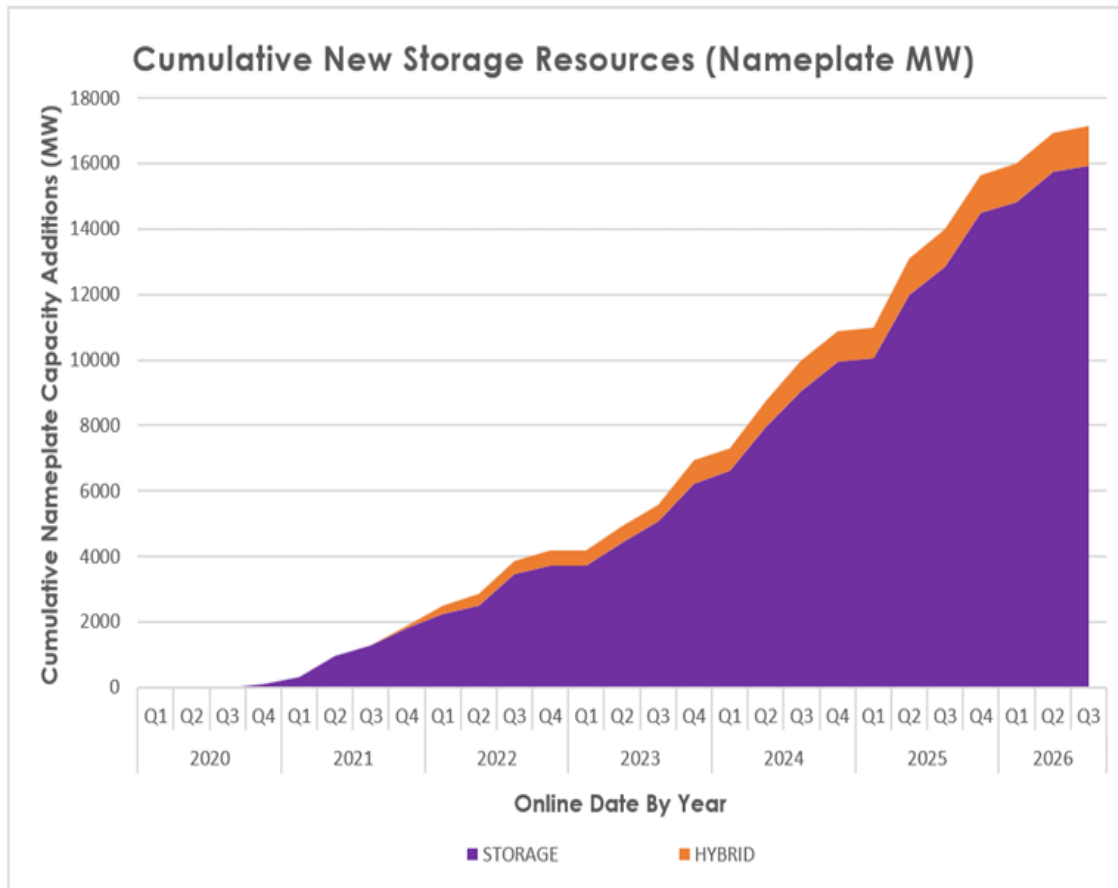
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Agenda

- Discuss why CAISO includes opportunity cost when calculating default energy bids for limited-energy storage resources
 - Supports reliability and market efficiency
- Discuss some current challenges and proposed changes to the storage default energy bid

