

California's Electrical System: Markets, Operations, and the Performance of Renewables and Storage



Consejería Insular de Industria, Comercio,
Sector Primario y Bienestar Animal
Consejería de Industria



California ISO

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Agenda

- About the California Independent System Operator (CAISO)
- California's energy context
- Battery energy storage and the electricity market
- Energy storage, renewable integration, and system operations



Part I. About CAISO

The CAISO is a federally-regulated nonprofit, independent, technology-neutral organization that manages the high-voltage electric grid for 80% of California and a portion of Nevada.



CAISO's core responsibilities

Within its balancing authority area, the California ISO:

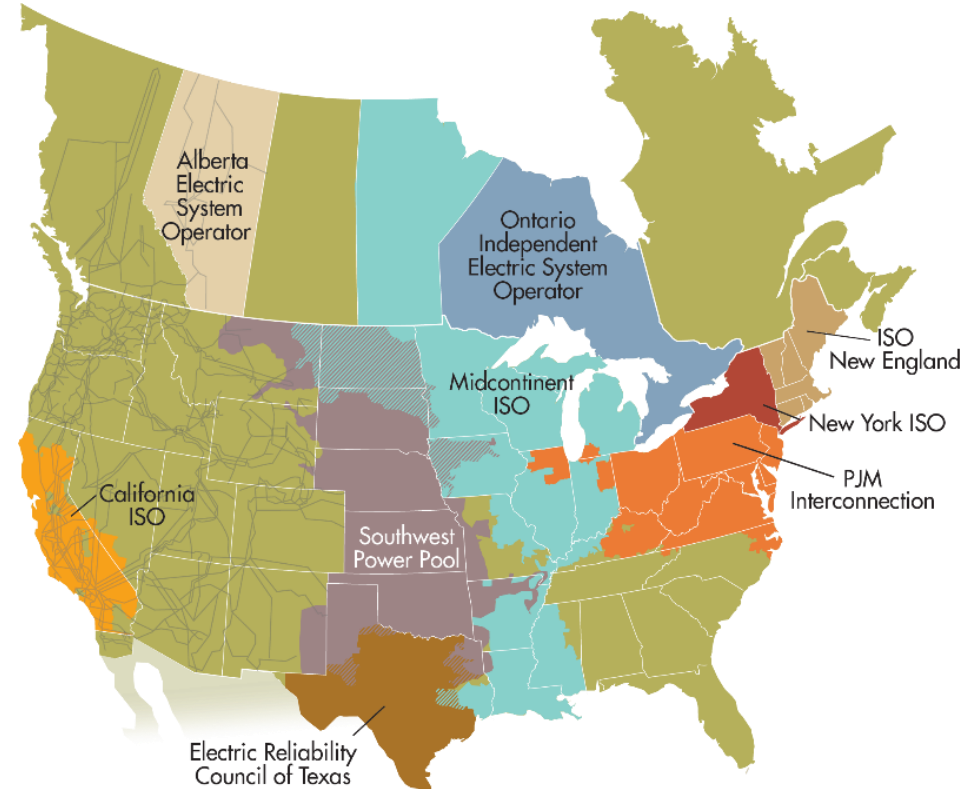
- **Operates the wholesale electric market (day-ahead and real-time)**
- **Maintains reliability on the grid**
- Manages the flow of energy
- Oversees the transmission planning process

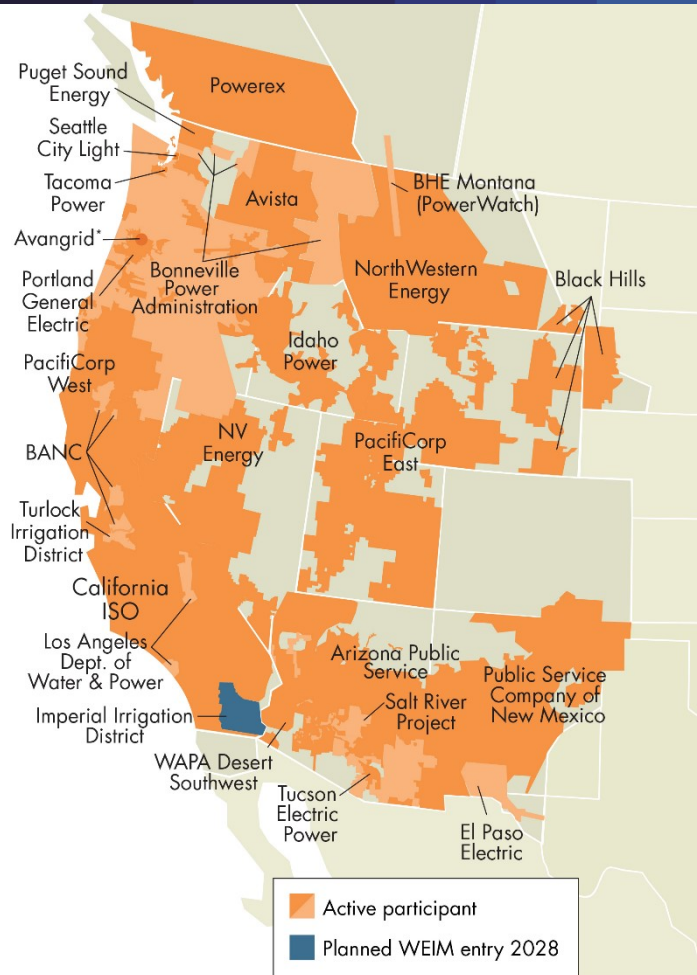
For much of the western U.S., the ISO:

- Operates the Western Energy Imbalance Market (WEIM)
- Serves as Reliability Coordinator (RC West)

CAISO by the numbers

- One of 9 ISO/RTOs in North America
- 32 million people served
- 239.2 million megawatt-hours of electricity delivered (2025)
- \$14.9 billion annual market (2025)



