

Extended Study of PJM's Real-Time Offer Cap Proposal

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Objectives and Agenda for this Presentation

OBJECTIVE OF PRESENTATION

Understand the potential impact of PJM's energy storage resource offer cap proposal via results from extended study.

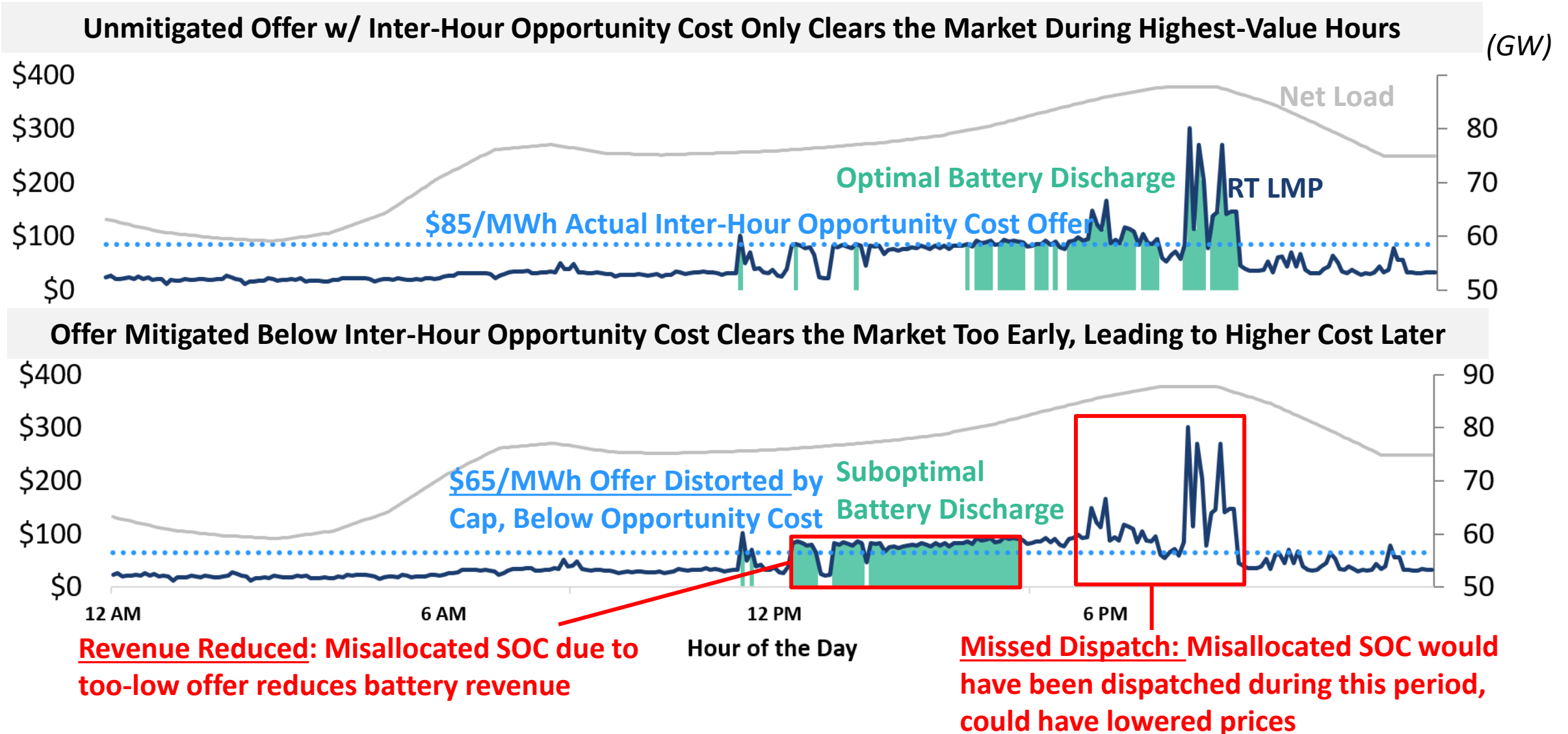
AGENDA

- **Recap** – Market power mitigation measures for energy storage resources can unintentionally undermine reliable and efficient operations
- **Extended Study Approach** – Modeling with extended geographic scope and time horizon to validate PJM results, measure offer distortion and assess revenue impact
- **Results** – Validate PJM's analysis of proposed offer cap; distorted offers occur on approximately 5–10% of days across all zones; revenue impact is modest, highest in constrained zones (DOM, BGE, and PEPCO)
- **Appendix**
 - Additional offer cap analysis of reserves impact on event days
 - Comparison of ISO/RTO approaches to battery market power mitigation