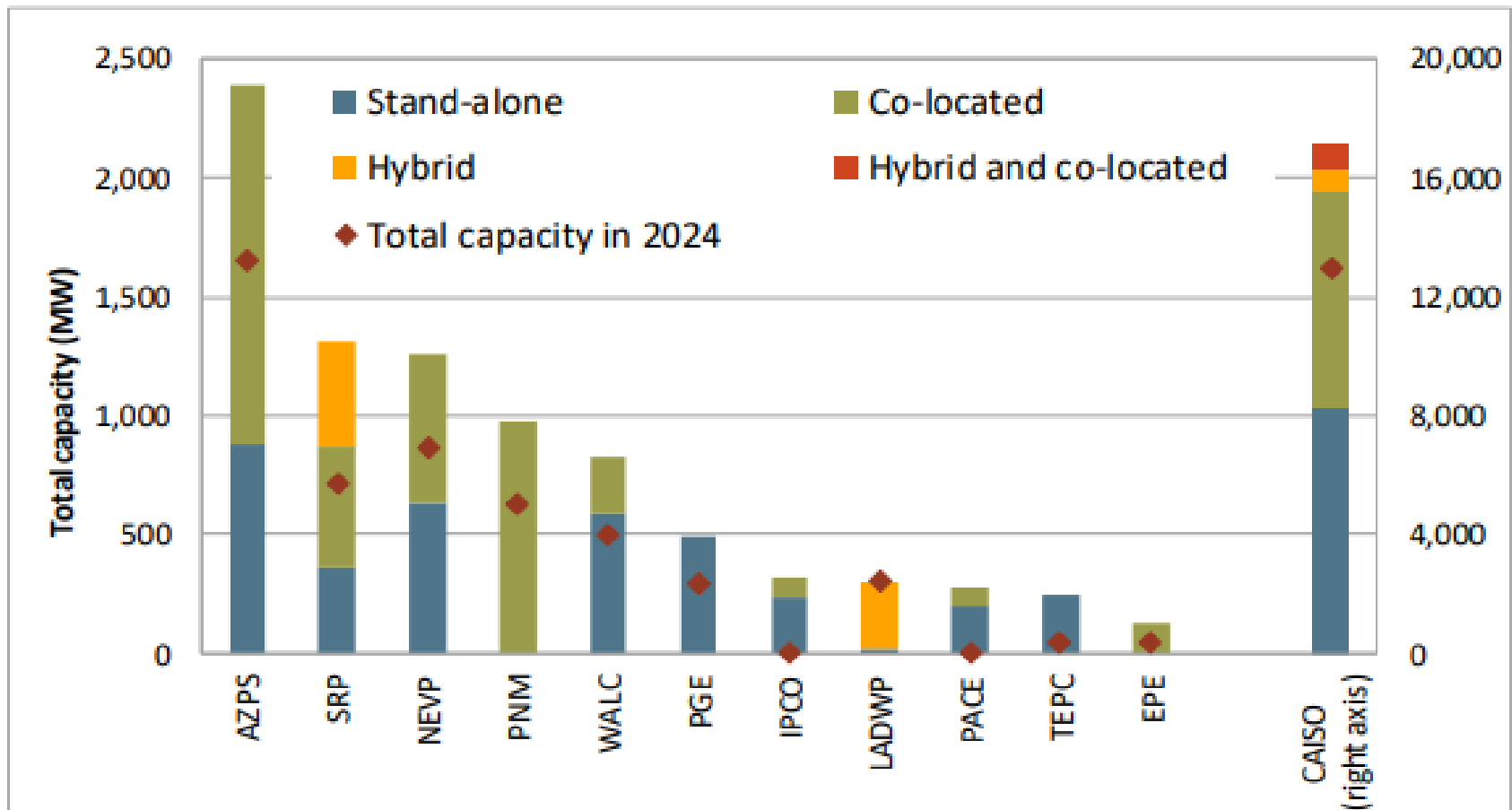
Storage growth in the past 6 years



- >17 GW storage nameplate capacity (June 2026)
- 12 GW nameplate capacity of additional storage assets are under contract and expected to come online by 2029

Source: CPUC, <https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/summer-2021-reliability/tracking-energy-development/resource-tracking-data-august-2026-release.pdf>

> 25 GW of storage across the West (inc. CAISO)



Source: DMM, <https://www.caiso.com/documents/departments-of-market-monitoring-update-mar-2026.pdf>

CAISO's storage paradigm allows storage to manage state-of-charge primarily through economic bids

- FERC 841: Resources using the participation model for electric storage resources must have the ability to self-manage their state of charge
- CAISO: Allows electric storage resources to self-manage their state of charge through the submission of economic bids and bidding parameters
- A high discharge bid is conveying that the cost to discharge during that interval is high because the value of the energy stored is higher than the currently prevailing price
 - “If I discharge now, I am foregoing revenues later in the day because I am energy-limited.”

Since economic bidding is the primary means to manage state-of-charge, the default energy bid's definition may impact state-of-charge outcomes

- Market power mitigation may modify the economic bid to the default energy bid, impacting state-of-charge management outcomes
- Formulation of the default energy bid must balance state-of-charge management, accurate cost estimation, and market power mitigation goals

CAISO default energy bid for storage

- CAISO may replace a resource's bid with a default energy bid
 - Limits the ability of local market power to affect market outcomes
 - The default energy bid is calculated by CAISO, using a previously agreed-upon formula
- The default energy bid seeks to reflect the resource's costs
 - What is the cost of a choice to generate for storage?
 - Marginal cost: Fuel cost (charging energy), wear and tear, degradation costs, etc.
 - Opportunity cost: What is the value of the stored energy?