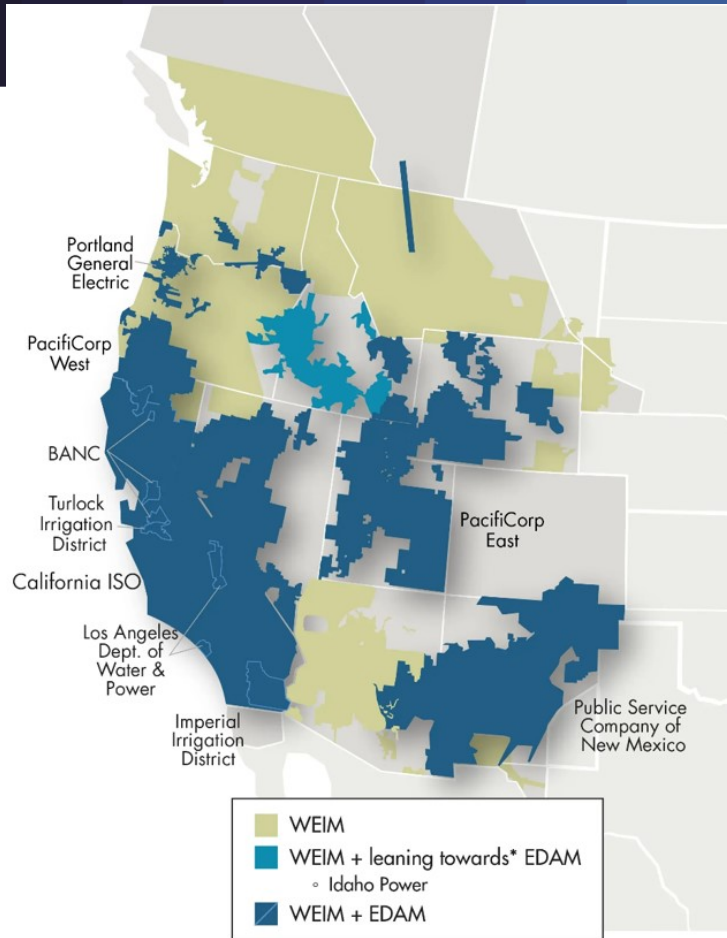


*Avangrid office; generation only BAA with distribution across multiple states.
 Map boundaries are approximate and for illustrative purposes only.
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The Western Energy Imbalance Market (WEIM)

Since its launch in 2014, the WEIM has enhanced grid reliability, generated billions of dollars in benefits for participants, and improved the integration of renewable energy resources.

- 23 participating entities
- Cumulative benefits exceed \$8.6 billion
- Reduced over 1.1 million metric tons of CO₂ emissions



Extended Day-Ahead Market (EDAM)

Building on WEIM, the ISO's EDAM optimizes the use of existing transmission and resources in the much larger day-ahead timeframe across an expanded Western footprint.

- Opens the door to significantly improved economic benefits through the commitment of least-cost generation across the market's broad geographic footprint.
- Enables improved situational awareness across balancing authority areas, enhancing reliability, and lowering emissions.

Part II. California's Energy Context

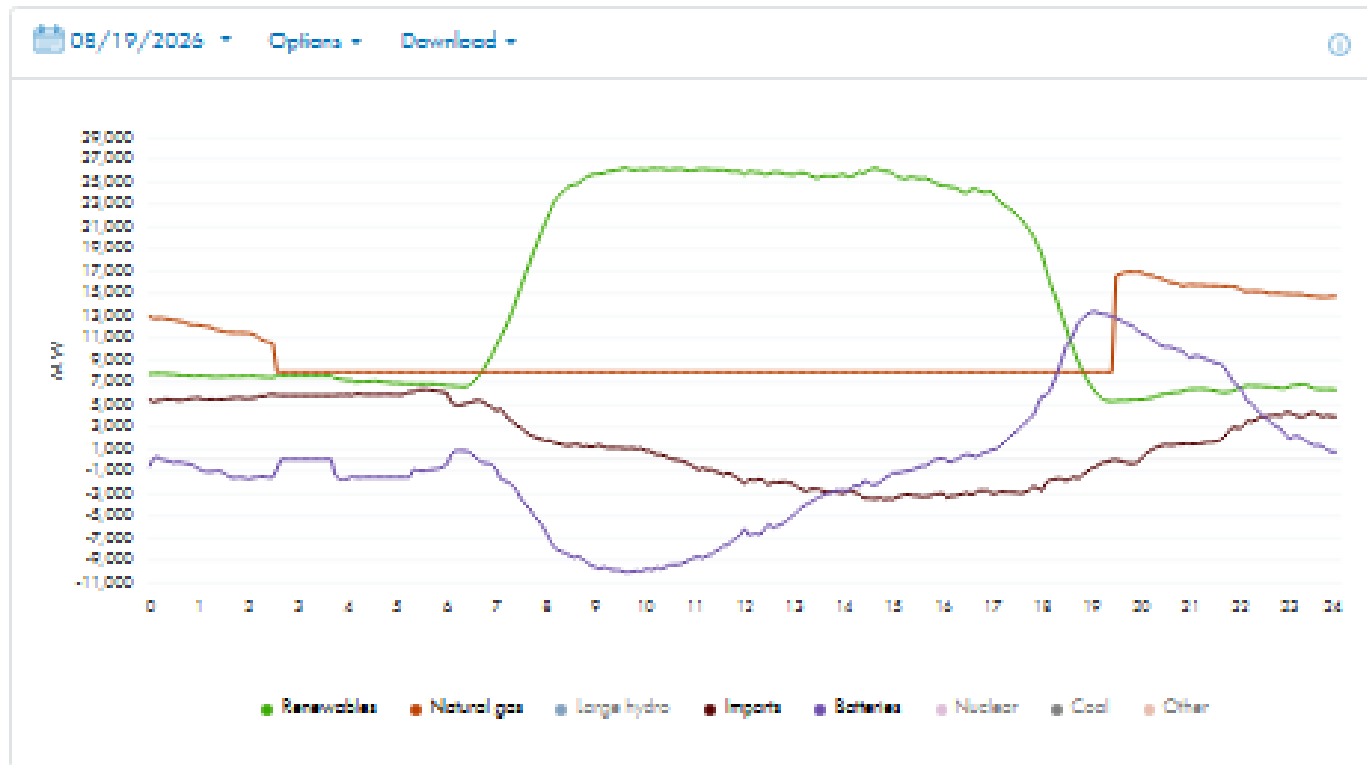
52,061 MW record peak demand
(September 6, 2022)

