Energy Storage Market Design Roadmap

WHOLESALE MARKET REFORMS TO UNLOCK THE POTENTIAL OF ENERGY STORAGE IN PJM, MISO, AND NYISO

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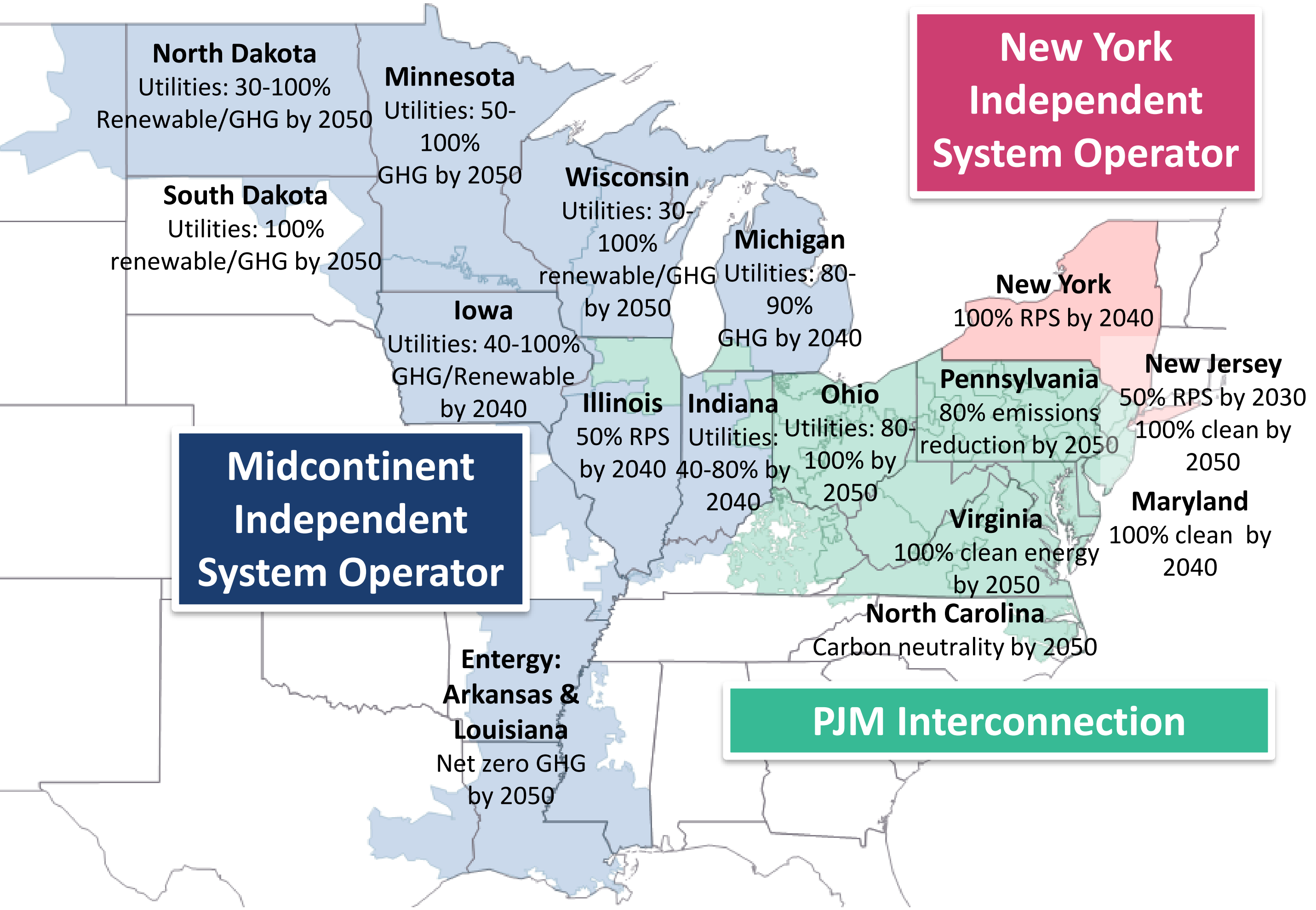
Introduction and Executive Roadmap

Energy Storage Market Design Roadmap Project



Source: Adapted from Illinois Renewable Energy Access Plan. See ICC Staff, The Brattle Group, Great Lakes Engineering, Illinois Renewable Energy Access Plan, December 2022.

Roadmap serves as an action plan for reforms to further unlock the value of storage

- Facilitate impactful, feasible market reforms
- Prioritize and guide policy engagement efforts of ACP and members
- Develop high-level concepts for solutions to address RTO-specific needs

Scope

- Wholesale market reforms
- Utility-scale applications, standalone and co-located

Focus on PJM, MISO, and NYISO because:

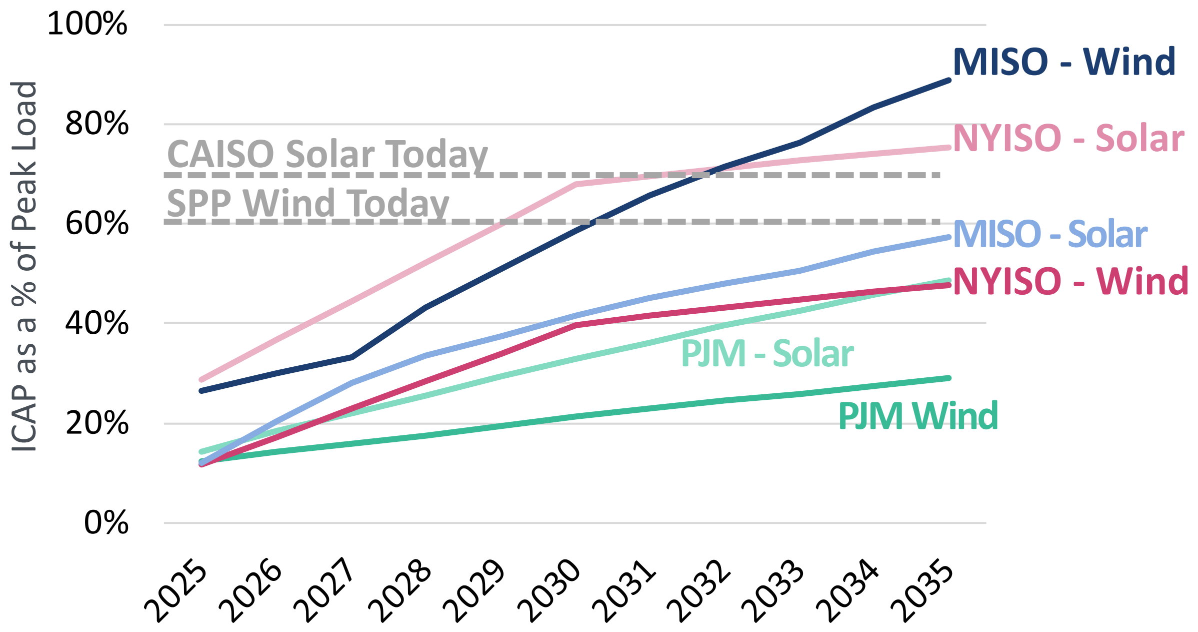
- Opportunities for market reform
- States pursuing decarbonization, anticipated rapid growth in demand and renewables
- Overall, a mix of central planning and market-based investment

The Case for Reform: Limits of Conventional Market Design

- Today's wholesale electricity market design is largely founded on the capabilities and limits of conventional generation
- Current challenges: load growth and retirements raise resource adequacy needs while increased reliance on variable resources (with fewer dispatchable fossil units) create flexibility needs
- Storage can meet these challenges, but storage value is constrained by market designs that do not currently address all system needs nor fully accommodate the special capabilities (and limitations of) storage resources

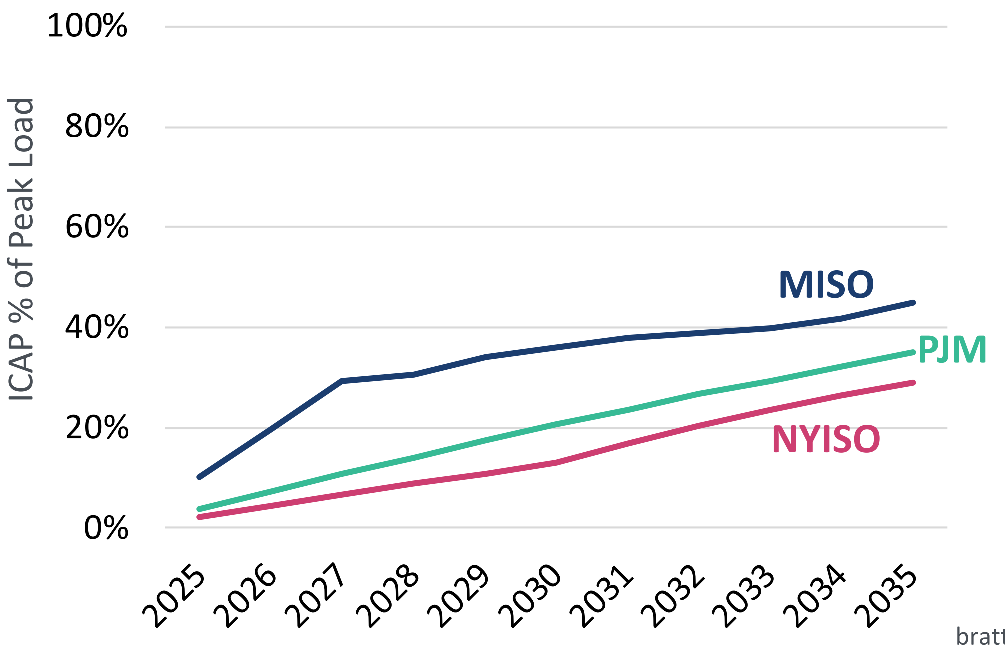
Growing Reliance on Variable Resources Will Increase Flexibility Needs Beyond the Limits of Current Market Design

Projected Renewable Deployment



New Facilities will be Needed to Replace Reliability Attributes of Retiring Fossil Units

Incremental Retiring Fossil

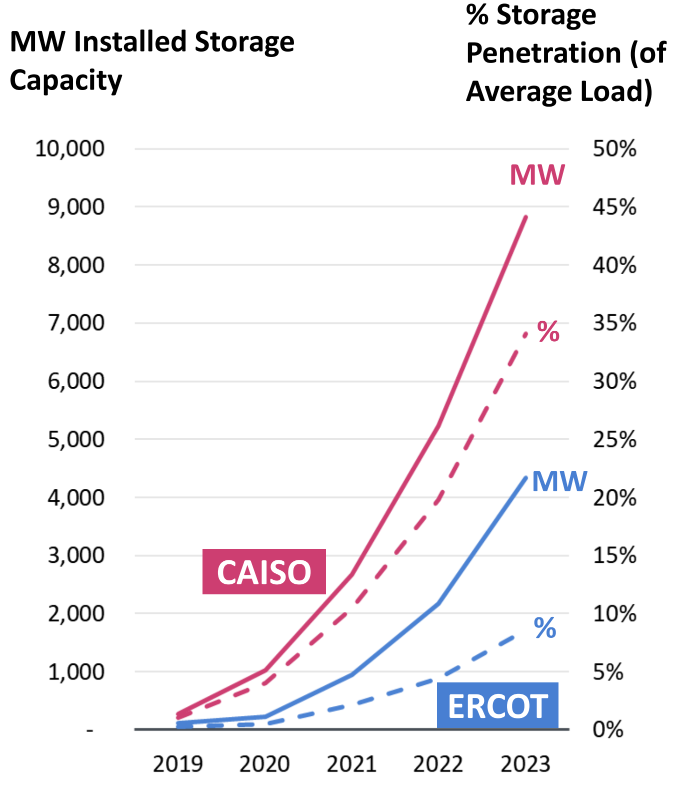


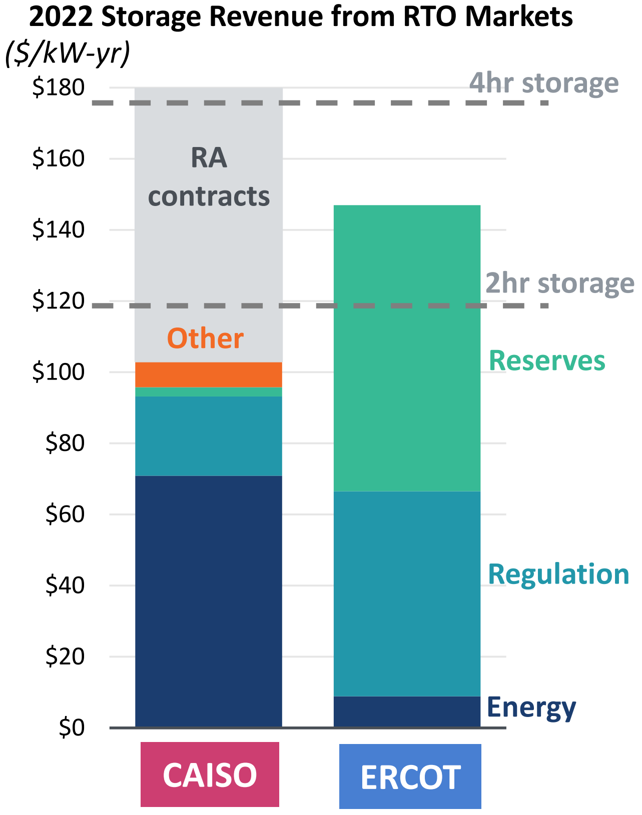
Markets Fund and Shape Storage Deployment (CAISO vs. ERCOT)

World-Leading Battery Deployment in ERCOT & CAISO

…Boosted by Revenues from Distinct Markets

Battery deployment in ERCOT and CAISO is due to high amounts of variable generation, along with enhanced market designs

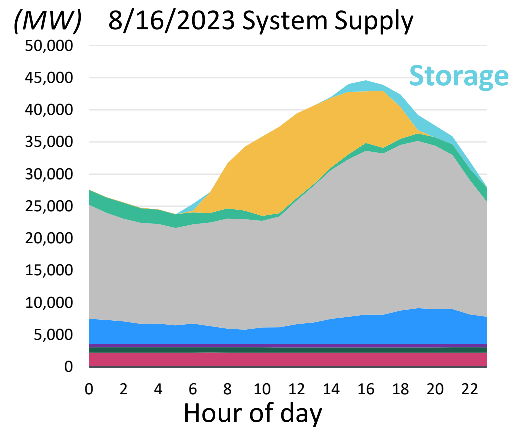


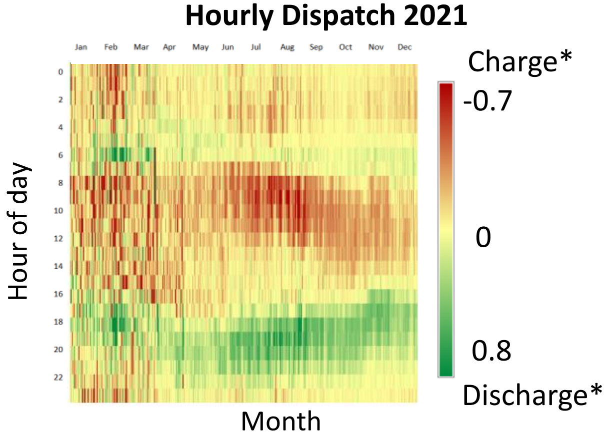


Sources and Notes: Figure reformatted from results in CAISO 2022 Special Report on Battery Storage Resources and from Modo Energy. In 2022, batteries in CAISO received nearly $30.5 million of bid cost recovery (BCR) mostly from RT market (~10% of all BCR settled despite being 5% of ICAP). Energy category includes revenues from Imbalance schedules. CA RA contract revenue ranging from $60 - $96 /kW-year is from Figure 16 ("RA only") CPUC 2023 Energy Storage Procurement Study.