What is storage marginal cost?

- For storage, the marginal costs relate to the costs directly associated with discharging an additional unit of electricity
- The storage marginal cost accounts for average charging cost, round-trip efficiency, and variable operating costs

A battery's charging cost is associated with its duration

- Assume a 4-hour battery can charge at its maximum power rating for 4 hours
- A profit-maximizing 4-hour battery would charge during the 4 lowest priced hours
- As a battery increases in duration, the battery charges for more hours
 - A profit-maximizing ___-hour battery would charge during the ___ lowest priced hours
 - The charging cost averages the ___ lowest price hours.

What is storage opportunity cost?

- For most technologies, generating in the current interval has limited impact on the ability to generate later
- For limited-energy resources, like storage, discharging now impacts the ability to discharge later
- The “opportunity cost” of storage is the foregone ability to discharge during a higher-priced hour

A battery's discharging opportunity cost is associated with its duration

- A fully charged 4-hour battery can discharge at its maximum power rating for 4 hours
- A profit-maximizing battery would discharge during the 4 highest priced hours
- As a battery increases in duration, the battery can discharge for more hours
 - A profit-maximizing ___-hour battery could discharge during the ___ highest priced hours
 - The opportunity cost is the ___ highest-priced hour

CAISO's current storage default energy bid takes the greater-of (1) marginal cost and (2) opportunity cost

$$\text{Discharge Default Energy Bid} = \text{Max} \{ [\text{Max} (En_{\delta/\eta}, 0) + \rho], PB_OC_{\gamma} \} * \text{Multiplier}$$

$$\text{Charge Default Energy Bid} = \text{Max} \{ [\text{Max} (En_{\delta/\eta}, 0)], PB_OC_{\gamma} \} * \text{Multiplier}$$

Where:

- En : Energy Cost
- η : Round-trip efficiency
- δ : Energy charging duration
- γ : Energy discharge duration
- ρ : Variable operations cost
- PB_OC : Price-based opportunity cost
- *Multiplier*: 110% multiplier

Including opportunity cost is necessary to balance state-of-charge management, accurate cost estimation, and market power mitigation goals

- **Supports reliability:**

- **Protects against premature incremental dispatch due to mitigation:** Recognizes that a discharged MWh cannot be used later when reliability needs may be higher, reducing the risk of premature depletion
- **Helps maintain state of charge heading into peak conditions:** Storage remains available when the reliability value of energy is greatest

- **Supports market efficiency:**

- **Reflects true marginal opportunity cost:** Recognizes that stored energy is limited and its value depends on future expected market conditions
- **Produces more efficient price formation:** Market prices are informed by the underlying scarcity of stored energy

CAISO and our stakeholders have identified three challenges with the current default energy bid

Current storage default energy bid

Relies on day-ahead market run values, which may be stale when used in real-time

Single real-time storage default energy bid may over- or under-estimate opportunity costs at different times of the day

If the price-based opportunity cost sets the default energy bid, the charge and discharge default energy bids are the same value