Recap of issue with conventional market power mitigation of batteries: mitigated offer too low to achieve optimal dispatch

The next slide illustrates this with backcast-based analysis of battery market operations on March 31, 2025 (a mild day with a mid-day jump in prices plus price spikes)

Under Offer-Driven Market Participation Approach, Market Power Mitigation w/o Opportunity Cost Can Lead to Misallocated Early Discharge



Note: Figures represent a backcast of a 4-hour battery dispatch on March 31, 2025, starting the day at 100% state-of-charge (SOC) under PJM RT price data. Offer with inter-hour opportunity cost set to the 48th highest RT LMP. Mitigated offer capped at highest DA LMP. Battery discharges every time the offer is less than the RT LMP, subject to rolling SOC limitations. brattle.com | 3

The extended backcast-based analysis quantifies efficiency and revenue impact of mitigated offers over two years, and further validates PJM's proposed RT offer cap

Extended Study Approach and Additional Key Metrics

- We follow PJM's ESR offer cap simulation using two years of historical RT and DA energy prices **expanded from 3 zones to all 21 zones**
- Rather than PJM's optimizer-based dispatch over a two year time horizon, this method deploys **simple, fast, backcast-based heuristic**
 - 1-daily cycle, discharge-only, SOC reset to full at midnight each day, perfect foresight, no price impact (assumes small price-taker battery)
- Main offer cap case evaluated is **PJM's proposed RT offer cap (Max DA Price** with additional detail of the Cost Offer Adjustment multiplier of 1.1X (which does not exceed \$100/MWh), plus the offer cap cases in PJM's study*
- As in PJM's analysis, this study assumes competitive offer behavior (except for interference from offer cap)

Extended Study Metrics that Quantify Impact of Offer Cap:

Metric Borrowed from PJM's Study:

- **Missed Discharge:** Percent (%) of 5-min intervals where the storage with the capped offer misses a discharge dispatch interval that the uncapped storage was able to meet (*effectively equivalent to PJM metric, "% of Failed Intervals"*)

Additional Metrics in Extended Study:

- **Offer Distortion:** Percent (%) of days when the offer cap is below inter-hour opportunity cost
- **Revenue Reduction:** Percent (%) of annual revenue (net of imputed charging cost) reduced with vs. without the proposed offer cap

Notes: Missed discharge metric checks whether the optimal storage discharge is greater than the suboptimal storage discharge for an interval

Extended Study Results Validate PJM's Findings at the Zonal Level

Extended study matched to PJM's Max DA Price offer cap (without 1.1 multiplier) broadly validate PJM's findings.

Of the three offer cap methodologies, the RT offer cap set by the Max DA LMP reduces misallocated SOC. Across the three offer caps, less than 2% of intervals have missed discharge (equivalent to PJM “% of Failed Intervals”).

Missed Discharge Metric:

Percent (%) of 5-min intervals where the storage with the capped offer misses a discharge dispatch interval that the uncapped storage was able to meet (effectively equivalent to PJM metric, “% of Failed Intervals”)

Percent of Intervals With No Missed Discharge (Non-Failed Intervals) by Offer Cap Method: PJM vs Extended Study Results for 4-hr Battery