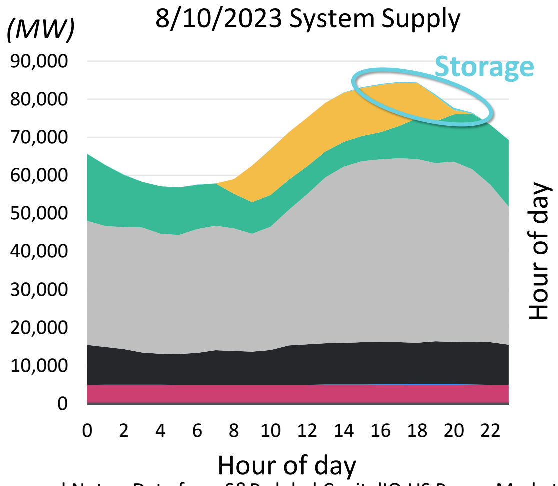
…Reflecting Divergent Applications and Operations

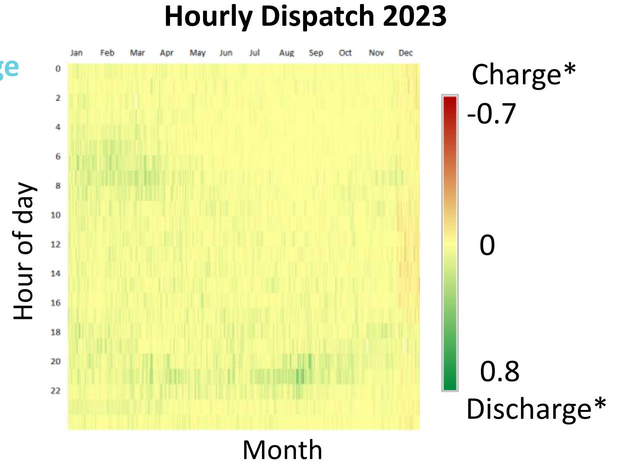
CAISO: Energy Arbitrage w/ Daily Cycling





ERCOT: Ancillary Services w/ Minimal Cycling





Sources and Notes: Data from S&P global CapitalIQ US Power Markets and Gridstatus.io; Note that charge and discharge is normalized for both ISOs as (MW charge or discharge) / (total end of month installed battery storage capacity). ERCOT only reports battery charging after December of 2023; figure only shows discharging, not charging.

Storage Roadmap: Continuing the RTO's Reforms for Energy Transition

Conventional Design

Today

Transitioned Markets

MISO

Capacity: Seasonal, hourly model for supply accreditation and demand curves
AS: ramp product, 30-min reserve covering multi-hour forecast error, dynamic AS volumes, scarcity pricing, dispatchable wind/solar
Energy: Storage market model, ELMP

NYISO

Capacity and Investment: MRI accreditation, broad solutions to transmission needs, storage as reference resource
AS: Balancing Intermittency Project: day-ahead uncertainty in reserves, dynamic reserve quantity, hourly reserve proposal
Energy: Storage market model, market power mitigation for storage, multi-interval dispatch, dispatchable wind/solar

PJM

Capacity: hourly model for demand curve, ELCC for all supply
AS: RegD, potential split up/down Regulation market, 30-min reserves, expanded AS volumes, scarcity pricing
Energy: Storage market model, dispatchable wind/solar

Energy Storage Market Design Roadmap

Other Reforms

Summary of Potential Reform Solutions

RTO	1. Capacity Value Section 1	2. Multi-Hour Uncertainty Product Section 2	3. Intra-hour Uncertainty/ Ramp Product Section 3	4. Alternative Reliability Solutions Post-Retirement Section 4	5. Opportunity Cost Bidding Section 5
MISO	Implement “Energy Equity” or “Capacity Equity/Even Loss” method	Develop Day Ahead Uncertainty product, mindful of key details to accurately reflect system value	Enhance existing ramp product	RFP for solutions to the reliability issue; consider lengthening deactivation notice period"	*None*
NYISO	Refine storage dispatch in reliability model		Develop ramp/uncertainty products, mindful of key details to accurately reflect system value	*None*	
PJM	*None*			RFP for solutions to the reliability issue; consider lengthening deactivation notice period"	Allow opportunity cost bidding, intraday flexibility

Rough Estimates Show Potential Depth of Market Reforms

THESE POLICY ASSESSMENTS ARE NOT FORECASTS

	Capacity Value	Day-Ahead Uncertainty Product	Intra-hour Uncertainty/Ramp Product (10-min flex)	Alternative Reliability Solutions	Opportunity Cost Bidding
Product	Capacity	New ancillary service	New ancillary service	Non-market reliability	Energy
Market size	Peak demand (or net demand)	24-hr ahead forecast uncertainty*: 1%-3% of peak demand **+** 5% - 15% of wind and of solar	Expected intrahour ramp-up† + intrahour uncertainty: 0.2% - 0.4% of peak demand **+** 0.5% - 1% of wind and of solar	5% - 15% of retiring units might leave reliability issues	Top 2 – 6+ hrs of daily net loads
Addressable by storage	10% - 30%	100%	100%	100% (mainly long duration)	10% - 30%
POTENTIAL STORAGE MARKET DEPTH IN 2030					
MISO	**14 to 41 GW**	**8 to 25 GW**	**700 to 1,700 MW + 700 to 1,400 MW**	**2.5 to 7.5 GW**	Deep
NYISO	**3 to 9 GW**	**2 to 6 GW**	**100 to 200 MW + 200 to 300 MW**	**0.3 to 0.9 GW**	Deep
PJM	**17 to 50 GW**	**6 to 19 GW**	**800 to 1,300 MW + 500 to 900 MW**	**2 to 6 GW**	Deep

(for Illustration only)

**Expected ramp and energy gap omitted from assessment of day-ahead and multi-hour ramp product, see Section 2 for further discussion*

†Expected ramp-up estimated from 80th to 95th percentile of June-August hourly change in net load for 2030 resource mix, divided by six for 10-min ramp. Sourced from GridStatus.io

Table of Contents of Energy Storage Market Design Roadmap

List of Acronyms and Abbreviations

AS: Ancillary Services

CR: Contingency Reserve

DA: Day Ahead

DAM: Day Ahead Market

GW: Gigawatt

Hr: Hour

ISO: Independent System Operator

Min: Minute

MW: Megawatt

NWA: Non-Wires Alternative

OCA: Opportunity Cost Adjustment (NYISO)

SOC: State of Charge

STR: Short Term Reserve (MISO)

Reg: Regulation Service/Reserve

RFP: Request For Proposals

RMR: Reliability Must Run

RT: Real Time

RTO: Regional Transmission Operation (used here to include ISOs)

VOLL: Value of Lost Load

Citations for Renewable Deployment and Retirements

RTO	Peak Demand	Solar Generation Capacity	Wind Generation Capacity	Generators at Risk of Retirement
MISO	137 GW in 2030 Source: MISO, MISO Futures Report: Series 2A, November 1, 2023	57 GW by 2030 Source: MISO, MISO Futures Report: Series 2A, November 1, 2023	80 GW by 2030 Source: MISO, MISO Futures Report: Series 2A, November 1, 2023	48 GW by 2030 Source: MISO, MISO Futures Report: Series 2A, November 1, 2023,
NYISO	30 GW by 2030 Source: State Scenario, NYISO, 2023-2042 System & Resource Outlook, Appendix H, July 23, 2024	20 GW by 2030, utility and BTM Source: State Scenario, NYISO, 2023-2042 System & Resource Outlook, Appendix H, July 23, 2024	12 GW by 2030, land-based and offshore Source: State Scenario, NYISO, 2023-2042 System & Resource Outlook, Appendix H, July 23, 2024	4 GW by 2030 Source: NYISO, 2023-2042 System & Resource Outlook, Appendix H, July 23, 2024
PJM	167 GW in 2030 Source: PJM, LTRTP Workshop Policy Study, October 1, 2024	55 GW by 2030 (includes solar + storage resources) Source: PJM, LTRTP Workshop Policy Study, October 1, 2024	35 GW by 2030 Source: PJM, LTRTP Workshop Policy Study, October 1, 2024	40 GW by 2030 Source: PJM, Energy Transition in PJM: Resource Retirements, Replacements & Risks, February 23, 2023
SPP	56 GW Source: SPP, 2024 Wind Solar and ESR Study Report, August 2024	Not evaluated	34 GW in 2024 Source: SPP, 2024 Wind Solar and ESR Study Report, August 2024	Not evaluated
CAISO	52 GW Source: CAISO, 2023 Annual Report on Market Issues & Performance, July 2024	36 GW (20 UPV and 16 BTM) Sources: CAISO, Installed renewable resources as of 11/7/2024; CAISO, Solar Eclipse Technical Bulletin, pp. 5, April 2024	Not evaluated	Not evaluated

* Source data interpolated to intervening years where necessary

1. Capacity Value of Storage Resources

Aspects of Storage Capacity Value Assessment in Reliability Models

Scope: assess two previously-identified topics that underestimate storage capacity value
without otherwise addressing the core risk modeling

Topic 1. Heuristic approach to capacity value assessment in reliability model

- Marginal ELCC/MRI methods evaluate the impact of incremental additions of a resource with three simulation scenarios (baseline, with test resource, and with benchmark resource)
- Unlike PJM and NYISO, MISO uses a less accurate one-step heuristic method that does not evaluate incremental additions; it instead looks only at the base scenario, leading to underestimation of storage value

Topic 2. Simulated dispatch order in the model

- Reliability models simulate stressful days in which storage is exhausted after discharging for many hours
- If storage is dispatched before emergency procedures in the simulation (counter to actual operations in some cases), it experiences more resource exhaustion before risk hours, reducing the reliability value storage otherwise could provide
- Furthermore, the dispatch order of similar energy-limited resources, (e.g. Demand Response) has substantial impacts on capacity value

Topic 1: Single-Step Capacity Evaluation in Reliability Models

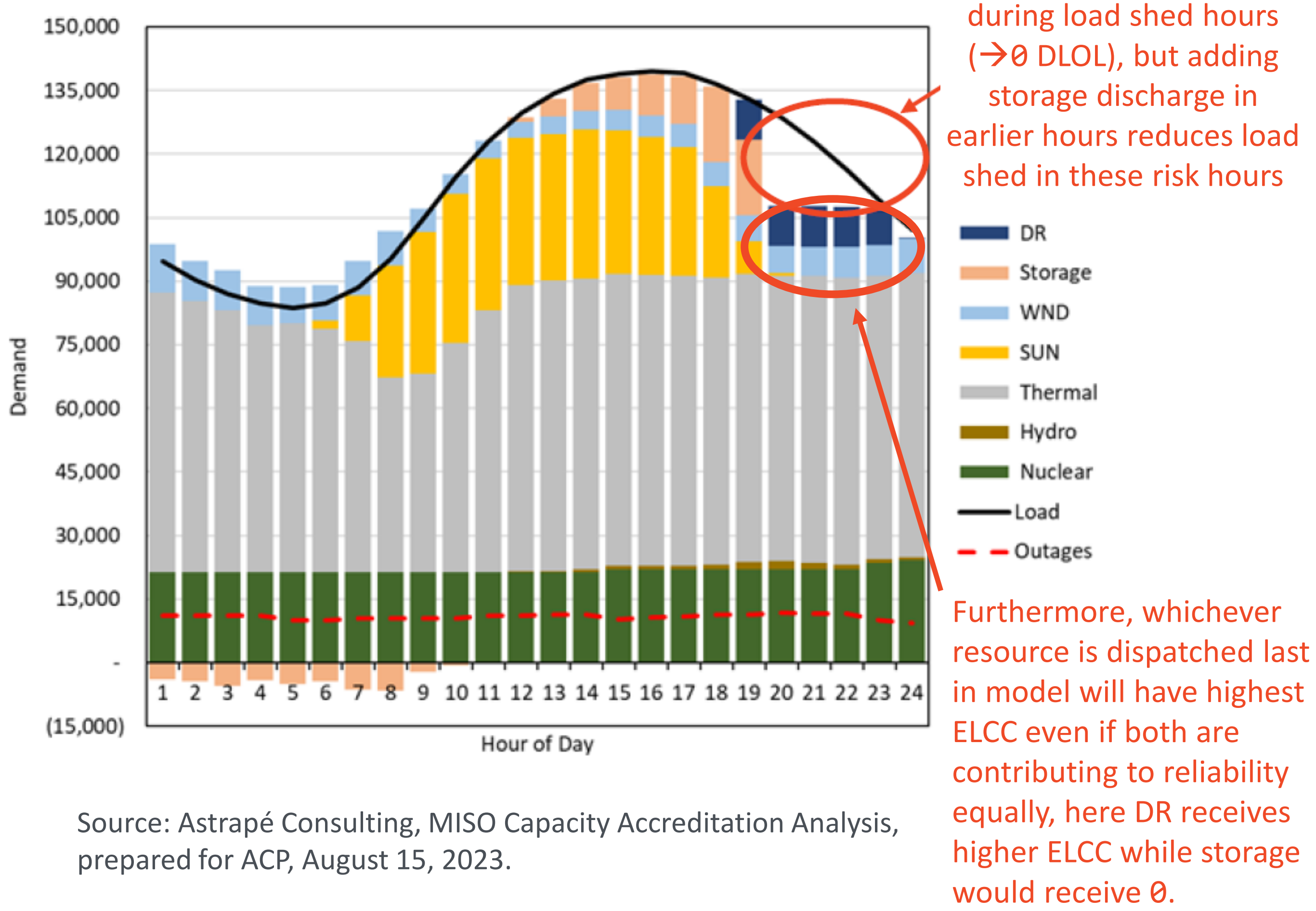
MISO's Direct Loss of Load (DLOL) approach to capacity accreditation relies on a single "snapshot" of underlying reliability risk in the model and accredits resources' contributions during reliability hours after dispatch decisions are made ex-ante

Capacity value of a resource under DLOL depends on modelled availability during risk hours (e.g., load shed hours) from that snapshot

Problems for storage: underestimates value of storage (and other resources such as solar and demand response) by failing to recognize that marginal storage additions (or additions of other resources) would change the modeled dispatch and move energy from non-risk hours into risk hours

(See example and reform solution on next slide)

Graphical Example of MISO's Proposed Direct Loss of Load (DLOL) Accreditation Approach



Source: Astrapé Consulting, MISO Capacity Accreditation Analysis, prepared for ACP, August 15, 2023.

