Sixth Review of the PJM's RPM VRR Curve Parameters

PRELIMINARY VRR CURVE ANALYSIS

PREPARED BY

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PRESENTED TO

PJM Market and Implementation Committee

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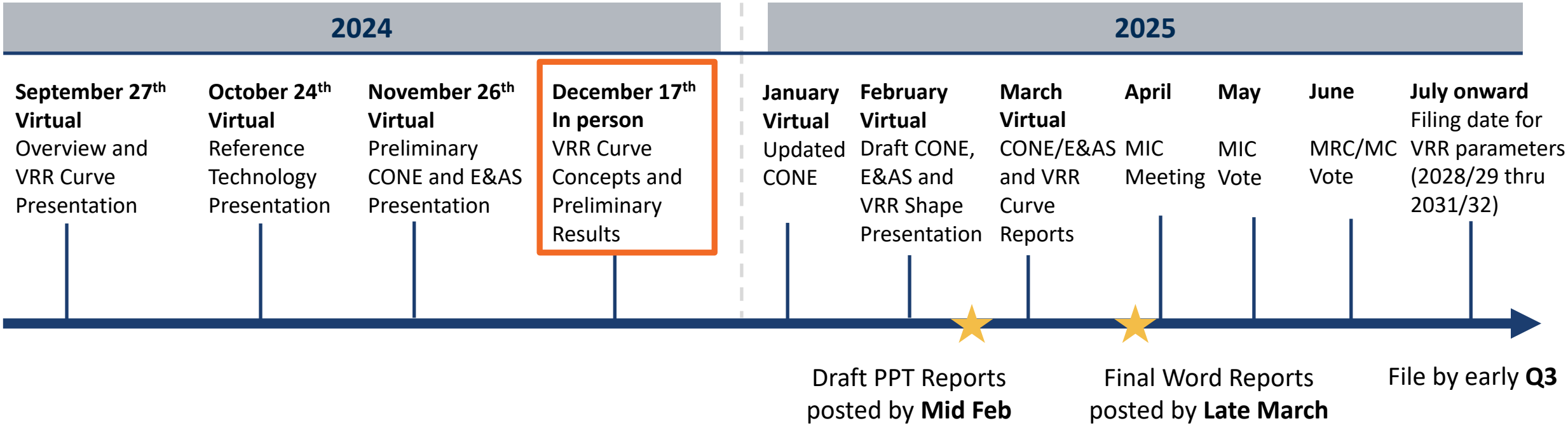
Brattle