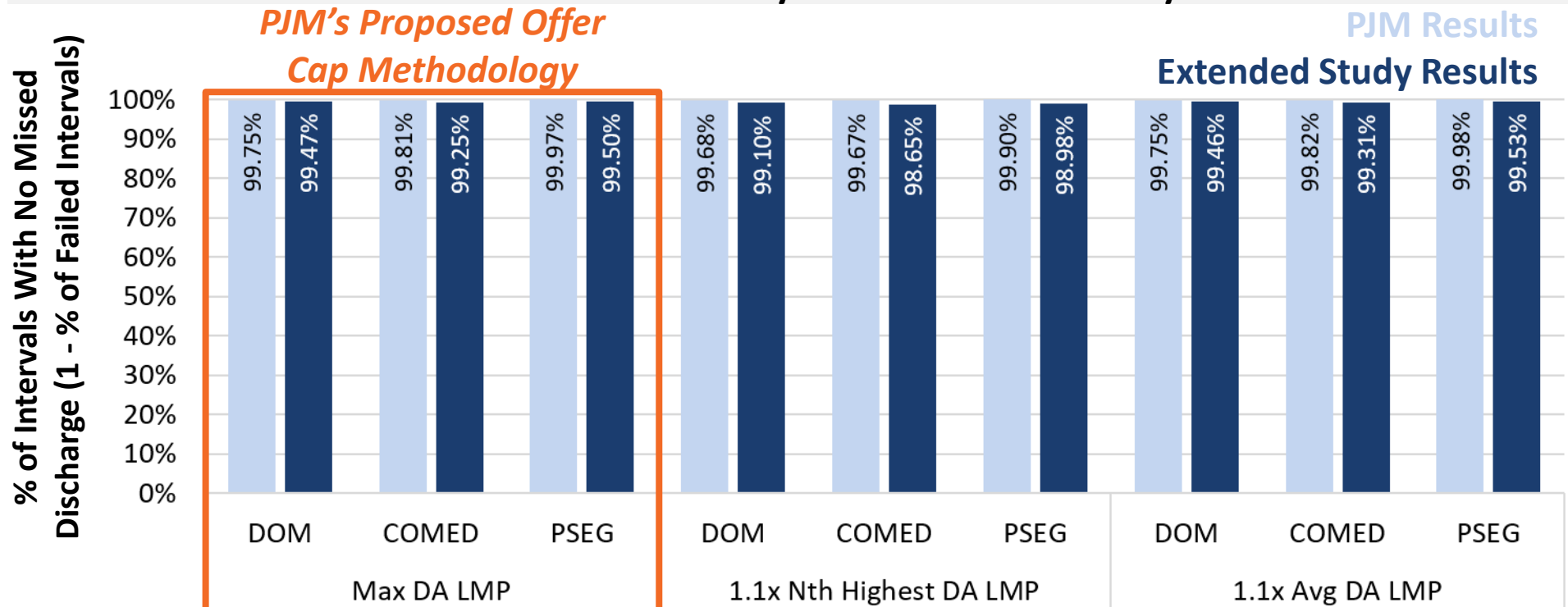


Figure Source/Notes: [PJM, Enhancing PJM's Energy Storage Resource Model for Anticipated Battery Growth, June 3, 2026.](#)

RESULTS

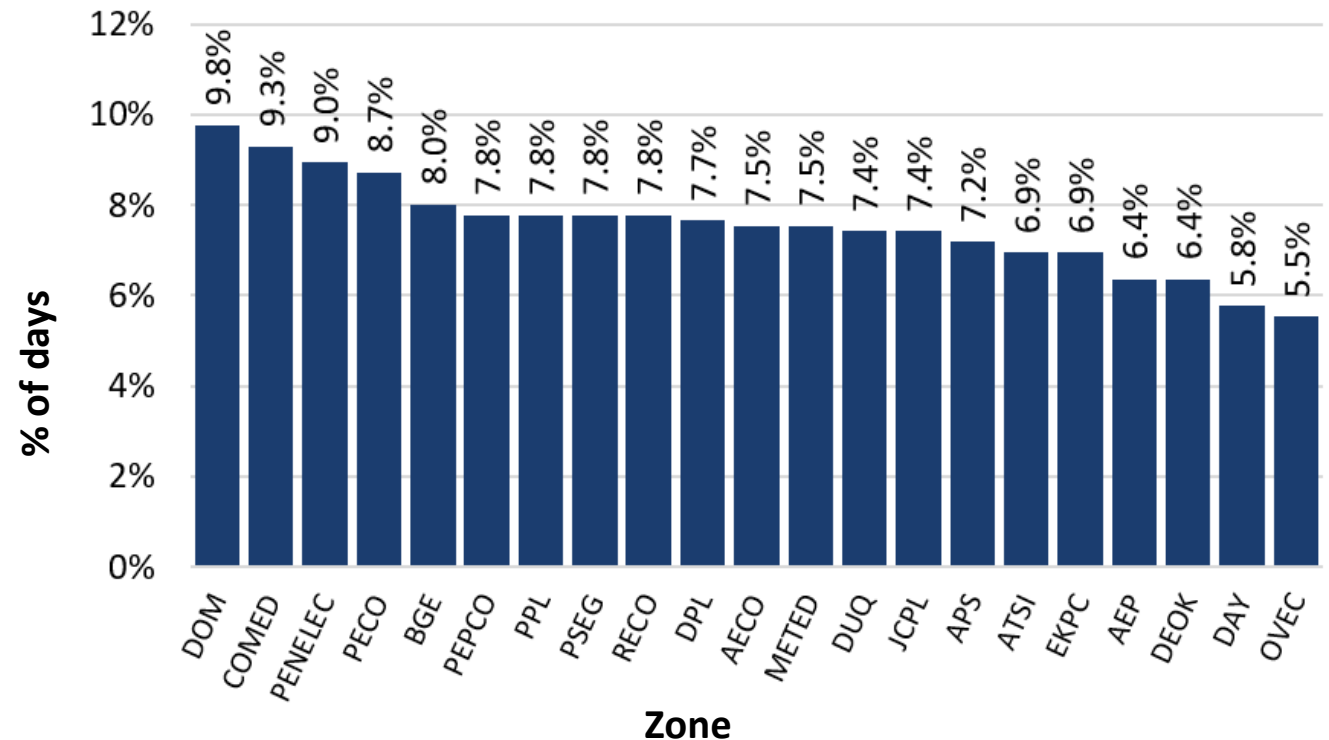
Offer Distortions and Missed Discharges under Proposed RT Offer Cap ($1.1 \times \text{Max DA LMP}$)