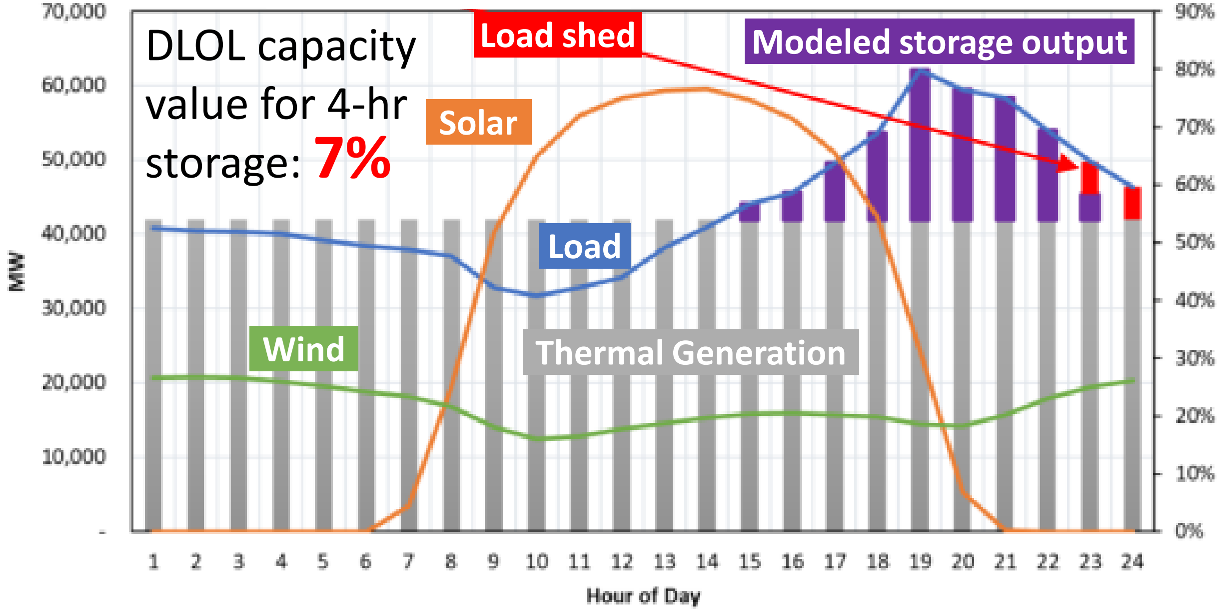
Topic 1 Reform: Change Simulated Storage Dispatch

DLOL approach sets capacity value according to output during load shed hours.

DLOL underestimates value of storage (and other resources) by failing to recognize that marginal storage additions can improve reliability by moving energy from non-risk hours into risk hours.

Alternatives to modelled storage dispatch mitigate (but do not fix) the issue

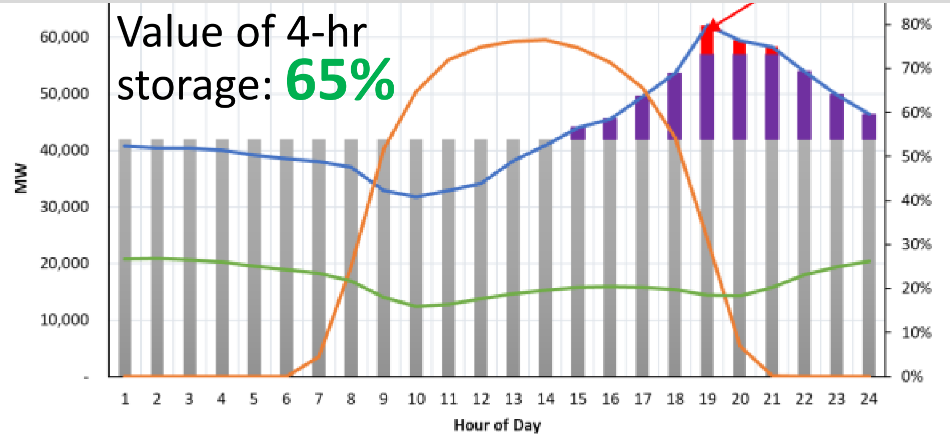
MISO Status Quo: Simulated Storage Meets Load Until Exhausted → Load Shed Is After Storage Exhaustion



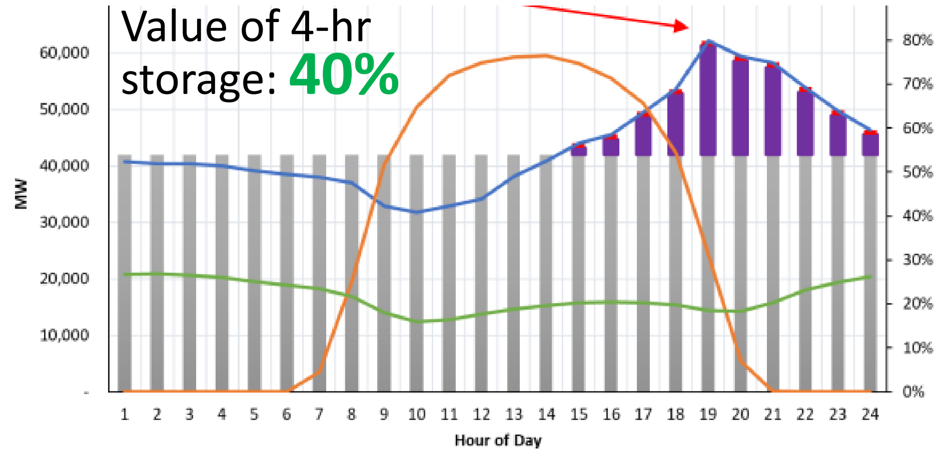
Alternative

Alternative

Capacity Equity/Even Loss Approach: Storage Dispatch Puts Shortfall in Peak Discharge Hours



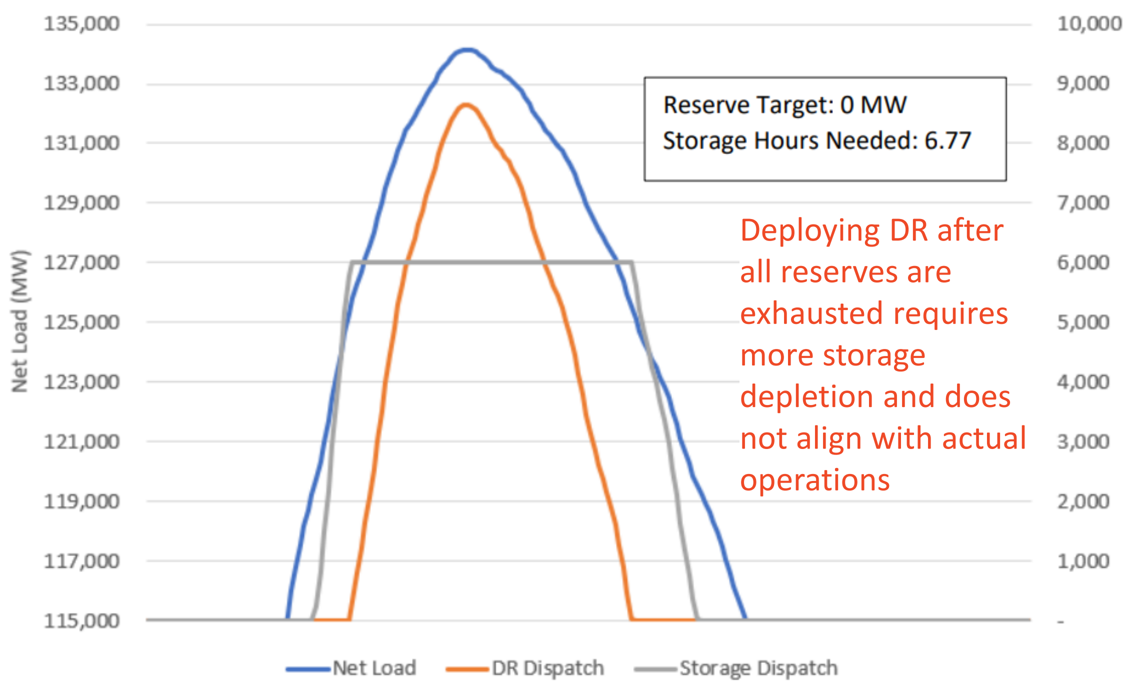
Energy Equity Approach: Storage Dispatch Puts Shortfall Across All Discharge Hours



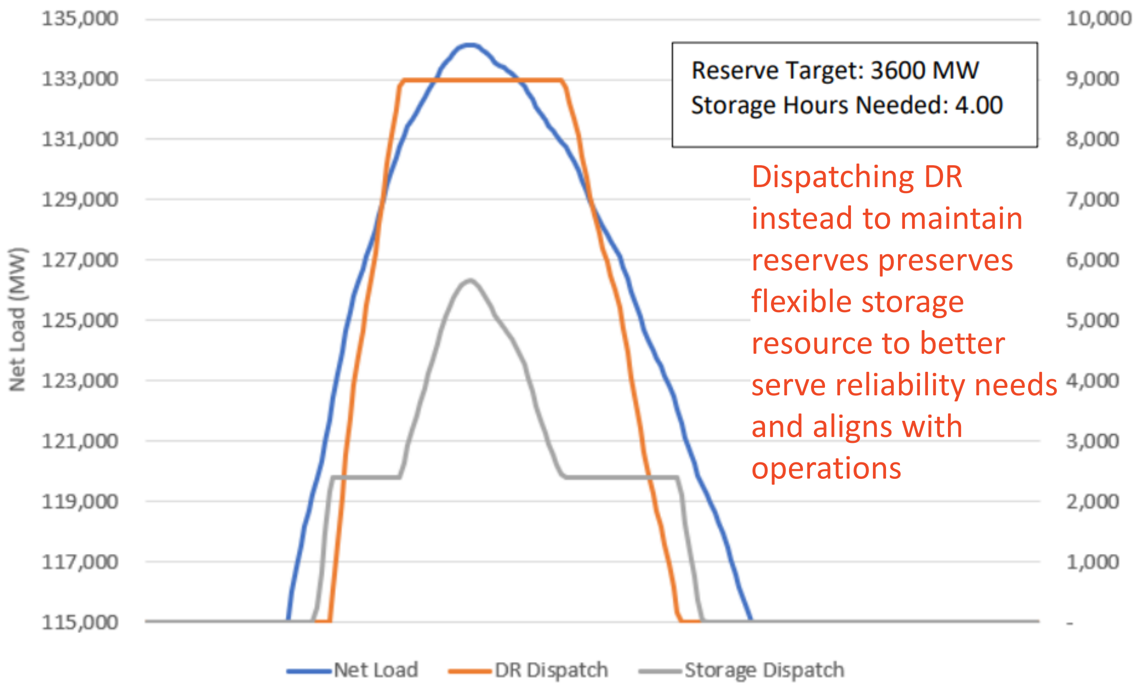
Source: Invenergy and Nextera Energy with Astrapé Consulting, DLOL Enhancements Proposal, August, 2023.

Topic 2: Dispatch Order in Reliability Models

DR Deployed After All Other Supply Is Exhausted



DR Is Deployed to Maintain Target Reserves Level Available from Other Supply (i.e., Storage)



"On a daily basis, maximize the reliability contribution of economic [Energy Limited Resource] *ELR by optimizing its utilization across energy and ancillary services by adjusting targeted reserves to be consistent with actual operating history. Reserve targets higher than operational minimums will result in slightly longer DR deployments but preserve storage capacity".*

Source: Kevin Carden, Astrapé Consulting, Draft Dispatch Methodology Proposal, presented to PJM Capacity Capability Senior Task Force (CCSTF), August 7, 2020.