23,896 MW solar peak
(August 19, 2026)

24,567 MW 3-hour ramp
(March 16, 2026, starting at
15:50)

17,225 MW installed battery capacity
(as of September 2, 2026)

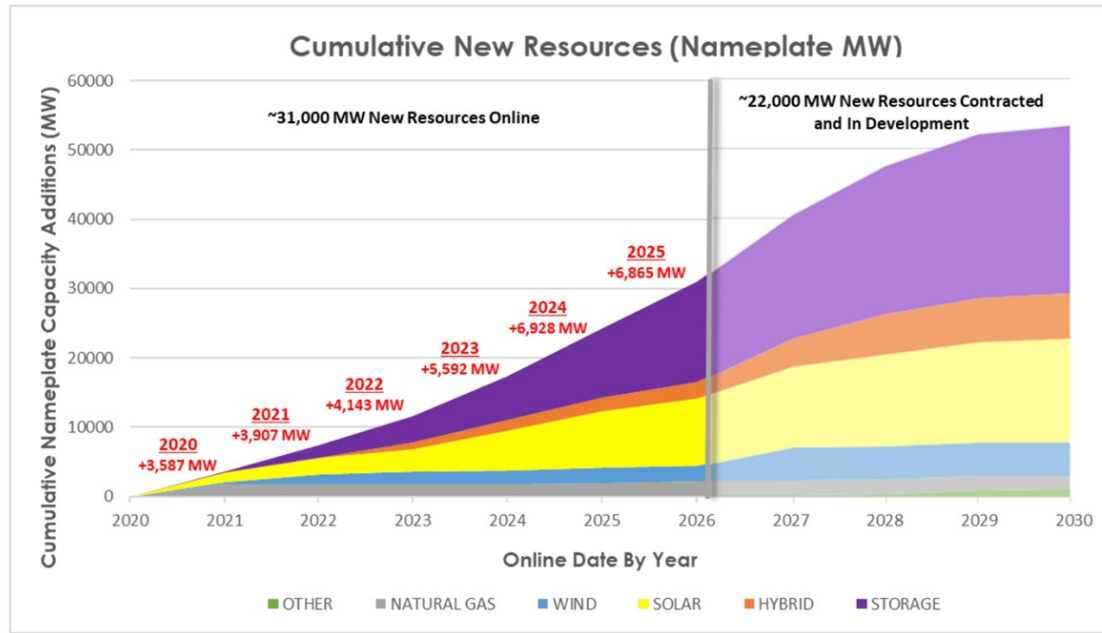
Ramping, Renewables, and Storage



California clean energy goals

- **SB 1078 (2002)** – Established a requirement that 20% of electricity retail sales must be served by renewable resources by 2017
- **AB 2514 (2010)** – Directs the establishment of procurement targets for energy storage systems for the state's investor-owned utilities (IOUs)
- **SB 100 (2018)** – By 2045, 100% of all energy retail sales must come from renewable energy and zero carbon resources
- **SB 1020 (2022)** – Establishes interim SB 100 clean energy targets – 90% by 2035 and 95% by 2040

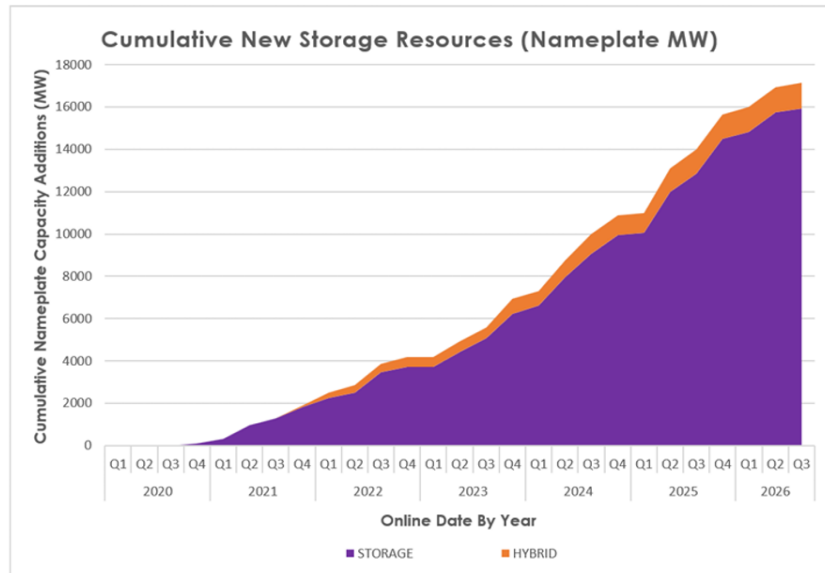
Rapid growth of new, clean resources on the CAISO grid



- About 31 GW new nameplate capacity added between 2020 and February 2026
- By 2030, over 22 GW additional new resources expected online

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

Part III. Battery energy storage and the electricity market



- ~17 GW storage nameplate capacity is online serving the grid as of September 2026
- ~13 GW nameplate capacity of additional storage resources 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>

How storage derives value from the electricity market

Capacity

- Revenues are derived from the Resource Adequacy (RA) framework
- The RA program is administered by the CPUC, which sets capacity obligations for each jurisdictional load-serving entity (LSE)
- This is a bilateral market, not a centralized market: Based on the CPUC's obligations, LSEs bilaterally contract capacity (no auction)
- Revenues are paid on a \$/MW-month basis

Energy

- Revenues are derived from participation in the CAISO markets
- Storage resources initially focused on the provision of ancillary services (AS), a market they quickly saturated
- Today, energy revenues are purely based on energy arbitrage
- Revenues are settled every trade day
- Resources with an RA contract have a must-offer obligation in the energy markets