Offer Distortion: Percent (%) of days where the capped offer is below inter-hour opportunity cost

Takeaway: Offer distortion occurs in ~5-10% of days

- Of the 5.5% to 9.8% of days with offer cap distortion, 86% to 97% had at least one missed discharge intervals
- Note: almost all distortion days have at least one missed discharge interval

Share of Days with Distorted Offers
for 4-hr Battery in 21 Zones



Revenue Reduction under Proposed RT Offer Cap (1.1×Max DA LMP)

Revenue Reduction: Percent (%) of annual revenue reduced with vs. without the proposed offer cap

Takeaway: Revenue impact is nonzero and highest in constrained zones BGE, DOM, and PEPCO, but still a small fraction of the total value

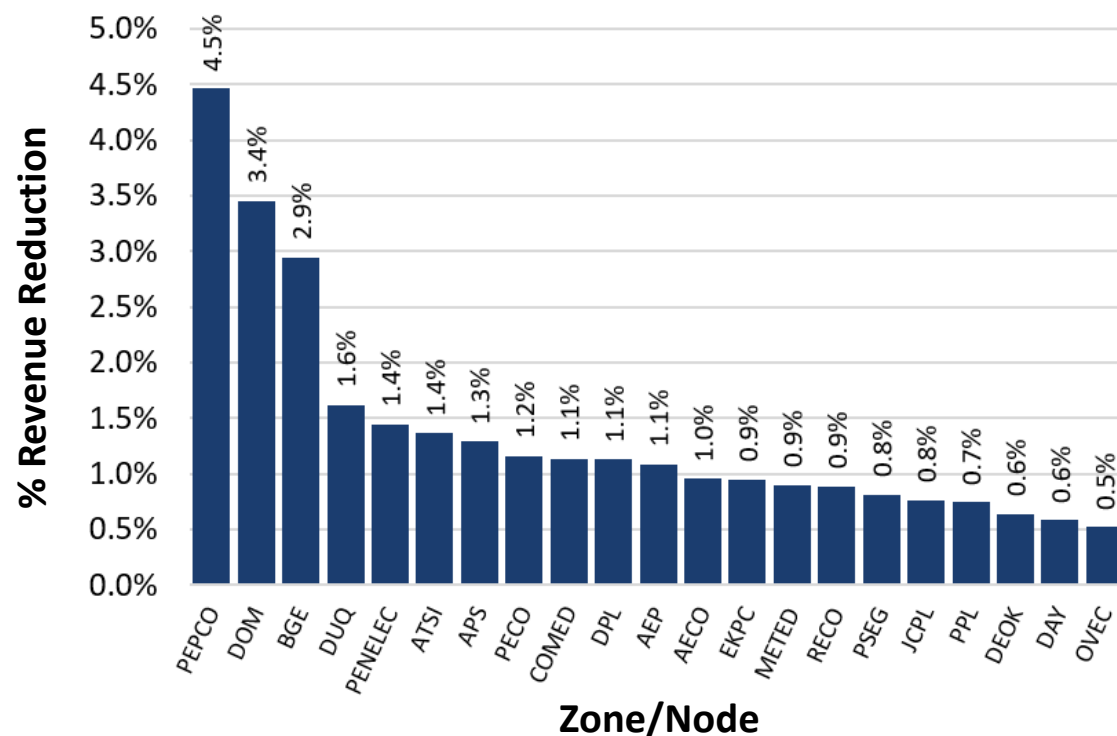
Offer cap results in 3% - 5% net energy revenue reduction in constrained BGE, DOM, and PEPCO zones