Gap Analysis: Capacity Value of Storage in MISO, NYISO, and PJM

RTO	Capacity Evaluation Approach	Class-based*	Marginal	Zonal	Full Multi-step ELCC?	Simulated Dispatch Order of Storage
MISO Direct Loss of Load (DLOL)	Simulated availability during Critical Hours (hours w/ load shed and potentially w/ modelled supply margin < 3%)	✓	✓	✗	**No**, only assesses 1 snapshot from reliability model; underestimates storage by failing to recognize that marginal resource would change the modeled storage dispatch and reduce storage exhaustion by moving energy from non-risk hours into risk hours	• Simulated storage dispatched before DR & emergency procedures • Storage dispatch modeling details subject to near-term refinement at the MISO RA Subcommittee and pending answer to FERC deficiency notice
NYISO Marginal Reliability Improvement (MRI)	Ratio of reduction in LOLE from marginal class resource relative to perfect resource in the same zone	✓	✓	✓	**Yes**, accurately captures the beneficial effect of redispatching storage when a resource is added on the margin**	• Simulated storage deployed before DR & emergency measures (except before 1PM) • DR deployed to maintain target reserves (but reserves not assigned to storage)
PJM ELCC	Ratio of reduction in EUE from marginal class resource relative to perfect resource	✓	✓	✗	**Yes**, accurately captures the beneficial effect of redispatching storage when a resource is added on the margin	• Simulated storage dispatched after DR, and longer-duration storage before shorter duration

* With unit-specific performance adjustment

**NYISO avoids the term "ELCC", since they (like PJM and others) use a perfect generator as a benchmark, rather than scaling up load as per the original formulation of ELCC in 1966.

Capacity Value of Storage : **MISO** Potential Reform Solutions

OVERALL PRIORITY: HIGH

Potential Reforms
Option 1: Move to a full multi-step ELCC assessment
Option 2: Second best option (practical given recent FERC approval): adjust storage dispatch under DLOL; no perfect solution, but "energy equity" and "even loss/capacity equity" approaches better recognize reliability value of any marginal output during the storage discharge cycle
Refine simulated dispatch to align more with actual operations (e.g. more realistic modelling of simulated DR deployment) (could be included in current stakeholder effort)

Priority Items

Capacity Value of Storage : **NYISO** Potential Reform Solutions

OVERALL PRIORITY: LOW

Potential Reforms
Continue to refine simulated dispatch to align more with actual operations (e.g., assess impact of simulated reserve provision by storage on state of charge; seek realistic modelling of dispatch order of different durations of limited energy resources)

Appendix: Storage Capacity Value Actions in Target Markets

RTO	Current Status of Reform	Elements of Preferred Solutions	Roadmap Summary
MISO Direct Loss of Load (DLOL)	• FERC approved DLOL filing despite concerns about storage modeling • Details of storage dispatch modeling under DLOL is still under debate with the Resource Adequacy Subcommittee (RASC) as of April 2025	• **Option 1:** Reform to multi-step ELCC accreditation (less likely given recent FERC approval for DLOL) • **Option 2:** Plug into in ongoing stakeholder reform effort to discuss storage dispatch approach and order	• Contribute to ongoing stakeholder process at the RASC to discuss storage dispatch approach and order under DLOL (current stakeholder process)
NYISO Marginal Reliability Improvement (MRI)	Currently ongoing stakeholder process under the 2022 Improving Capacity Accreditation project, reform titled "Modeling Improvements for Capacity Accreditation – SCR Modeling"	Align simulated dispatch order of storage in reliability modeling with actual operations (i.e. dispatching DR before storage and long-duration storage before short-duration storage)	Engage with ICAP Working Group and New York State Reliability Council (NYSRC) to ensure enhanced modelling of storage discussions also considers reliability modelling dispatch order (current stakeholder process)
PJM ELCC	No preferred reforms	No preferred reforms	No preferred reforms

Sources: Capacity Value of Storage (NYISO)

Number	Title (Date)	Author / Organization
[1]	NYISO Manual 4, Installed Capacity Manual (Issued May 2024), 7.2. Capacity Accreditation Factors	NYISO
[2]	NYISO ICAP Manual 4 Attachments (May 2024), Attachment J, Section 6.7: Calculation of UCAP for Energy Storage Resources	NYISO
[3]	NYISO Modeling Improvements for Capacity Accreditation (March 2024)	NYISO Management Committee
[4]	NYISO Final CAFs for the 2024/2025 Capability Year (Feb 2024)	NYISO
[5]	NYISO ICAP Manual Appendix Revisions (Feb 2024)	NYISO ICAP Working Group
[6]	NYISO Capacity Accreditation: Implementation Details (Dec 2023)	NYISO Business Issues Committee
[7]	NYISO Approach to Update ELR Output Restriction Starting 2024-2025 IRM (Aug 2023)	NYISO Installed Capacity Subcommittee
[8]	NYISO State of the Market Report 2022 (May 2023)	Potomac Economics
[9]	Support for NYISO Capacity Accreditation Project (March 2022)	GE Energy Consulting
[10]	NYISO ELCC Accreditation Analysis (Jan 2022)	Astrape for Clean Energy/Storage Groups
[11]	NYISO Capacity Accreditation: Consumer Impact Analysis (Nov 2021)	Potomac Economics
[12]	Sensitivity Using GE MARS in Modeling ELRs (Oct 2021)	NYISO ICAP Working Group
[13]	ELCC Allocation Methodologies: Marginal, Average, and the Delta Method (Sep 2021)	E3 to NYISO ICAP Working Group
[14]	Capacity Accreditation: Straw Proposal (Aug 2021)	NYISO ICAP Working Group
[15]	Installed Capacity Subcommittee White Paper on Energy Limited Resources Modeling (May 2021)	New York State Reliability Council

Sources: Capacity Value of Storage (MISO)

Number	Title (Date)	Author / Organization
[1]	FERC Deficiency Notice on MISO DLOL Approach (July 2024)	FERC
[2]	MISO LOLE Modeling Enhancement: Planned Outage Modeling (April 2024)	MISO
[3]	Comments and Protests of the Clean Energy Parties on MISO DLOL Approach (March 2024)	Clean Energy Parties
[4]	MISO Initial DLOL FERC Filing (March 2024)	MISO
[5]	DLOL Enhancements Proposal (August 2023)	Inverenergy/Nextera Energy/Astrape
[6]	MISO Resource Accreditation White Paper (May 2023)	MISO
[7]	MISO LOLE Modeling Enhancements: Storage Modeling, RASC (August 2024)	MISO

Sources: Capacity Value of Storage (PJM)

Number	Title (Date)	Author / Organization
[1]	FERC Order Accepting Tariff Revisions Subject to Condition (Jan 2024)	FERC
[2]	PJM Capacity Accreditation Analysis for ACP (Jan 2024)	Astrape Consulting
[3]	PJM Response to FERC Deficiency Notice (Dec 2023)	PJM
[4]	PJM Marginal ELCC Filing (Oct 2023)	PJM

Ramp/Uncertainty Products: Introduction

Ramp/Uncertainty Products Compensate Resources like Storage to Meet Growing System Flexibility Needs

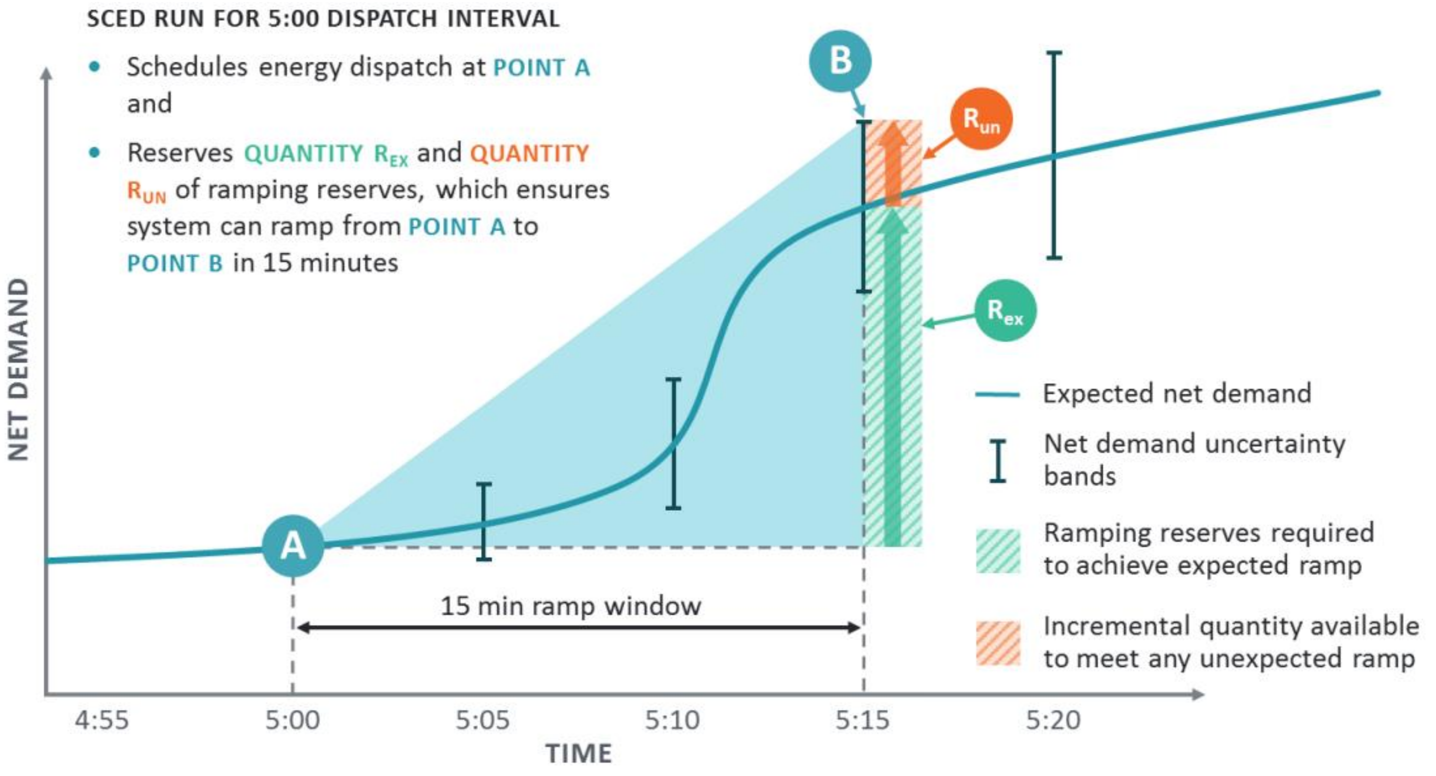
To reliably and efficiently meet growing variability and uncertainty, **new ancillary services can secure and pay for enough capability for expected and/or unexpected up-ramp in net demand**

- Expected ramp is more important in intra-hour intervals
- Uncertainty is more important when planning ahead for forecasted needs over the course of the day
- Procuring flexibility needs in-market will not only help position the fleet, but will signal efficient investment (unlike uplift for non-market commitment/dispatch instructions)

MISO, CAISO, and SPP launched the first ramping products in the **intra-hour** timeframe to address:

- Growing need for flexibility
- Spurious 5-minute price spikes due to transient shortfalls in ramp capabilities

Example of 15-minute Ramp/Uncertainty Product Procurement

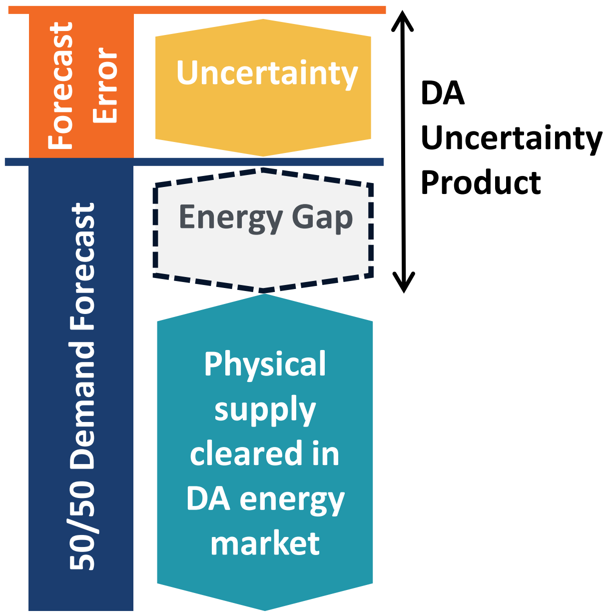


Source: Kathleen Spees and Sam Newell, [Modernizing Electricity Market Design – Efficiently Managing Net Load Variability in High-Renewable Systems: Designing Ramping Products to Attract and Leverage Flexible Resources], FERC Docket No. AD21-10-000, Post-technical conference comments on behalf of the New York State Energy Research and Development Authority, February 4, 2022

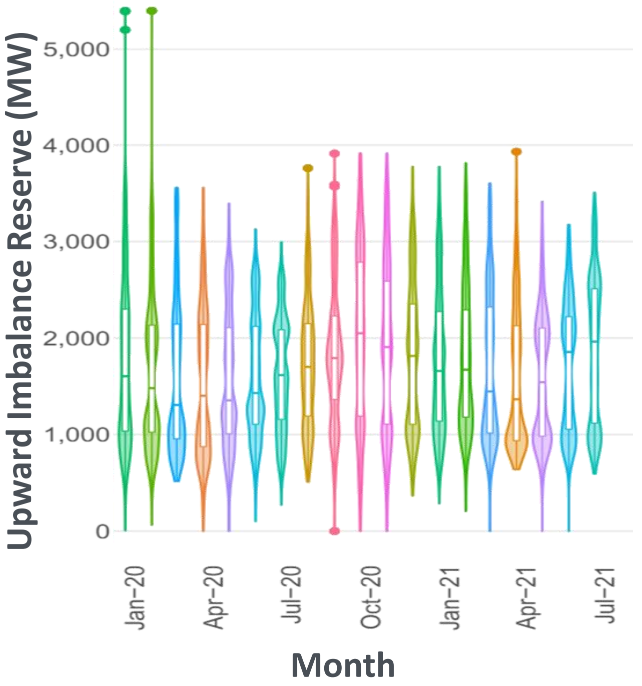
Ramp/Uncertainty Products Compensate Resources like Storage to Address Growing Multi-Hour Uncertainty

- Multi-hour uncertainty products are especially valuable in the day-ahead and hours-ahead timeframe, given higher uncertainty
- A Day-Ahead Uncertainty Product commits extra availability when needed to meet incremental forecasted needs, due either to:
  - The "energy gap", in which physical supply cleared in the day-ahead energy market falls short of the forecast, or
  - Uncertainty needs to cover scenarios in which net load comes in higher than forecasted
- A Day-Ahead Uncertainty Product replaces out-of-market actions that perform this same function today
- Day-Ahead Uncertainty Products are being developed and launched (CAISO and ISONE, and to some extent SPP and MISO)

Day-Ahead Uncertainty Product Covers Uncertainty and the "Energy Gap"



1-3+ GW Needed in CAISO to Cover Day-Ahead Uncertainty



Notes/Source: Data is for the CAISO footprint (i.e., future requirement will be higher given more renewables). See CAISO, Day-Ahead Market Enhancements Analysis Report, January 24, 2022, Figure 3, p. 9.