Where we are in the Net CONE & VRR curve review



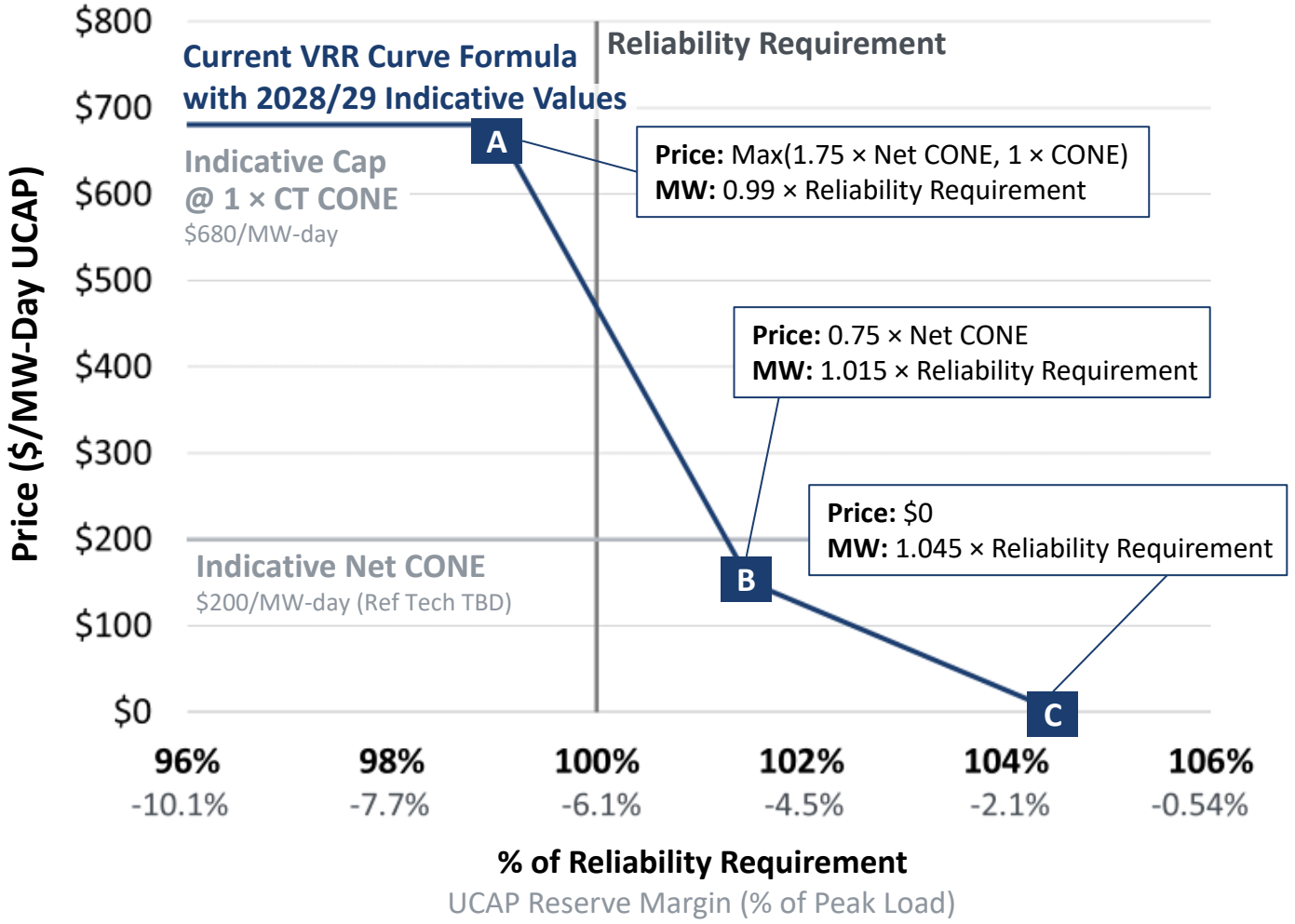
Overview: VRR Curve design objectives and focus areas

As in all prior reviews, the VRR Curve assessment is grounded by long-term capacity market design objectives (next slide)

Focus areas for the current VRR Curve review informed by stakeholder input and substantial shifts in RPM market:

- **RPM Design Changes:** How updates to reliability modeling, accreditation, and possible sub-annual market interact with VRR curve
- **Tight Market Conditions:** How to consider the recent contraction in supply-demand balance, outlook for tight supply, and compressed forward period
- **Uncertainty in Net CONE & Reference Technology:** How to manage uncertainties in VRR curve parameters and support long-term investment signals

Current VRR Curve Formula (Indicative 2028/29 Values)



Note: "Current Curve" based on current formula for Preliminary CONE estimates from November 26, 2024 MIC Meeting, slide 51. Values subject to change.

Design objectives: Any changes to VRR curve should improve performance relative to clearly-defined objectives

Demand Curve Design Objectives	
Reliability	• Maintain 1-in-10 LOLE system-wide planning target on a long-term average basis • For each LDA, normalized EUE no more than 40% above RTO-wide normalized EUE at criterion • Assess curve performance with additional criteria including LOLE, LOLH, and EUE on average and in extremes (ensure robustness across potential market conditions) • Maintain reliability across a range of potential market conditions • Rarely drop below a "minimum acceptable" level when PJM may intervene (<99% of reliability requirement)
Prices	• Outcomes reflective of economic fundamentals in a well-functioning, competitive market: prices high enough to attract entry when needed for reliability; prices low enough to enable efficient exit and retirements during surplus • Reduce price volatility due to small changes in supply and demand, but allow prices to move sufficiently to reflect changes in market conditions and enable competition • Mitigate susceptibility to exercise of market power • Few outcomes at the administrative cap • Mitigate customers' exposure to price spikes and the costs of over-procurement
Other	• Aim for simplicity, stability, and transparency • Provide a sustainable value proposition to states, members and market participants with diverse customer segments, business interests, policy requirements and regulatory models • Strike a balance among competing objectives

Notes: LOLE = Loss of Load Events; LOLH = Loss of Load Hours; EUE = Expected Unserved Energy; Net CONE = Net Cost of New Entry
Reliability criteria: See Manual 20-A, Section 1.3; and Reliability Assurance Agreement, Definitions, CETO.