Storage Resource Participation in the CAISO

- **Non-Generator Resource (NGR):** Storage resource capable of charging (negative energy) and discharging (energy) without transition times
- **Mixed-fuel Resource:** A Generating Facility with components that use different fuel sources or technologies
 - **Hybrid Resource:** A Mixed-fuel Resource with a single Resource ID at a single Point of Interconnection
 - **Co-located Resource:** A Generating Unit with a unique Resource ID that is part of a Generating Facility with other Generating Units

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
 - Market revenues are purely based on price arbitrage
- State-of-Charge (SOC) parameter tracks how much energy the battery has available for optimization by the day-ahead and real-time markets in MWh
- CAISO utilizes a multi-interval optimization (MIO) that allows the market to implicitly dispatch storage based on buy/sell spreads when SOC-limited

Scheduling Coordinators can submit self-schedules or economic bids in the ISO markets

Self-schedules are an offer to generate or consume energy regardless of price and only specify quantity (MW), making resources “price takers”

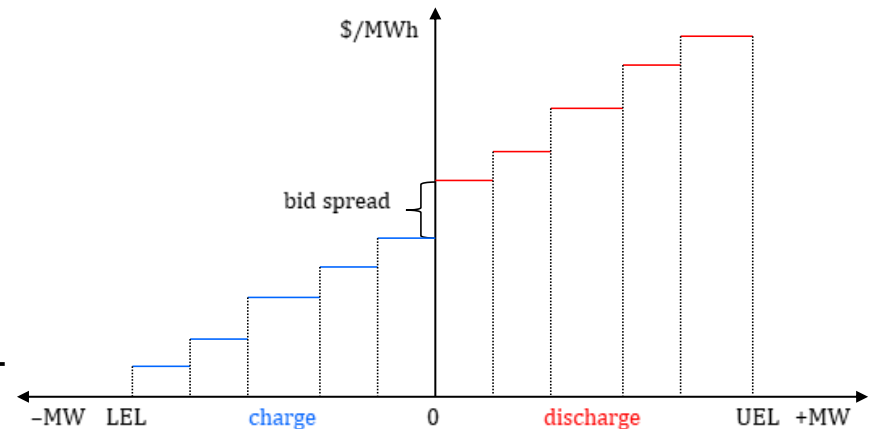
- These ensure the asset will perform as scheduled but has other implications, such as eliminating the possibility for bid cost recovery since assets are price takers

Economic bids include both a quantity (MW) and a price or price range for which generators are willing to sell Energy and AS

- Must be monotonically non-decreasing and can have up to 10 segments (quantity-price pairs)
- Resource Adequacy (RA) resources are required to submit economic bids in day-ahead and real-time

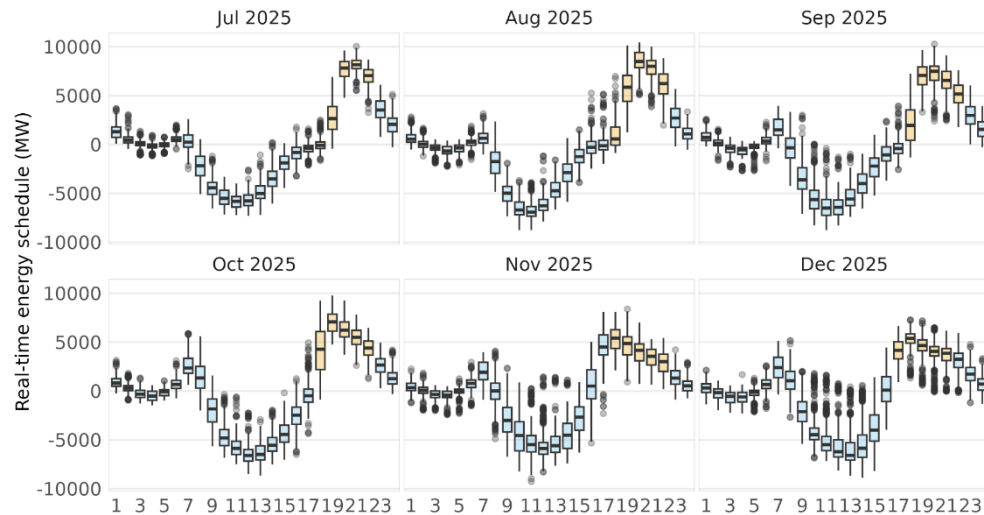
Storage Resource Participation in the CAISO

- Positive energy awards indicate discharge awards, state-of-charge decreases
- Negative energy awards indicate charging awards, state-of-charge increases by $\text{Energy Award} * \text{Charge Efficiency}$
 - Storage is not 100 % efficient
- Energy awards are limited in both directions by state-of-charge
- Resources submit bids as a 10-segment monotonically non-decreasing (MW and \$/MWh) bid curve



Part IV: Energy storage, renewable integration, and system operations

Storage consistently charges during solar hours and discharges during net load peaks