- Revenue impact analysis is net of imputed charging cost, assumes DA clearing of four-top-price hours (given \$1,000/MWh offer cap) and settlement with RT deviation
- RT-only dispatch results in 0.5% to 3.2% revenue reduction

Limitations of revenue reduction metric:

- The evolution depends on future expected volatility. For example, there may be more periods of longer duration (4+ hour) RT price spikes above the max DA price under changing system conditions, causing larger revenue reductions
- Under full granular production cost simulation approach, the storage operating with and without the offer cap could produce different battery dispatch, SOC trajectories, generator commitment, congestion, and LMPs with and without the offer cap, which could either mitigate or amplify the estimated revenue impact
- The revenue metric does not include any capacity market or ancillary services revenue

Percent Revenue Reduction Per Zone/Node Over the Study Period (2024-2026), 4-hr Battery



Notes: Revenue accounts for DA discharging dispatch under the \$1,000/MWh DA offer cap, with DA and RT settlement. Revenue is then settled against charging costs assuming an 85.7% round-trip efficiency, where charging occurs in the lowest 60 intervals.

Appendix:

I. Extended Offer Cap Analysis

II. ISO/RTO Approaches to Battery Market Power Mitigation

Reserves Impact Analysis: Misallocated SOC on Reliability Event Days Reduces Available Primary Reserves

Primary Reserve Replacement: Daily amount (GWh/day) of Primary Reserves that cannot be served by storage due to misallocated SOC across 4 GW battery fleet

Takeaway: capping offers at $1.1 \times \text{Max DA LMP}$ would cause **missing daily Primary Reserves of 2+ GWh** for four reliability event days in the two year study period

- Under the projected **4 GW** of battery storage in PJM by 2030, batteries could become a significant provider of Primary Reserves (~3 GW) on a system-wide basis
- On **reliability event days** supply is tight, and misallocated SOC across a large storage fleet will result in unnecessary system stress
- **5% of event days (four days over two years) had 2+GWh of missing Primary Reserve**
- Reliability events days are: Maximum Generation, EEA1, Hot Weather Alert, Cold Weather Alert, or Conservative Operations