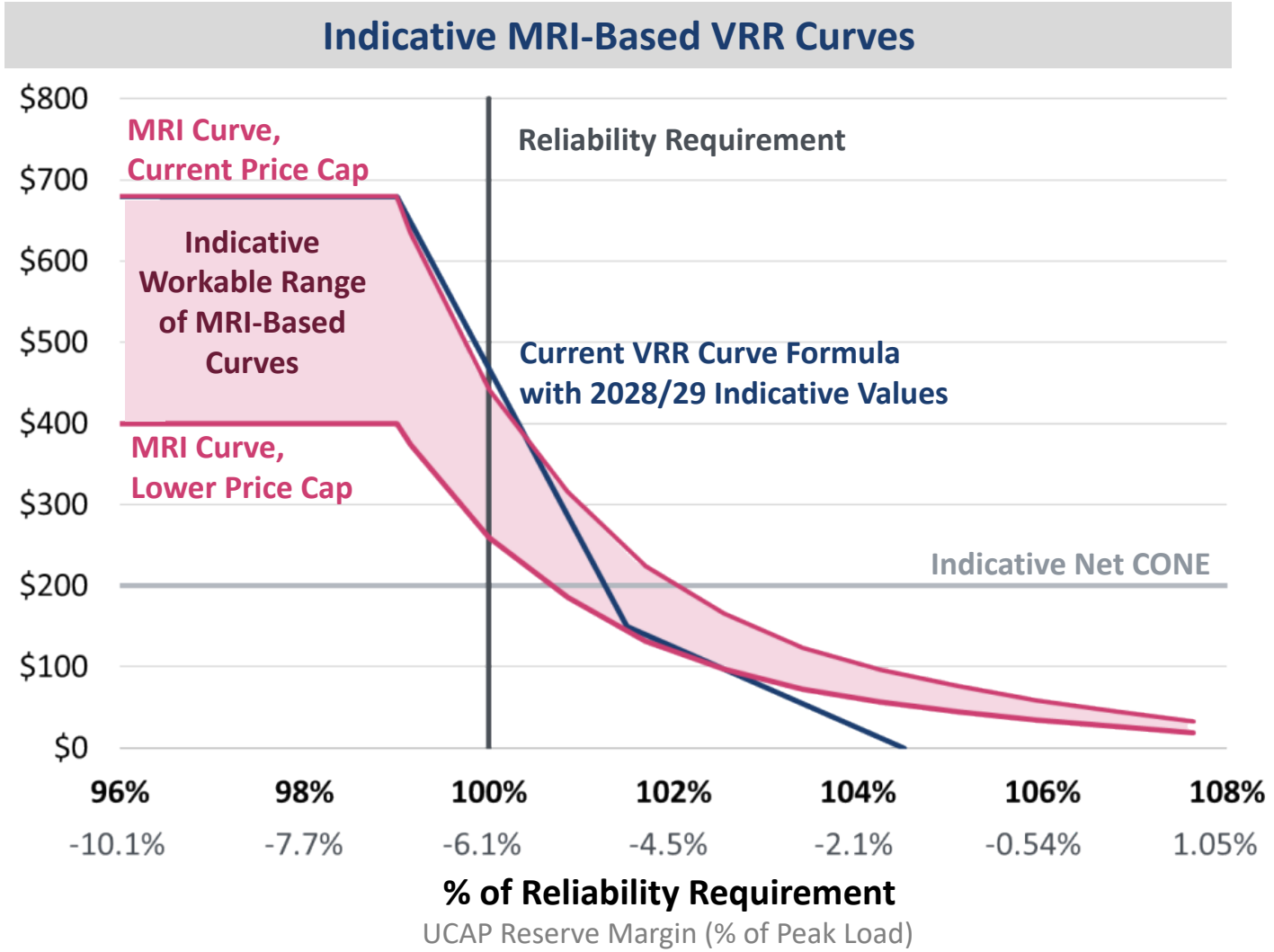
Direction of VRR curve updates based on preliminary assessment