Managing renewable integration involves all tools available to the ISO

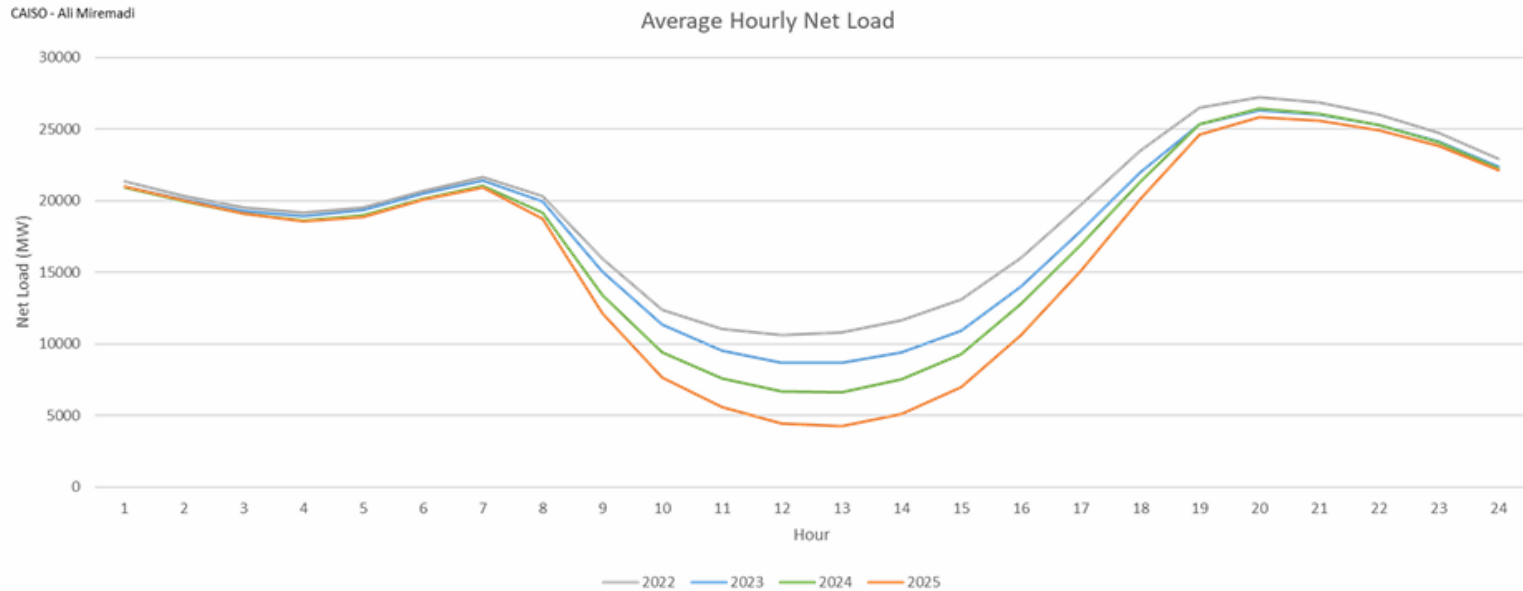
- **Battery energy storage**
- **Resource Adequacy**
- **Market design**
- Investigation and penalization of non-performance
- Regional integration and infrastructure

Managing renewable integration involves all tools available to the ISO

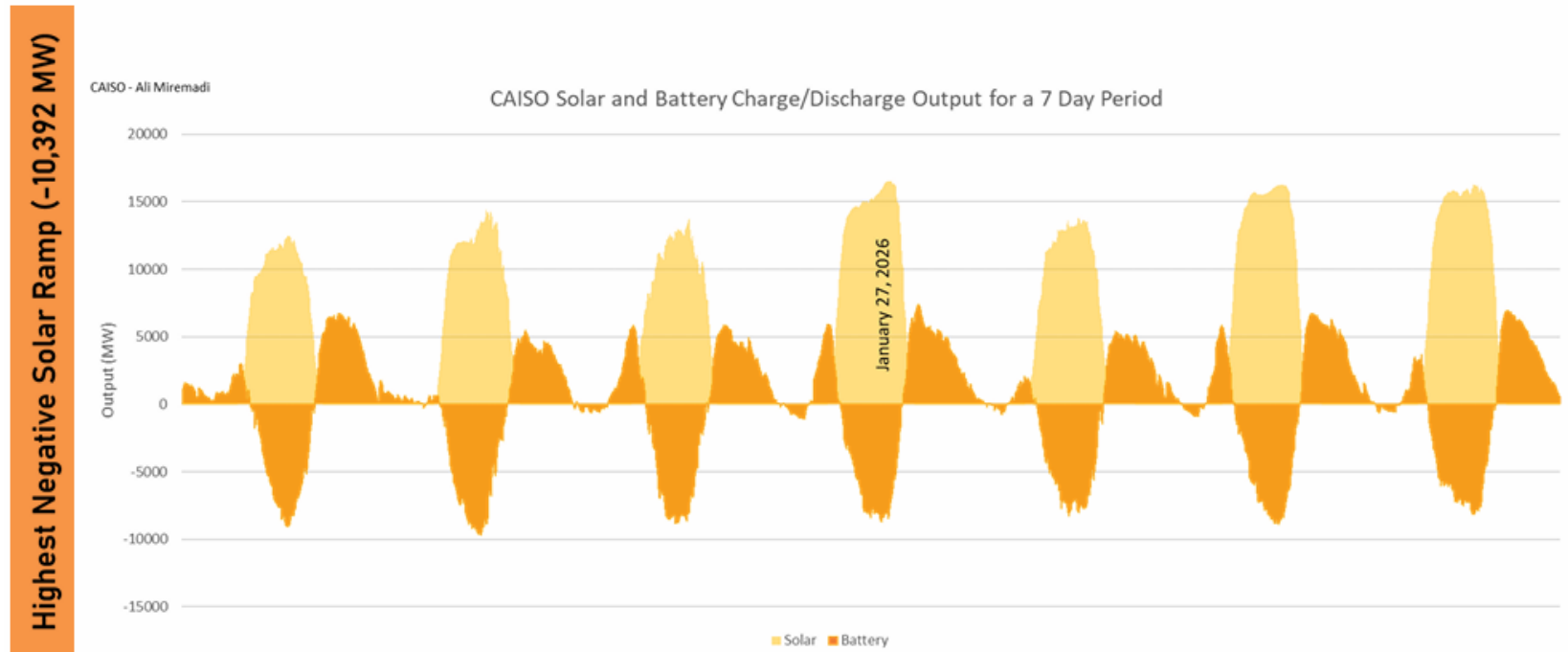
- **Battery energy storage:** ensure linear ramping and account for state-of-charge limitations in awarding all market products and ancillary services
- **Resource Adequacy:** properly account for solar/wind capacity, considering impacts on transmission system
- **Market design:**
 - Forward-looking market dispatch that considers a series of advisory intervals (5 - 18 15-minute intervals)
 - Allow for economic bidding by solar/wind facilities
 - Develop ramping products
 - Improve forecast accuracy to ensure adequate regulation procurement