New storage default energy bid should

Consider scaling that reflects differences between day-ahead and real-time

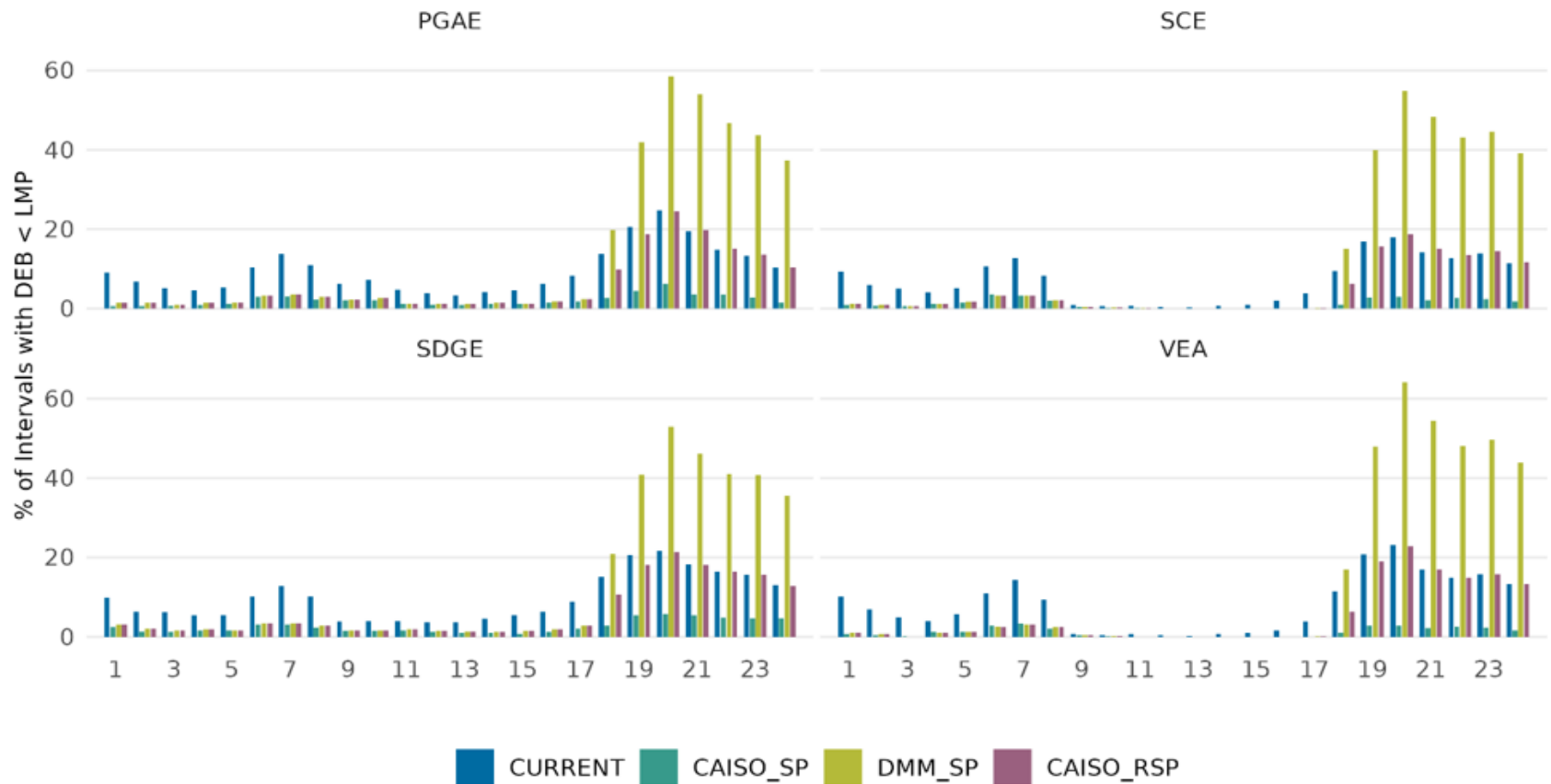
Reflect changing real-time opportunity costs

Minimize state-of-charge management risks posed by mitigation

Spotlight: The current proposal to enhance the storage default energy bid introduces a time-of day multiplier to reflect changing real-time opportunity costs

- >1 multiplier for hours before peak hours in real-time
 - Opportunity costs are greater before peak conditions
- Transitions from >1 to 1 at the later of either (1) the earliest of the Nth highest priced day-ahead LMPs, or (2) hour ending 18
 - Opportunity costs are lower during and after peak conditions

The time-of-day approach better recognizes changing price conditions and evolving opportunity costs related to daytime energy shifting



The time-of-day proposal further adapts to evolving price conditions and opportunity costs

$$DA\ Discharge = \text{Max}(\text{Variable Operations Cost} * 1.1, PB_OC * 1.1, Gas\ Floor * 1.1)$$

$$DA\ Charge = (DA\ Discharge\ DEB - \text{Variable Operations Cost})$$

$$RT\ Discharge = \text{Max}(\text{Variable Operations Cost} * 1.1, PB_OC * 1.1, Gas\ Floor * 1.1) * TOD\ Multiplier$$

$$RT\ Charge = (RT\ Discharge\ DEB - \text{Variable Operations Cost})$$

Where:

Variable Operations Cost: Represents cycling and other operational costs

PB_OC: Price-based Opportunity Cost

- In DA for EDAM, calculated by scaling the MPM outputs based on differences relative to DA LMPs
- In RT for EDAM, calculated by scaling DA LMPs based on differences relative to RT LMPs
- In RT for WEIM, calculated by scaling DGAP based on differences relative to RT LMPs

TOD Multiplier: A value of 1.4 before the hour that sets the price-based opportunity cost and 1 at the later of either (1) the earliest of the Nth highest priced day-ahead LMPs, or (2) hour ending 18 (only in real-time)

Gas Floor: 11,068 MMBtu/MWh * Fuel region gas price

Q&A