Ramp Product Definition Improved by Higher Scarcity Pricing in Broader Reserves Construct, Reflecting High Reliability Value

Overlapping Reserves

- When a MW of resource capability can sell two reserves at once, the reserves "overlap"
  - Conventional Operating Reserves are rarely defined to overlap, e.g., a MW cannot sell Regulation and Spinning Reserve in the same interval
- Because multi-hour uncertainty/ramp products target intervals much further in the future, they are more often allowed to overlap with conventional operating reserves
- Overlapping reduces price interaction between reserve products, and increases the MW of ramp supply

Nesting and Cascading

- When a MW assigned to one reserve product counts towards the need for a second product (or similar logic), it "nests"
- With nesting, scarcity pricing (or sometimes all pricing) in the parent product is added to (aka "cascades" into) all nested products
  - Reserve products are ranked so that lower priority products run scarce first, and are priced lower
- Nesting and cascading definition across reserve products are part of a coherent scarcity pricing framework

Solution Considerations

- MISO, NYISO, and PJM could **increase conventional operating reserve scarcity prices** to reflect their full reliability value, thus making room also for the full value of the ramp product
- **An intra-hour ramp product should not overlap with conventional reserves**, because they share the same time horizon; for the same reason, it should fit into the nesting/cascade construct
- Whether to overlap/cascade/nest are key design decisions for multi-hour ramp/uncertainty product

2. Day-Ahead and Other Multi-Hour Uncertainty Products

Jurisdictional Review of Day-Ahead and Multi-Hour Uncertainty Products

	CAISO Imbalance Reserve and Reliability Capacity [3]	SPP Uncertainty Product [4][5][6][7]	ISO-NE Day-Ahead Energy Imbalance Reserves [9][10]	MISO Short Term Reserves [11][12][13][14]	NYISO 60 min Product [19] (design concept, currently suspended)
Type of Product	DA Uncertainty Product	Multi-Hour Ramp/Uncertainty Product	DA Uncertainty Product	Multi-Hour Uncertainty Product	DA Uncertainty Product and Multi-Hour Uncertainty Product
System Needs Procured	DA uncertainty plus DA energy gap (shortfall of DA physical energy vs. ISO forecast)	Hour-ahead uncertainty plus expected ramp	DA energy gap (shortfall of DA physical energy vs. ISO forecast)	3-hour ahead uncertainty	DA and multi-hour ahead uncertainty
Required Flexibility	30-min ramp	1-hr ramp	1-hr ramp	30-min ramp	1-hr ramp
Minimum Duration Requirement	1 hr	1 hr	1 hr	1 hr	4 hr
Procurement Timeframe	DA	RT (with hour-ahead UC, plus DA forward)	DA	RT (and DA forward)	RT and DA
Ramping Demand Curve and Pricing	Multi-step penalty, highest at $55	Multi-step penalty, highest at ~$113/MWh	Penalty capped at $2,575/MWh	Multi-step penalty, highest at $500/MWh	TBD demand curve not nested in existing ORDCs
Allows Offer Costs (above Opp. Costs)	Yes	Yes, for offline units	Yes	Yes, for offline units, $100/MWh cap	TBD
Locational Approach	Nodal	Zonal	System-wide	Zonal	Zonal
Ramp Direction	↑↓	↑	↑	↑	↑

Solution Sketch for Day-Ahead and Multi-Hour Uncertainty Products

System Needs Procured	Sufficient procurement quantity to meet the energy gap, forecast error events, and otherwise satisfy operator conservativeness in the day-ahead timeframe (aim to replace all non-local RUCs); inclusion of expected ramp is less important in day-ahead, but the energy gap procurement may be needed to avoid unintended interactions with virtuals; multi-hour ramp/uncertainty products should cover expected ramp + uncertainty
Seller Offers	Price formation with broad inclusion of seller costs (replacing non-local uplift); allow sellers to offer premia to endogenous lost opportunity cost from energy sales
Demand Curve	High-value demand curve (e.g., up to a fraction of VOLL) that reflects system value of incremental reserves when forecasts show potential scarcity; most efficient pricing requires raising shortage pricing across all reserves
Resource Eligibility	Broad resource eligibility (including faster-starting units scheduled offline) to assuage cost impact concerns
Non-Performance Penalty	Inclusion of penalties indexed to VOLL
Ramp Capability Timeframe	TBD—0.5 to 12+ hrs, depending on interaction with intraday scheduling processes
Min. Duration Req’t	Requires RTO-specific analysis, likely multiple hours
Procurement Time	Day ahead, with intraday procurement optional
Locational Approach	More granular is better where feasible, zonal or better
Ramp Direction	Up more valuable, reflecting VOLL; down reflects the expected value of avoided RE curtailment, which can be appreciable especially for wind dominated systems

Principles for Minimum Duration Requirement for Day-Ahead and Multi-Hour Uncertainty Products

Duration is Implied by the Purpose and Desired Outcome of the Multi-Hour Uncertainty Product

- **Purpose**: ensure efficient quantity of long lead-time supply (or DR) has been committed to meet poor net load forecast outcomes (or under-commitment in DA energy market)
- RTO may need to depend on multi-hour ramp assigned in day-ahead for many hours **until the forecast error event resolves**, or until **operational alternative can be arranged**

Lead Time of Operational Alternatives

- Evaluation of the resource fleet typically available following a poor forecast event
  - E.g., offline conventional generators with 1 – 4 hr start time
- In the future: coordination with other, slower reserves

Duration of Forecast Error Events

Evaluation of the duration of historical net load underforecasting events

Total Under-forecasting Error (Ramp Up Energy) MWh

Duration of Error (Hours)	400	800	1310	1600	2000	2620	3000	4000	6000	10000	14000
1	147	0	0	0	0	0	0	0	0	0	0
2	110	5	0	0	0	0	0	0	0	0	0
3	57	14	1	0	0	0	0	0	0	0	0
4	26	34	8	1	0	0	0	0	0	0	0
5	12	30	17	2	3	1	0	0	0	0	0
6	5	20	21	5	3	0	0	0	0	0	0
7	1	11	11	6	4	2	0	1	0	0	0
8	1	8	13	4	11	7	2	2	1	0	0
9	0	4	6	4	3	5	2	3	1	0	0
10	0	0	0	9	3	2	0	0	0	1	0
11	0	0	1	2	8	10	0	1	1	0	0
12	0	0	1	2	2	1	1	2	2	1	0
13	0	1	0	2	1	4	8	2	2	2	1
14	0	0	0	3	2	1	1	0	5	4	0
15	0	0	0	1	1	1	1	3	9	2	0
16	0	0	1	0	0	1	2	0	4	2	1
17	0	0	0	0	0	3	2	1	4	3	0
18	0	0	1	0	0	0	0	2	10	3	1
19	0	0	0	0	0	1	1	2	3	3	0
20	0	0	0	0	0	0	2	0	10	2	0
21	0	0	0	0	0	0	0	0	2	6	2
22	0	0	0	0	0	0	1	0	2	4	2
23	0	0	0	0	0	0	0	0	2	1	0
24	0	0	0	0	0	0	0	0	0	2	1

Source: NYISO, [Balancing Intermittency: Uncertainty Reserve Requirement Calculation,] Sep. 5, 2024

Day-Ahead and Multi-Hour Uncertainty Products Need Not Include Expected Ramp, but Likely Need to Cover Expected Demand

A multi-hour uncertainty product designed to address uncertainty **in the day-ahead timeframe** does not necessarily need to account for expected ramp, because the day-ahead energy market already accounts for expected hour-to-hour ramp needs in the 24-hour schedule, and there are seldom multi-hour costs in DA to meet expected changes in net demand

- That is, generator ramp limits do not generally affect schedules in the day-ahead market, since the hourly time resolution is slow relative to ramp rates
- Some ISO/RTOs may not incorporate generator ramp limits into the day-ahead market

However, the day-energy energy market may not commit sufficient physical supply to meet the forecast (due to voluntary bids being too low, or clearing of virtual supply to meet demand); thus, **Day Ahead Uncertainty Products often procure extra capability to meet the “energy gap”** relative to the forecast

- Day-ahead demand is largely determined on the margin by virtual players, who may respond to larger DA reserve procurements by lowering aggregate DA energy demand (in anticipation of fewer high-priced RT shortage events, and generally lower RT energy prices).
- The system operator may respond in turn by increasing out of market reliability unit commitments, partly undoing the effect of the market-based commitments from the reserve product

Gap Analysis: Day-Ahead and Multi-Hour Uncertainty Products

RTO	Sufficient Procurement Quantity to Satisfy Day-Ahead Operator Conservatism?	Price Formation With Broad Incl. of Seller Costs?	Tall Demand Curve?	Broad Resource Eligibility?	Non-Performance Penalties
MISO (Short Term Reserve)	✓- Uncertainty covers 3-hr ahead instead of 24-hr ahead; ignores energy gap	✓	✗ Capped at $500	✓	✓
NYISO (Balancing Intermittency Phase 1 for 30-min reserves)	✓- Uncertainty covers 24-hr ahead; ignores energy gap (risking poor interaction with virtuals given the large day-ahead uncertainty)	✓ Broad offer allowance in day ahead	✓ Maximum value of $750/MWh for 30-minute reserves	✓ Includes DR, offline thermal generators w/ 2-hour start and faster	Proposed
PJM	✗ Has no multi-hour ramp/uncertainty product				

Day-Ahead and Other Multi-Hour Uncertainty Products: **MISO** Potential Reform Solutions

OVERALL PRIORITY: HIGH

Potential Reforms Relative to Existing Product (STR)

Priority Items

- Modify STR or add a new day-ahead uncertainty product with sufficient procurement quantity to satisfy operator conservativeness, addressing 24-hr ahead uncertainty plus energy gap and replacing all non-local RUCs; if timeframe remains intra-day, then add procurement of expected ramp
- Tall demand curve that reflects system value of incremental reserves when forecasts show potential scarcity
- Strengthen non-performance penalties (which boosts efficiency, price, and favors high performers)

Day-Ahead and Other Multi-Hour Uncertainty Products: **NYISO** Potential Reform Solutions

OVERALL PRIORITY: MEDIUM

Potential Reforms Relative to Proposal
(Balancing Intermittency Phase 1 Day-Ahead Procurement of 30-Min Reserve)

Priority Items

Propose reform to Uncertainty Reserve Requirement to add energy gap to DA requirement (avoiding poor interaction with virtuals); monitor implementation for sufficient procurement quantity to satisfy operator conservativeness (addressing 24-hr ahead uncertainty and replacing all non-local RUCs)

Increase maximum value of demand curve above $750/MWh to reflect system value of incremental reserves when forecasts show potential scarcity

Non-performance penalties (boosts efficiency, price, favors high performers)

Introduce slower multi-hour ramp/uncertainty reserve product for 60 minutes or slower ramp capability, like BI Phase 2 proposal, including a market mechanism to address the shortfall of bid-in energy demand relative to forecast demand

Day-Ahead and Other Multi-Hour Uncertainty Products: **PJM** Potential Reform Solutions

OVERALL PRIORITY: HIGH

Potential Reforms Relative to Status Quo (No Product)

Develop a new uncertainty reserve product w/ sufficient procurement quantity to satisfy operator conservativeness (addressing 24-hr ahead uncertainty and energy gap, thus replacing all non-local RUCs)

Price formation with broad inclusion of seller costs (replacing non-local uplift); allow sellers to offer premia to endogenous lost opportunity cost from energy sales

Tall demand curve that reflects system value of incremental reserves when forecasts show potential scarcity

Broad resource eligibility (including units scheduled offline) to ensure efficient outcome, lower cost impact

Non-performance penalties (which boosts efficiency, price, and favors high performers)

Priority Items

Appendix: Design Parameters of Ramp/Uncertainty Products

System Needs Procured: Uncertainty vs. Expected Flexibility Needs, Including the Energy Gap: Whether the ramp product is procured to meet needs from unexpected ramp (the potential for error in net demand forecasts over the ramp capability timeframe), the expected ramp (the forecasted change in net demand over that timeframe), or the energy gap (shortfalls in cleared physical day-ahead supply relative to forecast)

Required Flexibility: The number of minutes or hours over which the system needs (and a resource can provide) ramping capability

Ramp Product Procurement Timeframe: When the ramping product is procured for use in real-time. In general, it is either procured intra-hour, closer to real-time (typically with a forward procurement in the day ahead market), or it is procured in over a multi-hour timeframe (such as in the day-ahead energy market)

Ramping Demand Curve and Pricing: Nature of the demand curve for the ramp product (fixed requirement, multi-step penalty factor curve, or a smooth demand curve), and the maximum willingness to pay for the product.

Allows Offer Costs above Opportunity Costs: Co-optimized opportunity costs, where a resource offering to provide ramping product will automatically have the opportunity cost of not providing energy accounted for in clearing. Some ramping products also allow product-specific offers.

Locational Approach: Whether the product accounts for deliverability constraints and transmission (zonally or nodally) or is instead a uniform systemwide product.