Managing renewable integration involves all tools available to the ISO

Impact of Solar and Wind Growth

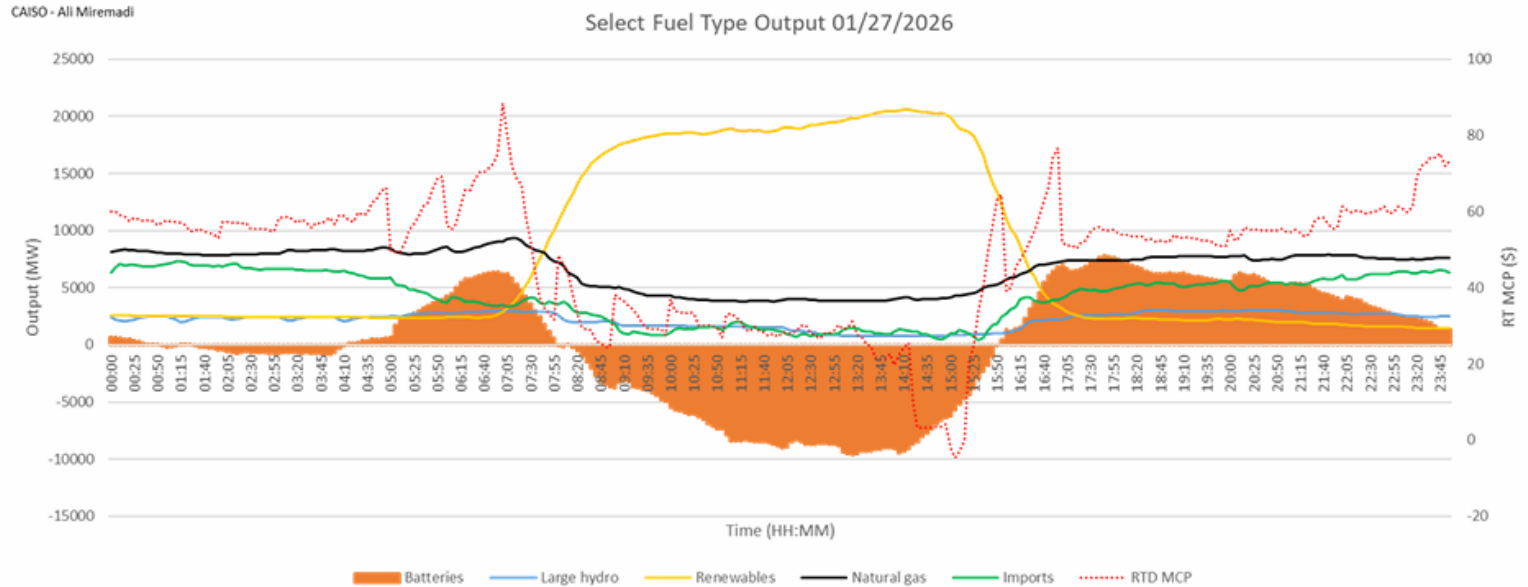


Managing renewable integration involves all tools available to the ISO

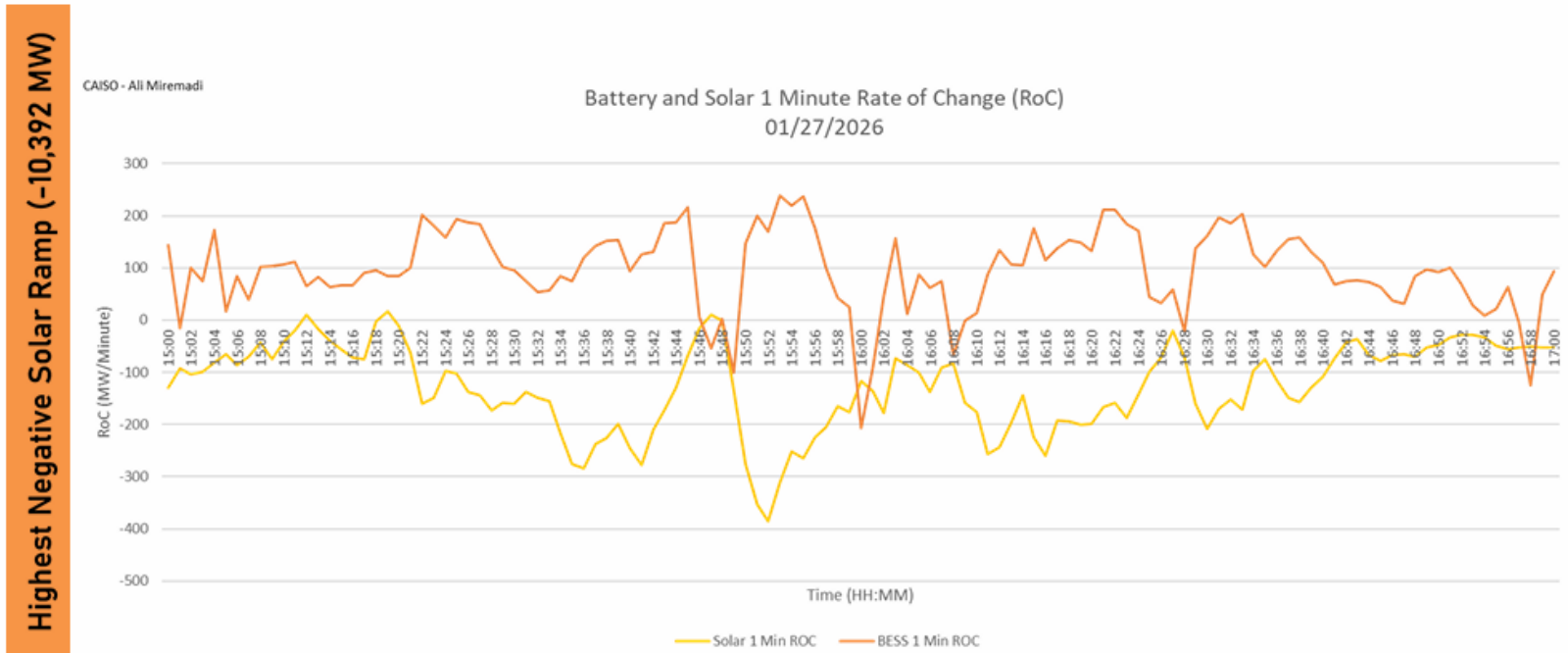


Managing renewable integration involves all tools available to the ISO