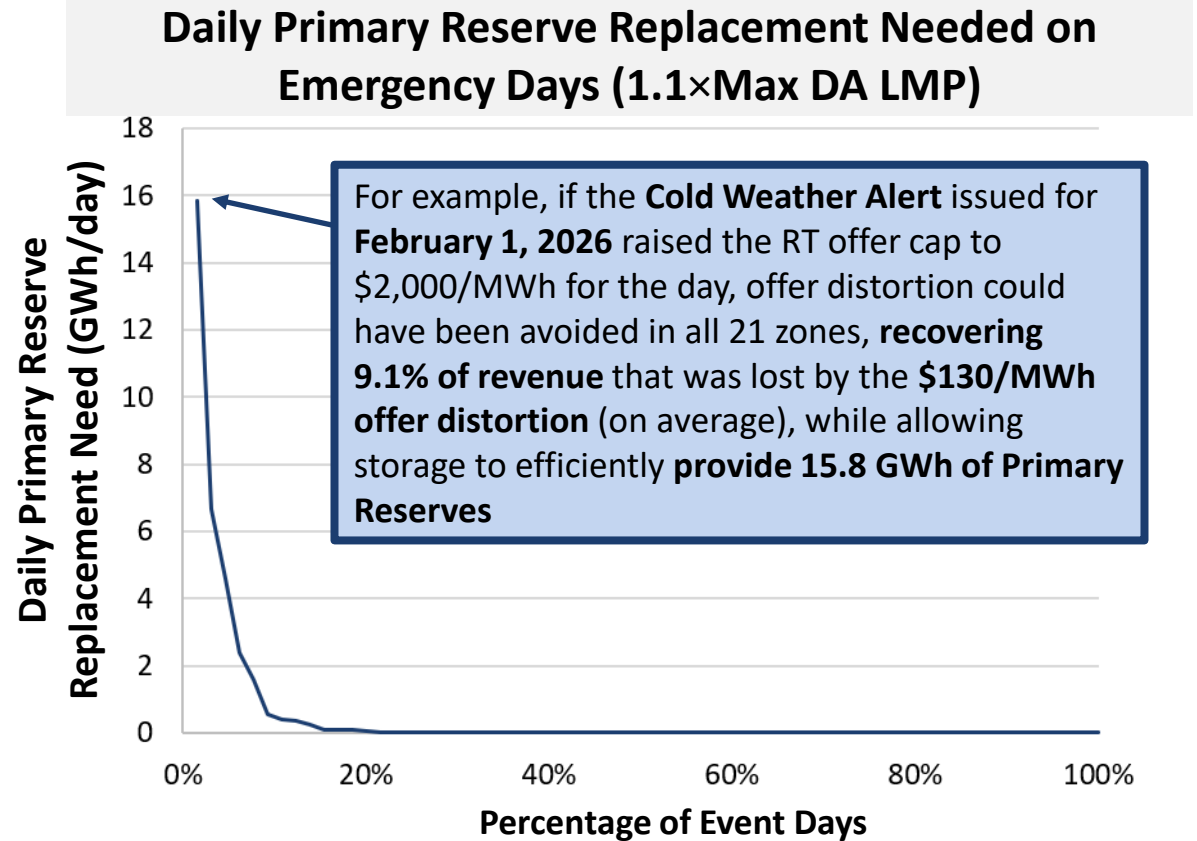


Figure Notes: 65 reliability events days from January 2024 to April 2026). Primary Reserve Replacement Need metric uses smoothed battery dispatch across the PJM footprint which assumes 4 GW of batteries are spread equally across each zone. Revenue accounts for charging costs, assuming an 85.7% round-trip efficiency, charging during the lowest 60 priced intervals.

ISO/RTOs Allowing Opportunity Costs in Mitigated Offer Prices

RTO	Is Inter-hour Opportunity Cost Bidding Allowed?	Market Power Mitigation Description
PJM	No	- Offers that fail Three Pivotal Supplier Test are mitigated - Mitigated offers in DA and RT based on charge cost and efficiency factor - Cannot increase RT offers above cleared DA offers (“Intraday Offers” rule)
ERCOT	Yes*	- Mitigation based on Constraint Competitiveness Test (the resource is mitigated only if it is under an uncompetitive constraint and has a shift factor below -0.2) - Storage offers are limited to alleviate congestion to avoid incurring costs above shadow price cap; allows batteries mitigated offers to be the highest price SCED will dispatch the battery to reduce congestion without manual actions - Batteries with a state of charge below 25% can bid up to the price cap even if they fail the Constraint Competitiveness Test
CAISO	Yes	- Market power mitigation based on the failure of Pivotal Supplier Test - CAISO-calculated opportunity cost allowed, can depend on SOC - RT mitigation uses DA prices; DA mitigation uses shadow prices from DA optimization
MISO	Yes	- Conduct + impact test. If resource fails, the bid is mitigated to a cost-based reference level - Allows for consultation between Market Participant and IMM to understand opportunity costs which can be used to set reference level
NYISO	Yes	- Allow the supplier to offer according to their own opportunity costs, by having any ex-ante mitigation (that exists only in zone J) incorporate opportunity costs that the supplier provides for each hour - Outside of zone J, there is no ex ante mitigation and all batteries can submit their own opportunity costs into the market with ex post review
ISO-NE	Yes	- Market power mitigation based on failure of Conduct + Impact Test - MPs can submit their own calculated opportunity costs but they must be able to analytically support the opportunity costs they submit with the IMM

*Note: ERCOT’s mitigated offer methodology is not based on opportunity costs directly, but resources with less than 25% state of charge are unmitigated meaning those resources can bid up to their opportunity costs. Mitigation of resources with greater than 25% state of charge is relatively lenient, but not directly tied to opportunity costs.