- **MRI-based Curve:** Transition to relative value-based curve based on marginal reliability impact (MRI), applied at system-wide and locational basis
  - Will improve price stability and alignment with reliability value to customers
  - Locational prices similarly rationalized to reflect the reliability value. Flatter and more graduated MRI-based curves reduce exposure to LDA price spikes, supporting modest price differentials as local supply-demand balance tightens
  - Robust to transition to sub-annual capacity market
  - Can build on MRI-based curves already adopted in ISO-NE (locational) and MISO (4-season)
- **Tight Market Conditions:** VRR curve must consider both near-term and long-term conditions to support reliability objectives
  - Curve should not attempt to achieve a specific outcome desired by customers or sellers, but rather allow for the expression of competitive forces and market conditions
  - Price cap should be sufficiently high to support new entry when needed and maintain investor interest in pursuing new developments, as well as attracting near-term reaction (e.g., DR, net imports, uprates)
  - But a too-high price cap is problematic if tight supply conditions are exacerbated or prolonged by barriers to entry (whether transient or persistent)
- **Uncertainty in Net CONE & Reference Technology:** Over the long run, prices should be expected to reflect the true long-run marginal cost (i.e. Net CONE) faced by competitive players – regardless of the administrative estimate. Challenge is to identify VRR curve robust to present uncertainties

Preliminary “workable range” of MRI-based VRR curves

Preliminary assessment of potential VRR curve adjustments include:

- **Workable Range:** Curves that provide reasonable balance of design objectives and support long-term reliability
- **Price Cap:** Potential for lower price cap while maintaining long-term investment signals. Performance of adjusted CONE and Net-CONE-based caps to be considered under different market conditions
- **Challenge:** Variability and uncertainty in Net CONE and reference technology. Assessing options to stabilize price parameters between periodic reviews (e.g., inflation-based updates?)
- **Further Adjustments:** To be examined based on assessing performance under a range of Net CONE and sensitivity case assumptions



Notes: The presented range assumes a Net CONE of $200/MW-Day and a CT Gross CONE of $680/MW-Day loosely based on preliminary CONE estimates in 2028$. Values will be updated once the Net CONE study process has concluded.

How do recent changes to RPM design & market conditions inform the VRR curve?

VRR curve should be updated to align with ongoing market reforms and be tested for performance against a range of potential market conditions

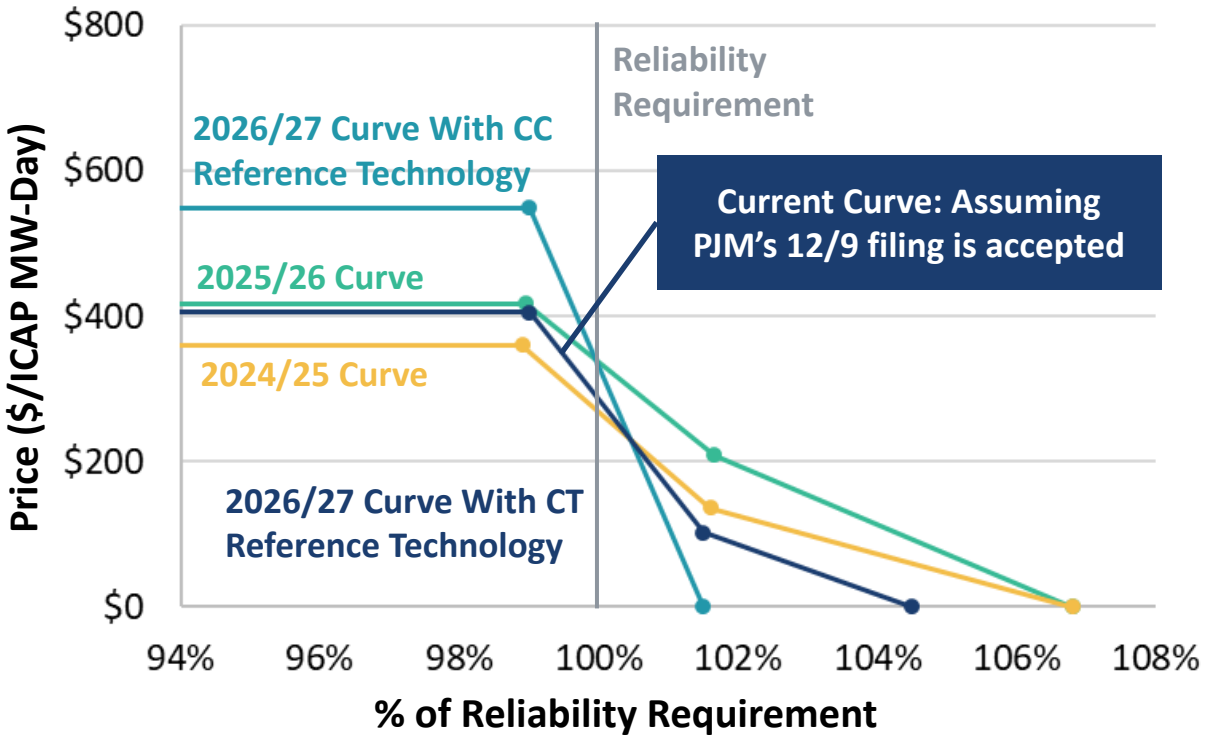
VRR curve review to consider:

- Updated reliability modeling and resource accreditation
- Unanticipated tight supply conditions observed in 2025/26 auction and potential for tight conditions to persist
- Contracted BRA forward period during transition
- Potential transition to sub-annual capacity market

Accreditation Changes: Customer costs & seller payments ~20% lower than they appear on a UCAP basis

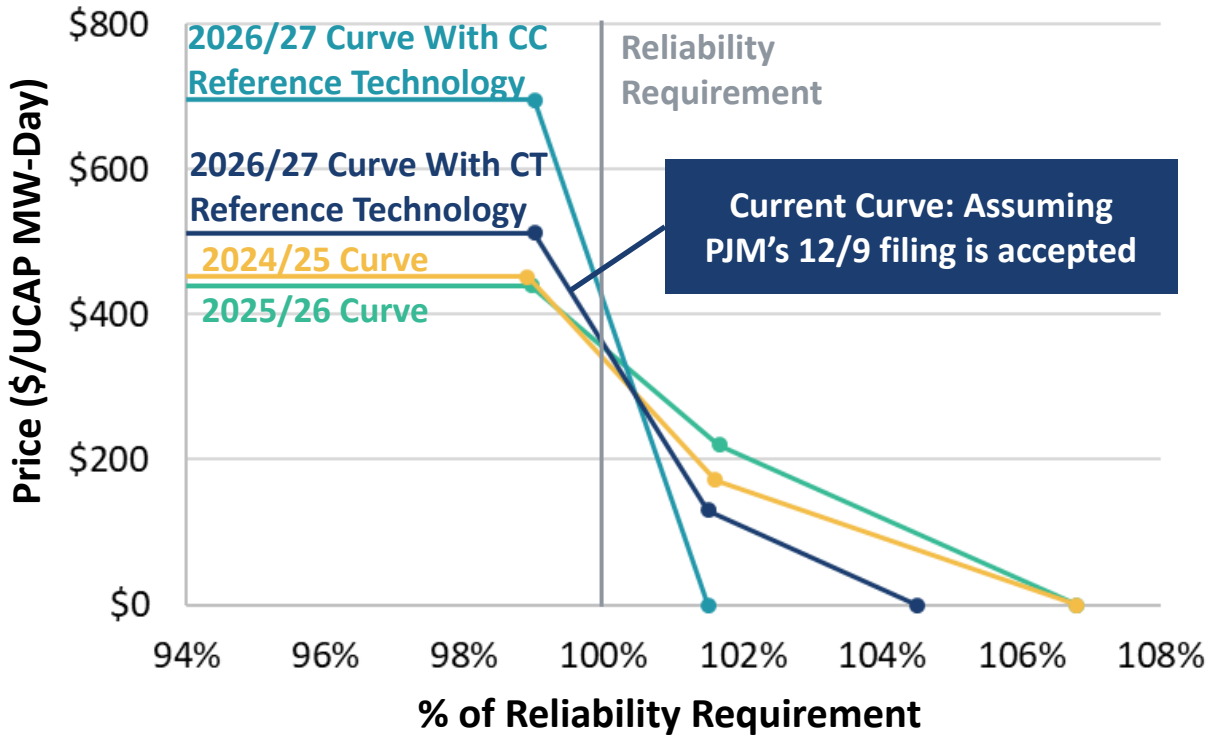
ICAP Accreditation

Prices have similar meaning across all curves.
Most accurately reflects revenues to sellers & costs to customers



UCAP Accreditation

New accreditation starting 2025/26. Sticker price is 20% higher than realized cost to customers & revenues to sellers



Source: Affidavit of Dr. Samuel A. Newell on Behalf of PJM Interconnection, L.L.C., Docket No. ER25-682-000. Filed December 9, 2024.

What explains sudden price increases in the last BRA?