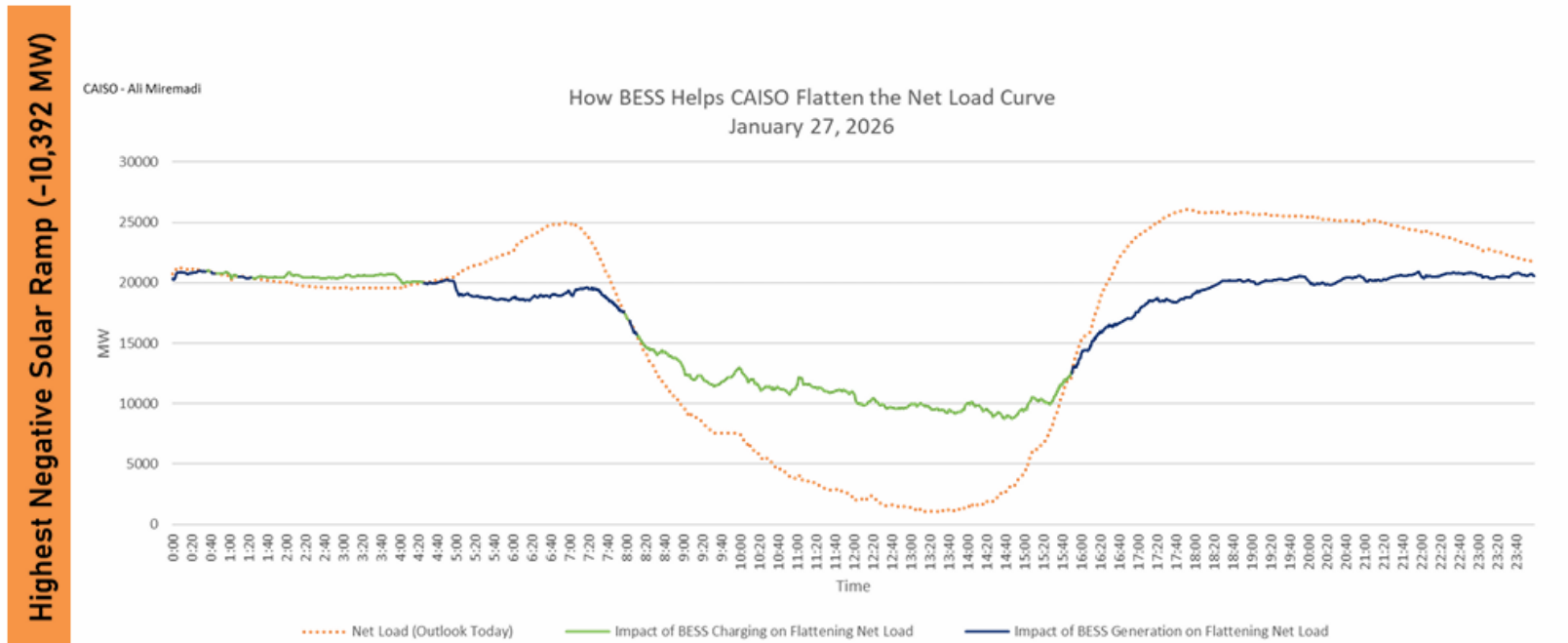
Highest Negative Solar Ramp (~-10,392 MW)



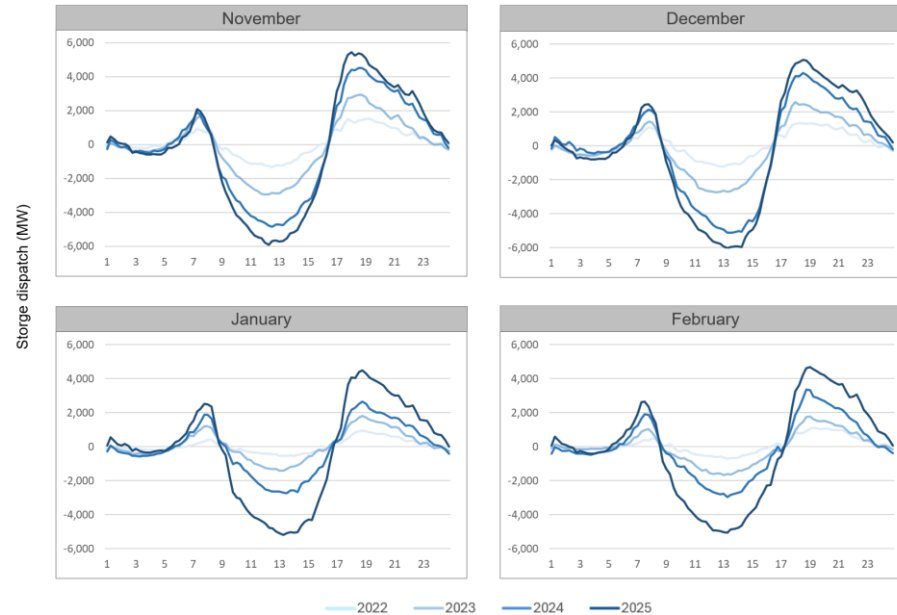
Managing renewable integration involves all tools available to the ISO



Managing renewable integration involves all tools available to the ISO



Storage resources have significantly increased energy arbitrage from midday hours to peak hours