ISO/RTO Comparison of Opportunity Cost Calculation Engines

RTO	Opportunity Cost Calculation Process
PJM	- No opportunity cost engine for batteries - Opportunity cost engine for environmentally restricted fossil units that calculates opportunity costs based on a projection of annual profits from generating in the highest priced hours of the year (optimal dispatch for the generator) - The engine uses three projected forward series with different levels of volatility and an opportunity cost adder resulting from this engine is included in mitigated offers for these environmentally limited resources
ERCOT	No centralized engine to calculate opportunity costs
CAISO	- CAISO-calculated opportunity cost allowed which can depend on a resource's state of charge - RT mitigation uses DA prices; DA mitigation uses shadow prices from DA optimization - The outputted sloped offer curve is based on battery SOC with bottom end set at either marginal cycling cost or the 4th highest DA LMP of the day and the slope set based on the difference between the 1st and 4th highest prices hour of the day
MISO	No centralized engine calculate opportunity costs for storage resources (sellers can consult directly with the IMM to set opportunity costs)
NYISO	- NYISO allows the seller to offer according to their own opportunity costs, by having any ex-ante mitigation (that exists only in Zone J) incorporate opportunity costs that the seller provides for each hour - Outside of Zone J, there is no ex ante mitigation and all batteries can submit their own opportunity costs into the market with ex post review - However, If batteries choose not to submit their own opportunity costs, NYISO will estimate opportunity costs using a centralized opportunity cost calculation engine - For opportunity cost in the DA Market: NYISO opportunity cost calculation relies on prices from the past 90 days; For RT: NYISO opportunity cost calculation relies on DA prices for the same day
ISO-NE	No centralized engine to calculate opportunity costs (sellers can meet with IMM to discuss opportunity costs calculation method)

Real-Time Offer Flexibility Across RTOs

Key observation: Other RTOs provide flexibility to increase unmitigated storage offers, unlike PJM

RTO	Can offers increase in real time?	Real Time Bid Latency (before dispatch)
PJM	No	65 minutes before dispatch hour
ERCOT	Yes	5 minutes before dispatch interval
CAISO	Yes	75 minutes before dispatch hour
MISO	Yes	30 minutes before dispatch hour
NYISO	Yes	75 minutes before dispatch hour
ISO-NE	Yes	30 minutes before dispatch hour

REFORM CASE STUDY:

- **Initial rule (pre-2021):** Real-time energy offers were locked at the end of the Adjustment Period for the upcoming Operating Hour; subsequent updates became effective only in the next Operating Period
- **Storage carve-out (April, 2021):** [NPRR986](#) allowed ESRs—but not thermal generators—roughly five-minute offer updates
- **Full reform (August, 2024):** [NPRR1058](#) extended intra-hour bid and offer updates to all Resources, with QSEs required to provide a reason for updates submitted after the Adjustment Period

Appendix: Sources for ISO/RTO Comparisons

RTO	Sources
PJM	Sources: PJM, Manual 15: Cost Development Guidelines, November 25, 2024, pg. 82.
ERCOT	Sources: ERCOT, NPRR 1255 Discussion, May 19, 2025; ERCOT, ERCOT Nodal Protocols, July 21, 2025, pg. 6-17.
CAISO	Sources: CAISO, Energy Storage Enhancements: State of Charge Implementation Update, October 2, 2023; CAISO, Fifth Replacement FERC Electric Tariff, Section 39, June 25, 2025.
MISO	Sources: MISO, FERC Electric Tariff, November 30, 2024, pgs. 29, 210; MISO, Business Practice Manual 2: Energy and Operating Reserve Markets, September 30, 2024, pg. 86.
NYISO	Sources: NYISO, NYISO Market Services Tariff, July 16, 2025; NYISO, NYISO Market Services Tariff: Attachment F – Bid Restrictions.
ISO-NE	Sources: ISONE, Market Rule 1 Appendix A: Market Monitoring, Reporting and Market Power Mitigation, February 28, 2025, pgs. 37-49; ISONE, Market Rule 1: Standard Market Design, February 28, 2025, pgs. 59, 61, 62, 83, 100; ISONE, Day-Ahead Energy Markets: New England Wholesale Energy Markets (NEWEM), May 21-22, 2025.