Ramp Direction: Upward and/or downward ramp

3. Intra-Hour Ramp/Uncertainty Products (e.g., for 10-Minute Ramps)

Jurisdictional Review of Intra-Hour Ramp/Uncertainty Product

Product Name and Jurisdiction	CAISO Flexiramp Product [1][2]	SPP Ramp Product [5][6][7]	Australia NEM Operating Reserve (not implemented) [8]	MISO Ramp Capability Product [13][14][15]	NYISO 10 and 30-Min Reserves w/ Uncertainty [16][17][18] (proposed)
Ramp Capability Timeframe	5-min ramp (and 15-min via FMM)	10-min ramp	30-min ramp	10-min ramp	10- and 30-min ramp
Minimum Duration Requirement	N/A	N/A	N/A	N/A	1 hr
Procurement Timeframe	RT (5 and 15 min)	RT (and DA forward)	RT	RT (and DA forward)	RT (and DA forward)
Flexibility Needs Procured (Procurement Quantity)	**Unexpected** and **expected** ramp	**Unexpected** and **expected** ramp	**Unexpected** and **expected** ramp minus other reserves.	**Unexpected** plus **expected** ramp	**Unexpected** ramp
Ramping Demand Curve and Pricing	Multi-step penalty factor, highest at $247/MWh	Multi-step penalty factor, highest at $23/MWh	Multi-step penalty factor, highest at $10,214/MWh	Multi-step penalty factor, highest at $31/MWh	One lower value step on 10- and 30-min ORDCs, highest $40/MWh
Allows Offer Costs (above Opp. Costs)	No	No	Yes	No	No
Locational Approach	Nodal	None	None	Zonal	Zonal
Ramp Direction	↑↓	↑↓	↑	↑↓	↑

Sketch of Preferred Solution for Intra-Hour Ramp/Uncertainty

Procurement Quantity	Include uncertain ramp + expected ramp in procurement (at short timescales, expected dominates, and is not otherwise fully procured and priced in-market); quantify uncertainty dynamically, potentially capturing day-specific meteorological scenarios
Seller Offers	Allow sellers to offer premia to endogenous lost opportunity cost from energy sales (above penalty risk)
Demand Curve	High-value demand curve (e.g., up to a fraction of VOLL) to reflect system value of incremental reserves when forecasts show potential scarcity; requires raising shortage pricing across all reserves
Resource Eligibility	Online and fast start
Non-performance Penalty	Include non-performance penalties (which boosts efficiency, price, and favors high performers), ideally indexed to VOLL for failures during emergencies
Ramp Capability Timeframe	Close to real-time (present assessment assumes 10-minutes)
Min. Duration Requirement	None (or 5 minutes)
Procurement Timeframe	RT (with DA forward)
Locational Approach	More granular locational approach is better, zonal or better
Ramp Direction	Up more valuable, reflecting VOLL; down reflects the expected value of avoided RE curtailment, which can be appreciable especially for wind dominated systems

Principles for Minimum Duration Requirement for Intra-Hour Ramp/Uncertainty Product

Purpose and Desired Outcome of Intra-Hour Ramp Product Points to Short-Duration Needs

- **Intra-hour Ramp Purpose**: produce an energy dispatch optimized for upcoming ramp needs; avoid exhausting ramp capability and the resulting transient shortage
- Focus is on expected ramp over 10 minutes
- The intra-hour ramp product has a distinct purpose from that of traditional 10-minute or 30-minute contingency reserves
- The headroom available for energy market dispatch changes w/ every 5 minute interval, esp. during ramps

No Duration Requirement Needed Given Short-Duration Application

- **The purpose implies a 5-minute duration requirement,** consistent with the lack of a duration requirement on existing intra-hour ramp products in MISO, SPP, and CAISO.
- NYISO has proposed an intra-hour ramp product that is integrated with contingency reserves, and therefore inherits the corresponding duration requirement

Gap Analysis: Intra-Hour Ramp/Uncertainty Products

RTO	Procurement Quantity Includes Expected + Uncertain Ramp?	Dynamic Procurement Quantities for Uncertain Ramp?	Tall Demand Curve?	Allows Sellers to Offer Above Endogenous Opp. Cost?	Non-Performance Penalties
MISO	✓	Under development	✗ Limited to $31/MWh	✗	✗
NYISO (proposed)*	✗ Unexpected only	✓	✗ Limited to $40/MWh	✗	Under development†
PJM	Has no ramp product				

*Rated against recent Uncertainty Reserve Requirement proposal from Balancing Intermittency Project

†Source: NYISO, Operating Reserves Performance: Penalty Proposal, October 22, 2024

Intra-Hour Ramp Product: **MISO** Potential Reform Solutions

OVERALL PRIORITY: MEDIUM

Potential Reforms to Existing Product

Priority Items

- Dynamic procurement quantities for uncertain ramp needs based on more sophisticated data (in progress)
- Raise the offer cap (currently implicitly at zero)
- Tall demand curve to reflect high system value of incremental reserves when forecasts show potential scarcity (ideally w/ increase in scarcity pricing for all reserves)
- Non-performance penalties (which boosts efficiency, price, and favors high performers)

Intra-Hour Ramp Product: **NYISO** Potential Reform Solutions

OVERALL PRIORITY: HIGH

Potential Reforms (vs. Recent Proposal)
Include expected ramp in market procurement (at short timescales, it dominates, and it's not otherwise fully procured and priced in-market)
Remove or reduce 60-min. duration requirement for ramp product
Raise the RT offer cap (currently at zero in RT, but not DA)
Increase operating reserve scarcity pricing/demand curve to reflect high system value of incremental reserves (ideally w/ increase in scarcity pricing for all reserves)
Non-performance penalties (in progress) boosts efficiency, price, and favors high performers)

Priority Items

Intra-Hour Ramp Product: **PJM** Potential Reform Solutions

OVERALL PRIORITY: HIGH

Potential Reforms (Requires Developing New Product)
Develop new ramp product that includes expected and unexpected ramp in procurement quantity
Dynamic procurement quantities for uncertain ramp needs based on more sophisticated data
Very tall demand curve to reflect system value of incremental reserves when forecasts show potential scarcity (ideally w/ increase in scarcity pricing for all reserves)
Include a nonzero offer cap
Non-performance penalties (which boosts efficiency, price, and favors high performers)

Priority Items

Sources: Ramp Products (CAISO, SPP, ISO-NE, AEMO)

Number	Title (Date) and Notes	Author / Organization
[1]	Tretheway Direct Testimony, Attachment C, Tariff Amendment to Implement Flexible Ramping Product, pp. 140, FERC Docket ER16-2023-000 (June 24, 2016). Unexpected ramp covers 97.5th percentile of forecast error over same duration as ramp capability time horizon.	CAISO
[2]	Market Performance Planning Forum, pp. 73 (2023)	CAISO
[3]	Day-Ahead Market Enhancements (May 2023). Unexpected ramp calculated by quantile regressions of net load forecast errors. Target implementation date in Fall 2024	CAISO
[4]	Integrated Marketplace Calculation Guide (2021). Unexpected ramp for both SPP products covers 97.5th percentile of forecast error over same duration as ramp capability time horizon.	SPP
[5]	Uncertainty Product Prototype Design Whitepaper (2020)	SPP
[6]	State of the Market, pp. 117 (May 2023)	SPP
[7]	State of the Market, pp. 65 (Fall 2023)	SPP
[8]	Operating Reserve Design (November, 2022) Unexpected ramp covers 97.5th percentile of forecast error over same duration as ramp capability time horizon. Working model for discussion, not implemented	AEMO
[9]	Tariff Amendment to Establish Jointly Optimized Day-Ahead Energy and Ancillary Services Market, FERC Docket ER24-275-000 (October 31, 2023) Expected ramp only does not address uncertainty – procurement is the amount of the day ahead energy gap only, so procurement quantity is zero roughly half of the time.	ISO-NE
[10]	Comments in Support of the Day-Ahead Ancillary Services Initiative (November 2023)	IMM for ISO-NE

Sources: Ramp Products (MISO, NYISO)

Number	Title (Date) and Notes	Author / Organization
[11]	Short-Term Reserve Primer (March 2021) Unexpected ramp requirements are manually set and static by hour based on aggregated zonal contingency events. Addresses net load forecast uncertainty and contingencies.	MISO
[12]	Continued Reforms to Improve Scarcity Pricing and Price Formation (July 14, 2022)	MISO
[13]	Scarcity Pricing White Paper: Value of Lost Load and Operating Reserve Demand Curve (March 2024). Ramp Capability Product quantity procured set at 1,075 MW.	MISO
[14]	Ramp Product Enhancements (December 2022), MISO Seasonal Readiness Workshop: Winter 2023-24 (October 2023), slides 45 - 47	MISO
[15]	Business Practice Manual No. 2, pgs. 301-302. Confirms non-performance penalties for MISO STR.	MISO
[16]	Quarterly Report MISO, pp.40 (Spring 2023)	IMM for MISO
[17]	Locational Examples and Initial Tariff Revisions (August 1, 2024) Unexpected ramp covers 95th percentile of historical net load, wind, FTM solar and offshore wind forecast uncertainty.	NYISO
[18]	Market Design Concept Proposed (November 10, 2023)	NYISO
[19]	Percentiles and Shortage Pricing Curves (March 4, 2024)	NYISO
[20]	Balancing Intermittency: Uncertainty Reserve Requirement Calculation (September 5, 2024); 1h Notification w/ 4h Duration Operating Reserves Product (October 12, 2023) Actual procurement quantity of unexpected ramp TBD.	NYISO

4. Alternative Reliability Solutions:

Meeting Needs the Market Has Failed to Address

Alternative Reliability Solutions: Meeting Needs the Market Has Failed to Address

Energy Transition Raises the Potential for Increasing Reliability Issues that the Market Cannot Address

- Many legacy generators were intentionally planned to support location transmission needs, esp. in load pockets; retirements will continue to trigger transmission reliability violations (often major)
- Some of these violations are too localized for zonal capacity markets to solve
- Transmission infrastructure, supply resources like storage, or other non-wires solutions can all contribute to solving these reliability problems at lower cost to consumers
- RTOs should identify solution(s) that lead to the lowest costs for ratepayers when procuring reliability solutions out of market

Gaps in Current Market Rules

- Currently, nearly all post-retirement reliability violations are solved through new transmission, with reliability must-run (RMR) contracts as an interim solution
- Some RTOs (PJM) do not consider non-wire solutions as a long-term solution
- Other RTOs consider non-wire solutions in their post-retirement planning processes, but they are rarely selected due to lack of a comprehensive benefit-cost analysis, exacerbated by short notice period between the solicitation and the required online date

Social Benefits to Considering Alternative Solutions Following Retirement

Competitive solicitations usually lead to lower prices for ratepayers

- Studies have shown the benefits of competitive solicitations both in transmission infrastructure procurement and generator procurement
- On average, the cost of RMRs in PJM has been ~$300/MW-Day, compared to typical capacity market clearing prices in the long term of ~$100/MW-Day

A technology-neutral procurement may lead to outcomes that can both solve the reliability need of issue and provide other beneficial services to the grid at a lower cost

- Energy storage (especially long-duration and multi-day storage) may be able to resolve both transmission security constraints and provide flexibility value to the grid
- Depending on the scope of the reliability need, batteries or other non-wires solutions can be significantly lower cost and more easily deployed than transmission infrastructure

Jurisdictional Review of Post-Retirement Reliability Solutions

RTO	Post-Retirement Reliability Sol'ns	Recent Examples	Compensation	Retirement Notice Requirement	Long-Term Solution Procurement Process
NYISO	**RTO assesses, procures short- and long-term reliability alternatives**	Gowanus and Narrows Plants (2025, 565 MW)	Cost of service or availability & performance rate	12 months	• Competitive solicitation for long-term solution can include non-wires solutions as part of "Short Term Assessment of Reliability" • Generation solutions can be "market-based" or cost-of-service rates
MISO	**RTO IDs but does not procure reliability alternatives**	Rush Island plant (2022, 1,195 MW)	Cost of service	12 months	• MISO will consider any generators/storage in the interconnection queue as a solution to avoid need for System Support Resource (SSR) • MISO lacks a process to fund those resources
PJM	**Transmission and RMR only**	N/A	N/A	3+ months	• PJM IDs transmission solution(s) through Regional Transmission Expansion Plan (RTEP); TO builds • No consideration of non-wires solutions
ERCOT	**Only transmission considered for long-term solution** **RTO assesses alternatives to RMR for short term**	Braunig units (2024, 652 MW)	Cost of service	5 months (150 days)	• ERCOT IDs long-term transmission solutions to address reliability needs from retiring unit • ERCOT solicits proposals for must-run alternatives (MRAs) to replace RMRs in the short-term (can include non-wires solutions) • An MRA solution is only until the long-term transmission solution is in-service at which point the MRA would only receive market revenues
CAISO	**RTO and/or TO (w/ CPUC direction) assess and procure short- and long-term reliability alternatives**	Oakland (2016, 165 MW), 1,262 MW since 2016	Cost of service	3 months	• CAISO's "Transmission Planning Process" and CPUC's "Local Resource Adequacy Program" coordinate to solicit solutions to address reliability needs from generator retirement: CAISO handles transmission solutions, CPUC directs utilities to procure non-wires solutions • Many RMR units do not retire when RMR expires

Case Study #1: CAISO and Oakland Station Natural Gas Plant

In 2017, CAISO Selected Competitive Solution Including NWA Following 165 MW Peaker Retirement

- Dynegy filed to retire 165 MW gas-fired Oakland power plant by 2016
- CAISO identified local reliability need, issued RMR contract to the plant while opening a competitive solicitation for solutions; received transmission, storage, demand response, and hybrid responses
- CAISO recommended PG&E's Oakland Clean Energy Initiative (OCEI), including a mix of transmission upgrades, storage, and demand response, meeting the need lower cost than transmission or generation solutions alone

Source: Google Earth. Includes data from: GoogleLandsat / CopernicusAirbusData SIO, NOAA, U.S. Navy, NGA, GEBCO; Imagery from the dates: 9/24/2009–6/7/2024 Note, some visible imagery has unknown date information.

NWA ("OCEI") Solved Reliability Need at Lower Cost

	Estimated Capital Cost (2022 $M)	Total Cost (2022 $M)
OCEI	$56-$73[1]	$102[2]
115 kV	$193-$217	$367[3]
230 kV	$316	$574[4]
Generation	$232	$368[5]

Source: CAISO, 2017-2018 Transmission Plan, March 22, 2018, pg. 129.