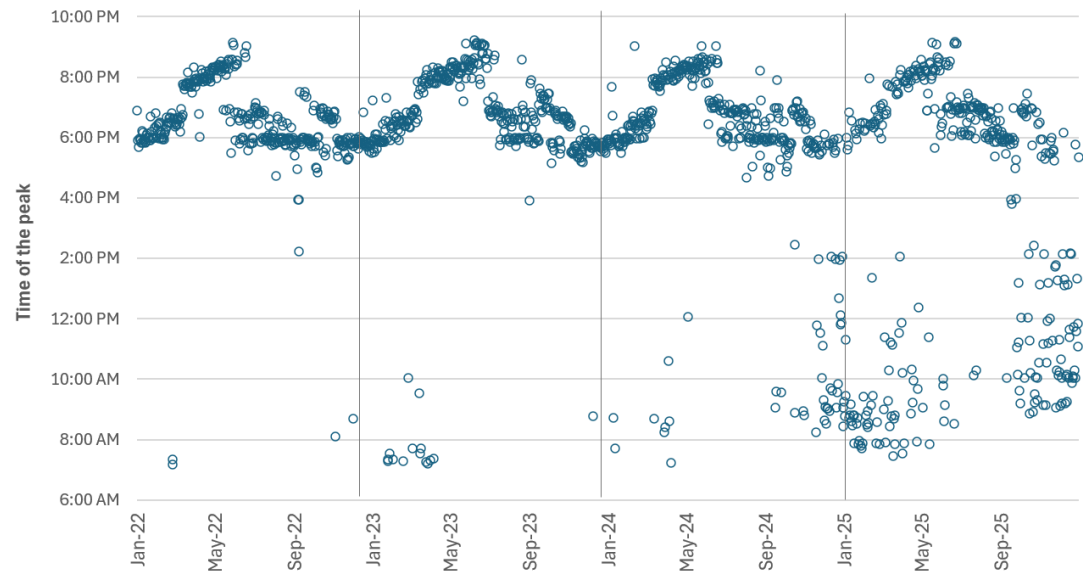


Storage resources are helping to flatten the load that needs to be met with conventional resources



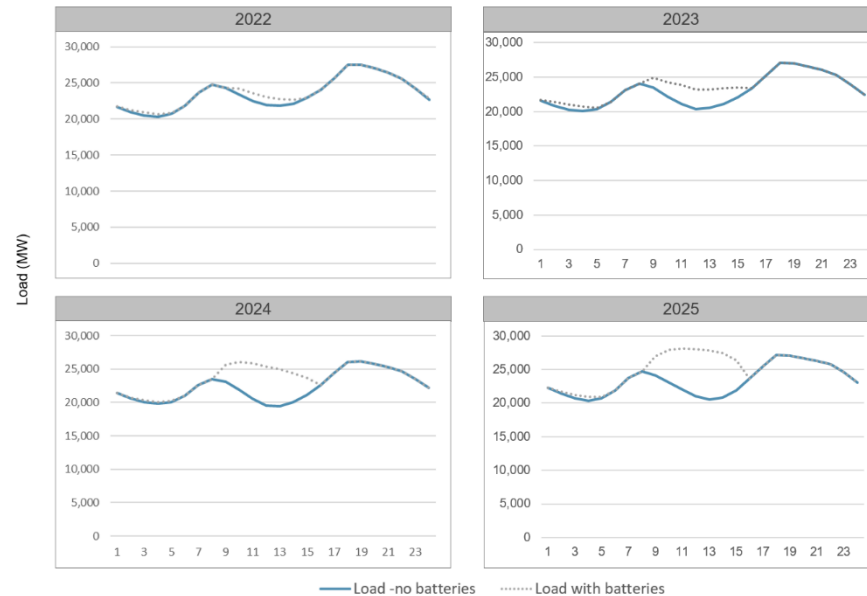
These trends are based on a sample periods of November

The increasing level of additional demand imposed by charging is shifting the daily demand peak to midday hours more frequently in winter periods



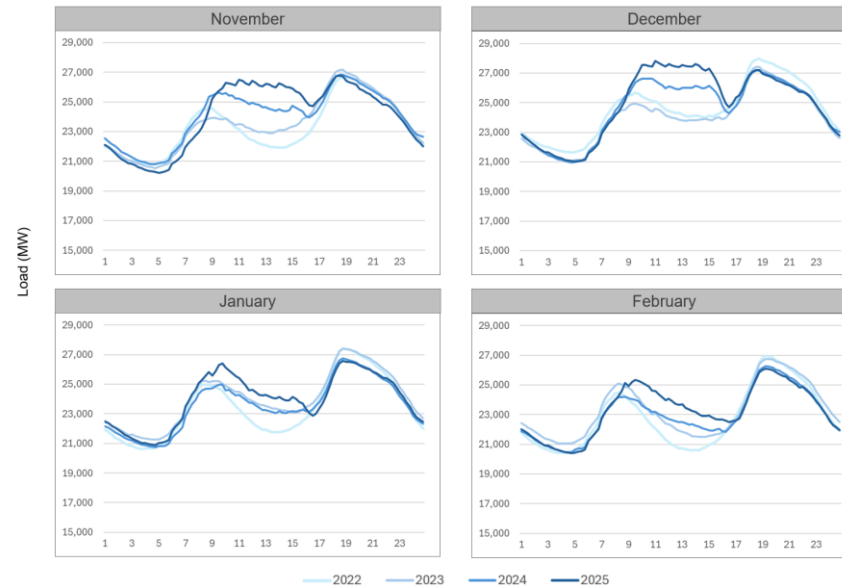
This profile reflects total load, which includes pump and charging of storage resources

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This profile reflects total load, which includes pump and charging of storage resources

Conclusions

California's energy grid is defined by its significant share of solar resources, which is well complemented by battery energy storage

The development of storage resources in California is linked to proactive state policies which have transformed the electric market

CAISO's experience shows that storage resources can be deployed at scale and allowed to participate in a similar manner to other assets within energy markets

Conclusions

The economics of storage makes it so that these assets consistently charge during solar hours and discharge during net load peaks

Storage resources are helping to flatten the load that needs to be met with conventional resources and are well-suited for regulation

The increasing level of additional demand imposed by charging can have significant effects on daily demand peak patterns

Thank you!

Q&A