Case Study #2: NYISO and Narrows and Gowanus Plants

NYISO Recently Solicited but Did Not Select RMR Alternatives for 565 MW Peaker Retirement

- Narrows and Gowanus plants are dual-fuel gas generator barges in NYC totaling 565 MW, slated for retirement in 2025 due to NY's Peaker Rule
- NYSERDA had planned to replace their reliability value with the Champlain-Hudson Power Express (CHPE), a 1,250 MW transmission line carrying firm hydropower from Quebec
- NYISO ID'd a short-term reliability need following CHPE's delay to 2027, issued a competitive solicitation for short-term reliability solutions
- Neither of the two responses could resolve the reliability need by 2025

Source: Astoria Generating Company, L.P., Gowanus Generating Station Gowanus Repowering Project Preliminary Scoping Statement, New York State Siting Board on Electric Generation Siting and the Environment Case Number – 18-F-0758, May 2019

Alternative Solutions After Generator Retirement: Sketch of Preferred Solutions

1. Consider Alternative Resources and Tx Solutions as a Long-term Solution to Post-Retirement Reliability Issues

- Following a post-retirement reliability violation finding, complete a competitive, technology-neutral solicitation to resolve reliability need determined by the RTO
- Solutions should resolve specific reliability needs for the long-term to avoid further out of market procurements

2. Conduct a Holistic Cost-benefit Analysis on All Qualifying Alternatives

The cost-benefit analysis should account for the costs over the expected operating lifetime of the alternative in comparison to the system costs with generator contracts in the short-term then the long-term transmission solution

3. Use Long-term Contracts for Compensation

Cost-effective supply resources may need additional revenues beyond the market revenues

4. Lengthen the Deactivation Notice Period

- Notice period needs to be long enough for reliability solutions to be constructed prior to the generator's retirement
- Complementary to interconnection reforms allowing rapid post-retirement interconnection procedures (e.g., PJM's under-development CIR replacement process)

Gap Analysis: Alternative Solutions After Generator Retirement

RTO	Considers Non-Wires Solutions	Long-Term Contracts to Supply Resource Solutions	Holistic Cost-Benefit Analysis	Deactivation Notice Period
MISO	Yes, but limited by lack of RTO procurement	✗	N/A, no RTO procurement	12 months
NYISO	✓	✓	✓	12 months
PJM	✗	N/A	N/A, no RTO procurement	3+ months

Alternative Solutions After Generator Retirement: **MISO** Potential Reform Solutions

OVERALL PRIORITY: MEDIUM

Potential Reforms
Conduct a competitive solicitation for alternative resources and Tx options as a long-term solution to reliability issues the market didn't solve
Conduct a holistic cost-benefit analysis on all qualifying alternatives
Lengthen the deactivation notice period

Priority Items

Alternative Solutions After Generator Retirement : **NYISO** Potential Reform Solutions

OVERALL PRIORITY: LOW

Potential Reforms
Consider lengthening the deactivation notice period

Alternative Solutions After Generator Retirement : **PJM** Potential Reform Solutions

OVERALL PRIORITY: MEDIUM

Potential Reforms
Conduct a competitive solicitation for alternative resources and Tx options as a long-term solution to reliability issues the market didn't solve
Conduct a holistic cost-benefit analysis on all qualifying alternatives
Use long-term contracting for compensation
Lengthen the deactivation notice period

Priority Items

Sources: MISO

Number	Title (Date)	Author / Organization
[1]	Attachment Y Review Rush Island Units 1 and 2: Rush Island Annual Review Process (May 31, 2024)	MISO Central Subregional Planning Meeting

Sources: PJM

Number	Title (Date)	Author / Organization
[1]	RMR History and Issues (November 9, 2023)	Monitoring Analytics
[2]	IMM State of the Market Report discussion of Part V (RMR) issues (October 12, 2023)	Monitoring Analytics
[3]	RTO/ISO Deactivation Processes (January 18, 2023)	PJM Interconnection, Deactivation Enhancements Senior Task Force
[4]	Avoiding Reliability Must-Runs/System Support Resources (2023)	Gridlab

Sources: ERCOT

Number	Title (Date)	Author / Organization
[1]	Reliability Must Run (RMR) Process (March 2024)	ERCOT
[2]	ERCOT Nodal Protocols (August 1, 2024) pp. 422-445.	ERCOT

Sources: NYISO

Number	Title (Date)	Author / Organization
[1]	Responses to Questions About the 2023 Quarter 2 Short-Term Reliability Process Solution Solicitation (September 21, 2023)	NYISO
[2]	Open Access Transmission Tariff (August 20, 2024) pp. 2580-2677	NYISO
[3]	Short-Term Assessment of Reliability: 2023 Quarter 2 (July 14, 2023) pp. 29.	NYISO
[4]	Short-Term Reliability Process Report: 2025 Near-Term Reliability Need Solution Selection (November 20, 2023)	NYISO

Sources: CAISO

Number	Title (Date)	Author / Organization
[1]	Decision on reliability must-run and capacity procurement mechanism enhancements proposal (March 20, 2019)	Keith Casey
[2]	2023 Report on Market Issues & Performance (2023) pp. 301-304.	CAISO
[3]	Reply Brief of the California Independent System Operator, Application 20-04-013 (December 4, 2020)	CAISO

5. Opportunity Cost Bidding

Opportunity Cost Bidding is Fundamental to Storage Participation in Energy Markets

Storage resources selling energy now give up the chance to sell later, **incurring an opportunity cost @ forecast of later energy/AS value**

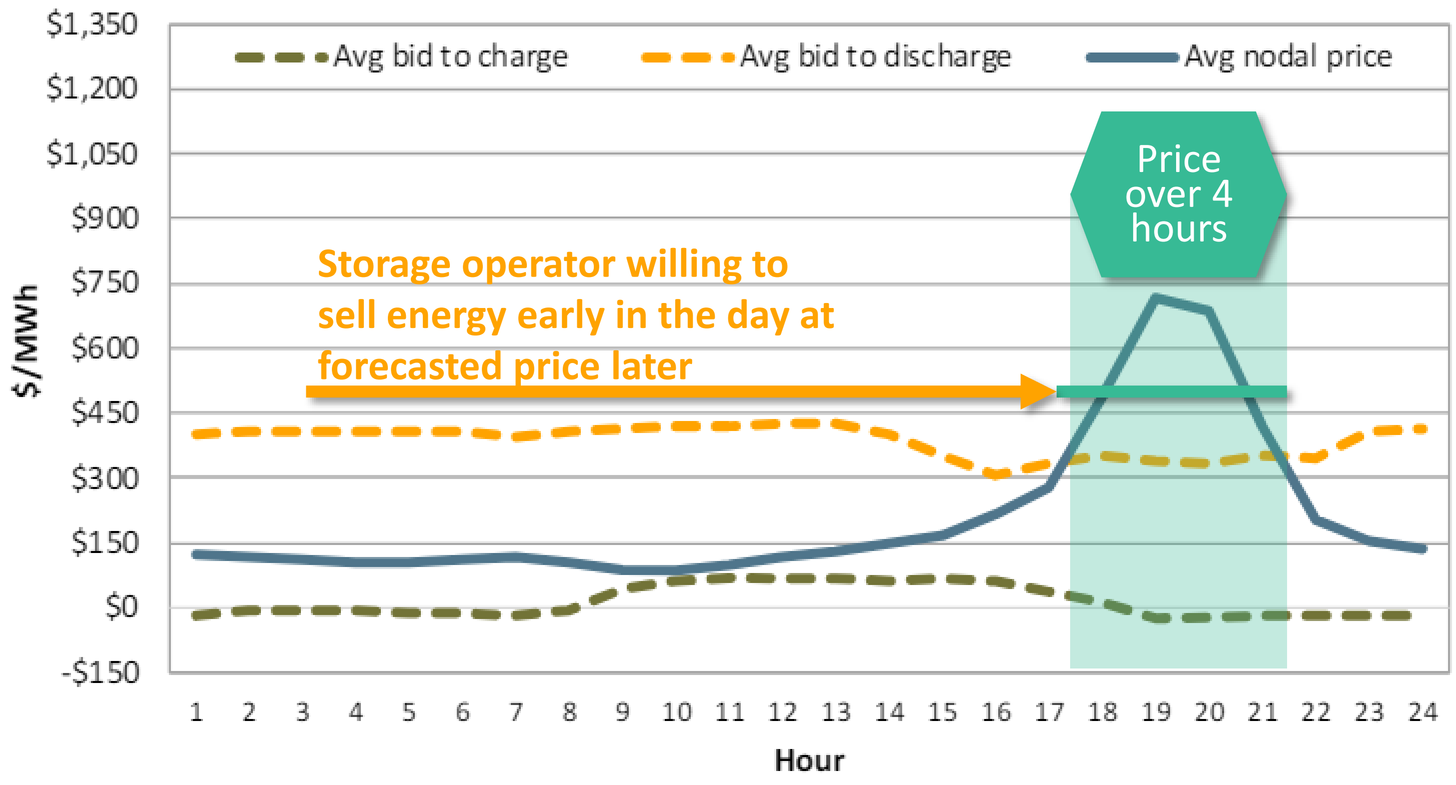
- Opportunity cost is complex and varies by seller, state of charge
- Sellers have different forecasts, incl. low-probability high-price outcomes
- AS (such as Regulation) can also entail opportunity cost in offers

Accurate storage offers are essential for optimal reliability outcomes by avoiding depleting limited energy before it is most needed during scarcity conditions

Accurate storage offers facilitate efficient price formation in a flexible clean resource mix

Storage Offers Reflect Value Over Hours Later in Day

Average CAISO day-ahead battery bids and nodal prices August 31-Sep. 9, 2022



Source: CAISO, Special Report on Battery Storage, July 7, 2023

Gap: ISO/RTOs can Underestimate or Prohibit Opportunity Cost

ISO/RTOs do not always allow accurate opportunity-cost offers

- E.g., when capping reserve offers, mitigating market power, in emergencies, etc.
- Due to limits to changes in offers intraday
- PJM prohibits them entirely when mitigated due to local market power

ISO/RTOs limit updates to offers through lead time requirements and other rules**,** even though opportunity costs can change dynamically

This leads to **suboptimal reliability and distorted prices** (too low early in the day, too high later), especially in high storage systems and especially during scarcity

Storage offer reform is important even though offers are only infrequently mitigated (e.g., ~1-2% in PJM):

- Mitigation is targeted at **high-value load pockets** of interest to storage developers
- Uplift payments can be based on cost-based offers
- Under PJM's Capacity Performance rules, resources that are not dispatched in an emergency due to opportunity-cost based offers in excess of charging cost would be penalized for failure to perform
- Restricting intraday offer updates incentivizes non-dispatchable status, limiting efficiency and revenue
- Low AS offer caps force uneconomic clearing of AS without accounting for impact on later availability

Opportunity Cost Bidding Jurisdictional Review

RTO	Oppo Cost Bids	RT Offer Update Latency	Avoids *Ex-Ante* Mitigation	Intra-Day Opportunity Cost Method when Energy Offers Are Mitigated
MISO	✓	30 mins before clock hour	✗	• Opportunity costs allowed in consultation with the IMM • Otherwise, based on offers when cleared in past 90d
NYISO	✓	75 mins before clock hour	✓	• Allow the supplier to offer according to their own opportunity costs, by having any ex-ante mitigation (i.e., in Zone J) incorporate opportunity costs that the supplier provides for each hour • If seller in zone J doesn't submit their own opportunity costs, offer may be based on NYISO calculation of optimized schedule: using 90-day average DA prices for DA; and the DA price in RT
PJM	✗	65 mins before clock hour	✗	• **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	✓	**5 mins before RT dispatch**	✓	• Pending reform limiting storage offers that alleviate congestion to avoid LMPs above price cap
CAISO	✓	75 mins before clock hour	✗	• CAISO-calculated opportunity cost allowed, can depend on SOC • RT mitigation uses DA prices; DA mitigation uses shadow prices from DA optimization

Sketch of Preferred Solution for Opportunity Cost Offers

1. No *ex-ante* mitigation

- Too dynamic and difficult
- See NYISO for equivalent approach (for storage)
- Can develop distant second best in case *ex-ante* mitigation is mandated, following principles for #2

2. Limited ex-post review of concerning patterns that the market monitor identifies

- Safe-harbor for most cases via simple **structural test** of ability to exercise market power (e.g., a "small fish" rule)
- Could further test for incentive to withhold (but contractual positions can confound)
- For others, principled review of offers in comparison to competitive benchmarks (e.g., shadow price of a MWh in storage each interval, accounting for: SOC uncertainty, updated price forecasts, stochastics, performance penalty risk, impact of SOC depletion on multi-hour A/S opportunities, and a margin allowing for variation in approaching these tricky topics
- Consequences for repeated disagreements or violations (e.g., referral to FERC)?

3. Raise the offer cap for some ancillary services

e.g., Regulation depletes energy, offers should be allowed to include reasonable opportunity costs (especially under a must-offer obligation) beyond endogenously-calculated energy-opportunity cost

4. Allow offer updates

Allow intraday changes in energy and ancillary services offers in order to track highly dynamic forecasts

Second Best *Ex-Ante* Mitigation Alternative (if Preferred Reform Fails)

1. Test storage *ex ante*, only mitigate if **all tests are failed (structural, conduct, impact, etc.)**

- Structural test to safe-harbor most cases, checks for the ability to exercise market power; e.g., "small fish" rule
- Optional incentive test to assess whether portfolio position is net improved via withholding, noting that portfolio positions can also depend on contracts outside the ISO/RTO
- Conduct plus impact test should reference opportunity costs calculated by the IMM or the RTO
- Opportunity cost calculation used for reference price and mitigation level should include updated LMP forecasts as close to the dispatch period as possible (~1 hour before) and should account for SOC uncertainty, stochastics, performance penalty risk, impact of SOC depletion on multi-hour A/S opportunities, and a margin allowing for uncertainty in estimation

2. In case of failed tests, ***ex-ante* mitigation** based on opportunity costs calculated by the RTO or IMM

- *Ex-ante* mitigation is not preferable due to its calculation complexity, but may be more likely to be accepted by certain RTOs (e.g., PJM which has a history of strict market power mitigation regimes and may be unlikely to accept only ex-post mitigation)

3. The reference offer level used for conduct + impact test and offer replacement should include **a high degree of cushion** for the seller's offers

- The threshold for both the conduct and impact tests should be higher than is used for thermal resources to reflect the uncertainty in opportunity cost calculations and risks to a battery losing its available charge if prices spike later

Gap Analysis: Storage Offer Rules in Target ISO/RTOs

RTO	Opportunity Cost in Reference Prices	Avoids *Ex-Ante* Mitigation for Storage	Structural Test	Impact Test	RT Offer Update Latency	Unlimited RT Offer Updates?	AS Offer Caps ($/MW/hr)
MISO	✓	?	✗	✓	**30** mins before clock hour	✓	Reg: $500 CR: $100
NYISO	✓	✓	✗	✓	**75** mins before clock hour	✓	Reg: unit-specific mitigated offers in DA and RT CR: unit-specific mitigated offers in DA, $0 in RT
PJM	✗	✗	✓	✗	**65** mins before clock hour	**Intraday offers cannot exceed cleared DA offers (potentially all hours for always-on batteries)**	**Reg: $12** (or $100 unmitigated) **CR: ~$0 in DA** and RT

Opportunity Cost Bidding: **MISO** Potential Reform Solutions

OVERALL PRIORITY: LOW

Potential Reforms
Clarify the process and temporal requirements for sellers to submit opportunity costs
Establish a clear structure for ex-post review of opportunity cost submissions, starting w/ structural and other tests; if failed, mitigation accounts for uncertainty in LMP forecasts, stochasticity, SOC uncertainty, performance penalty risk, AS opportunity cost, and a large margin for uncertainty
Consider a "small fish" rule exempting owners with portfolios <5% market share from any mitigation
Decrease latency of intraday offers (requires significant software and business process changes)

Opportunity Cost Bidding: **NYISO** Potential Reform Solutions

OVERALL PRIORITY: LOW

Potential Reforms
Establish a clear structure for ex-post review of opportunity cost submissions, starting w/ structural and other tests; if failed, mitigation accounts for uncertainty in LMP forecasts, stochasticity, SOC uncertainty, performance penalty risk, AS opportunity cost, and a large margin for uncertainty
Consider a “small fish” rule exempting owners with portfolios <5% market share from any mitigation
Decrease latency of intraday offers (requires significant software and business process changes)

Opportunity Cost Bidding: **PJM** Potential Reform Solutions

OVERALL PRIORITY: HIGH

Potential Reforms
Allow inter-hour opportunity cost in mitigated offers, w/o ex-ante review; clear structure for ex-post review including structural test (looser than 3 pivotal supplier) and reference prices that allow leniency in submitted offers
For storage, allow intraday offers above cleared DA offers
Increase AS offer cap, especially in day ahead
Exempt owners w/ portfolios <5% market share from mitigation ("small fish" rule)
Decrease latency of intraday offers (requires significant software and business process changes)

Priority Items

Appendix: Market Power Mitigation Methods

MPM Trigger: Determines what resources are flagged to have the ability to exercise market power and thus may be forced to bid below their initial offer price

- **Structural Test:** Assesses whether a resource can exercise market power, e.g., PJM's Three Pivotal Supplier test which determines whether there is sufficient supply without the generation from the supplier being tested and the two largest suppliers in the local area
- **Conduct + Impact Test:** A two-part test to determine if a supplier may be exercising market power: the conduct test compares the supplier's offer to a reference level, while the impact test measures the effect of the offer on the clearing prices in the local area

Mitigated Offer: The level a resource's bid is mitigated to if they are flagged as having the ability to exercise market power—generally set at the marginal cost

Optimization of storage schedules across the day is a potential fix, but transfers control from participant to RTO (and requires costly software changes by the RTO)

Appendix: Details of Jurisdictional Review

RTO	Local MPM "Trigger"	Intra-Day Opportunity Cost Method for Energy
MISO	Conduct + impact test (ex ante)	• Can submit opportunity costs in consultation with the IMM • Otherwise, mitigated offer cap set like other resources (based on prices when cleared in past 30d) • Can update offers 30 mins before the dispatch period
NYISO	Conduct + impact test (ex ante in NYC, ex post elsewhere)	• Opportunity Cost Adjustment (OCA) for ex ante mitigation (in NYC) allows sellers to choose offers in DA and RT; ex post, may be asked by market monitor to justify offers • Otherwise, opportunity costs based on optimized energy arbitrage schedule: in DA, using 90-day average DA prices; in RT, using the DA price (no provisions for more updated forecasts other than using OCA). • Can update opportunity costs 75 mins before the dispatch period
PJM	Structural Test (ex ante)	• Mitigated offers in DA and RT based on average charge cost and the efficiency factor • Can update offers ~65 mins before the hour • Cannot increase RT offers above cleared DA offers ("Intraday Offers" rule)
ERCOT (Current)	Structural test (ex ante)	• Mitigated offer cap for storage set at system-wide offer cap (effectively exempting mitigation) • Can update offers 5 mins before the dispatch period
ERCOT (Proposed)	Structural test (ex ante)	• Mitigated offer for storage capped at the "shadow price cap" of the relevant transmission constraint ($2,800+/MWh) times the relevant shift factor (as low as a few percent)
CAISO	Structural test (ex ante)	• Opportunity cost dependent on state of charge (e.g., if SOC is 1 hour then oppo cost is highest LMP hour of day and if SOC if 4 hours then oppo cost is 4^{th} highest consecutive LMP of day) • RT mitigation uses DA prices; DA mitigation uses prices from the DA SCED mitigation run • Can update mitigation 75 mins before the dispatch period

Sources: Opportunity Cost Bidding (NYISO)

Number	Title (Date) and Notes	Author
[1]	Opportunity Costs for Energy Storage Resources, **Market Issues Working Group**	**NYISO**
[2]	Energy Storage Resources: Opportunity Costs and Mitigation Measures, **Market Issues Working Group**	**NYISO**
[3]	Manual 34: Reference Level Manual, **pp. 35-36**	**NYISO**
[4]	Market Services Tariff (MST), **pp. 678-712;** The conduct plus impact test in NYISO uses the following thresholds for resources in unconstrained areas (system-wide mitigation): An MP fails the conduct test if its bid is the lower of 300% or $100/MWh higher than the reference price which is set at the opportunity cost and it fails the impact test if it raises LMPS by either 200% or $100/MWh. In constrained areas (where shadow price is over $0.04/MWh for the transmission into the area) the conduct threshold is set equal to (average fuel price X 2 X 8760) / number of constrained hours.	**NYISO**
[5]	Market Services Tariff (MST), **Section 23.3.1.4.5**	**NYISO**
[6]	Manual 12: Transmission and Dispatch Operations Manual, pp 71	**NYISO**

Sources: Opportunity Cost Bidding (PJM)

Number	Title (Date) and Notes	Author
[1]	PJM Manual 15: Cost Development Guidelines, Revision 44 (August 1, 2023) **pp. 78-80.**	**PJM Interconnection**
[2]	Temporal Opportunity Cost for Energy Storage Resources (ESR) Real Time Cost Offer (May 10, 2019)	**Dominion Energy**
[3]	PJM Manual 11: Energy & Ancillary Services Market Operations, Revision 131 (June 27, 2024). PJM uses the Three Pivotal Supplier Test which is a screen to measure whether there is enough available supply to meet demand in a constrained area without the supplier being tested and the two other largest suppliers in the region	**PJM Interconnection**

Sources: Opportunity Cost Bidding (MISO)

Number	Title (Date) and Notes	Author
[1]	Business Practice Manual No. 9: Market Monitoring and Mitigation (August 31, 2023) The conduct plus impact test in MISO uses the following thresholds: An MP fails the conduct test if its bid is the lower of 300% or $100/MWh higher than the reference price which is set at the opportunity cost and it fails the impact test if it raises LMPS by either 200% or $100/MWh. In narrow constrained areas (where its expected to be constrained for at least 500 hours/year) the conduct threshold is set equal to the net cost of a peaker plant divided by the number of constrained hours	**MISO**
[2]	FERC Electric Tariff Module D: Market Monitoring and Mitigation Measures (November 19, 2023) **pp. 92-105.**	**MISO**
[3]	MISO Energy and Ancillary Services Co-optimization	**MISO**
[4]	Business Practice Manual 2: Energy and Operating Reserve Markets**, pp. 266-267**	**MISO**

Sources: Opportunity Cost Bidding (ERCOT)

Number	Title (Date) and Notes	Author
[1]	ERCOT Nodal Protocols (August 1, 2024) pp. 586-588. ERCOT uses the Constraint Competitiveness Test as their structural market power screen	**ERCOT**
[2]	Draft Report: Mitigated Offer Caps for Energy Storage Resources (ESRs), Wholesale Markets Subcommittee, (November 1, 2023)	**ERCOT Wholesale Markets Subcommittee**

Sources: Opportunity Cost Bidding (CAISO)

Number	Title (Date) and Notes	Author
[1]	Final Proposal – Energy Storage and Distributed Energy Resources – Storage Default Energy Bid (October 22, 2020)	**CAISO**
[2]	Energy Storage Enhancements – Energy Storage Model and Market Power Mitigation (February 11, 2022)	**CAISO**
[3]	Energy Storage Enhancements – Final Proposal (October 27, 2022)	**CAISO**
[4]	Open Access Transmission Tariff **pp. 1405-1414.** CAISO uses the Three Pivotal Supplier Test which is a screen to measure whether there is enough available supply to meet demand in a constrained area without the supplier being tested and the two other largest suppliers in the region	**CAISO**
[5]	Storage Bid Cost Recovery and Default Energy Bid Enhancements: Issue Paper and Straw Proposal for Track 1 (July 26, 2024) **pp. 24-25.** CAISO uses a three pivotal supplier test as their structural market power screen.	**CAISO**

6. Assessment of Potential Reform Solutions

Rough Estimates Show Potential Depth of Market Reforms

THESE POLICY ASSESSMENTS ARE NOT FORECASTS

	Capacity Value	Day-Ahead Uncertainty Product	Intra-hour Uncertainty/Ramp Product (10-min flex)	Alternative Reliability Solutions	Opportunity Cost Bidding
Product	Capacity	New ancillary service	New ancillary service	Non-market reliability	Energy
Market size	Peak demand (or net demand)	24-hr ahead forecast uncertainty*: 1%-3% of peak demand **+** 5% - 15% of wind and of solar	Expected intrahour ramp-up† + intrahour uncertainty: 0.2% - 0.4% of peak demand **+** 0.5% - 1% of wind and of solar	5% - 15% of retiring units might leave reliability issues	Top 2 – 6+ hrs of daily net loads
Addressable by storage	10% - 30%	100%	100%	100% (mainly long duration)	10% - 30%
POTENTIAL STORAGE MARKET DEPTH IN 2030					
MISO	**14 to 41 GW**	**8 to 25 GW**	**700 to 1,700 MW + 700 to 1,400 MW**	**2.5 to 7.5 GW**	Deep
NYISO	**3 to 9 GW**	**2 to 6 GW**	**100 to 200 MW + 200 to 300 MW**	**0.3 to 0.9 GW**	Deep
PJM	**17 to 50 GW**	**6 to 19 GW**	**800 to 1,300 MW + 500 to 900 MW**	**2 to 6 GW**	Deep

(for Illustration only)

**Expected ramp and energy gap omitted from assessment of day-ahead and multi-hour ramp product, see Section 2 for further discussion*

†Expected ramp-up estimated from 80th to 95th percentile of June-August hourly change in net load for 2030 resource mix, divided by six for 10-min ramp. Sourced from GridStatus.io

Methodology and Citations for High-Level Market Depth Estimates (Not As A Forecast, But A Rough Indicator)

	Intra-Hour Uncertainty/Ramp Product	Multi-Hour and Day-Ahead Uncertainty Product	Alternative Reliability Solutions
Methodology	Total market size assumed to be equal to the expected + unexpected ramp for 10 minutes after real time dispatch. Expected ramp calculation is based on the 80th to 95th percentile of net load hourly ramp, divided by 6 to estimate 10-min ramp. June – August 2024 hourly data; load, wind, and solar are scaled to reflect projected 2030 levels. Source: GridStatus.io Unexpected ramp = 0.2%-0.4% of peak demand + 0.5% - 1.0% of wind and solar nameplate capacity. Uncertainty ranges are based on historical analysis of 10-minute ahead load, wind, and solar forecast error assuming a ramp product will procure up to the 97.5th percentile confidence interval (consistent with existing ramp products).	Total market size assumed to be equal to the expected + unexpected ramp from 1 day before real time dispatch Unexpected ramp = 1%-3% of peak demand + 5% - 15% of wind and solar nameplate capacity Uncertainty ranges are based on historical analysis of DA load forecast error and DA wind/solar forecast error	Assumed that batteries could be an economic solution to replace retiring fossil generators 5% - 15% of the time Values for retiring fossil taken by outlook studies completed by the individual RTOs

RTO	Peak Demand	Solar Generation	Wind Generation	Generators at Risk of Retirement
MISO	137 GW in 2030 Source: MISO, MISO Futures Report: Series 2A, November 1, 2023	57 GW by 2030 Source: MISO, MISO Futures Report: Series 2A, November 1, 2023	80 GW by 2030 Source: MISO, MISO Futures Report: Series 2A, November 1, 2023	48 GW by 2030 Source: MISO, MISO Futures Report: Series 2A, November 1, 2023
NYISO	30 GW by 2030 Source: State Scenario, NYISO, 2023-2042 System & Resource Outlook, Appendix H, July 23, 2024	20 GW by 2030 Source: State Scenario, NYISO, 2023-2042 System & Resource Outlook, Appendix H, July 23, 2024	12 GW by 2030 Source: State Scenario, NYISO, 2023-2042 System & Resource Outlook, Appendix H, July 23, 2024	4 GW by 2030 Source: State Scenario, NYISO, 2023-2042 System & Resource Outlook, Appendix H, July 23, 2024
PJM	167 GW in 2030 Source: PJM, LTRTP Workshop Policy Study, October 1, 2024	55 GW by 2030 (includes hybrids) Source: PJM, LTRTP Workshop Policy Study, October 1, 2024	35 GW by 2030 Source: PJM, LTRTP Workshop Policy Study, October 1, 2024	40 GW by 2030 Source: PJM, Energy Transition in PJM: Resource Retirements, Replacements & Risks, Feb. 23, 2023