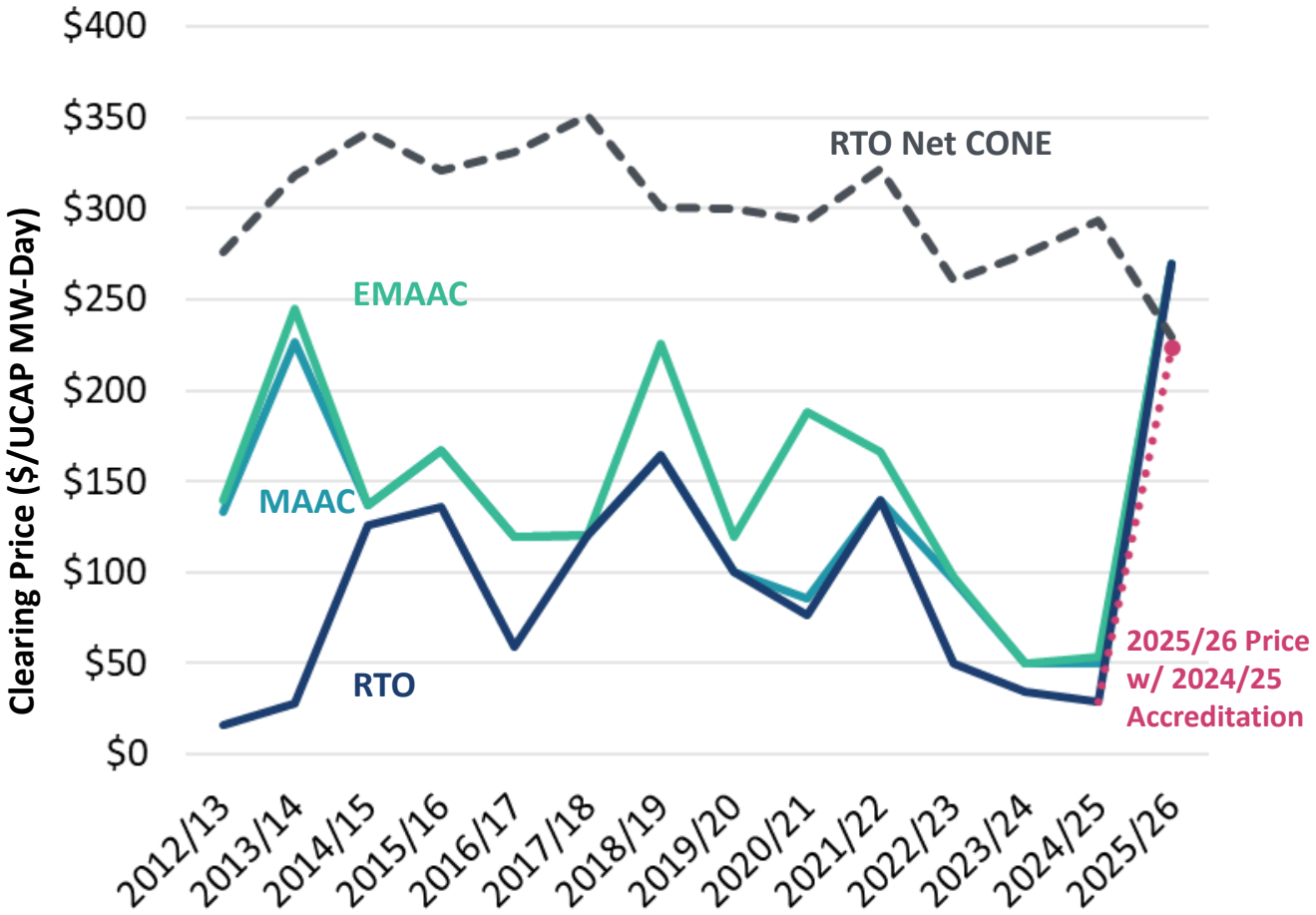
Context

- Historically, RPM prices ranged $50-$250/MW-day RTO-wide and in biggest LDAs
- Attracted large volumes of new investment (34 ICAP GW of new gas CCs) since the 2015/16 auction, despite prices substantially below administrative Net CONE estimate
- But over 2022/23-24/25 auctions, prices remained <$50/MW-day, reflecting long market conditions (lower supply-side interest as sellers considered retirement/exit rather than entry)

2025/26 Tight Supply

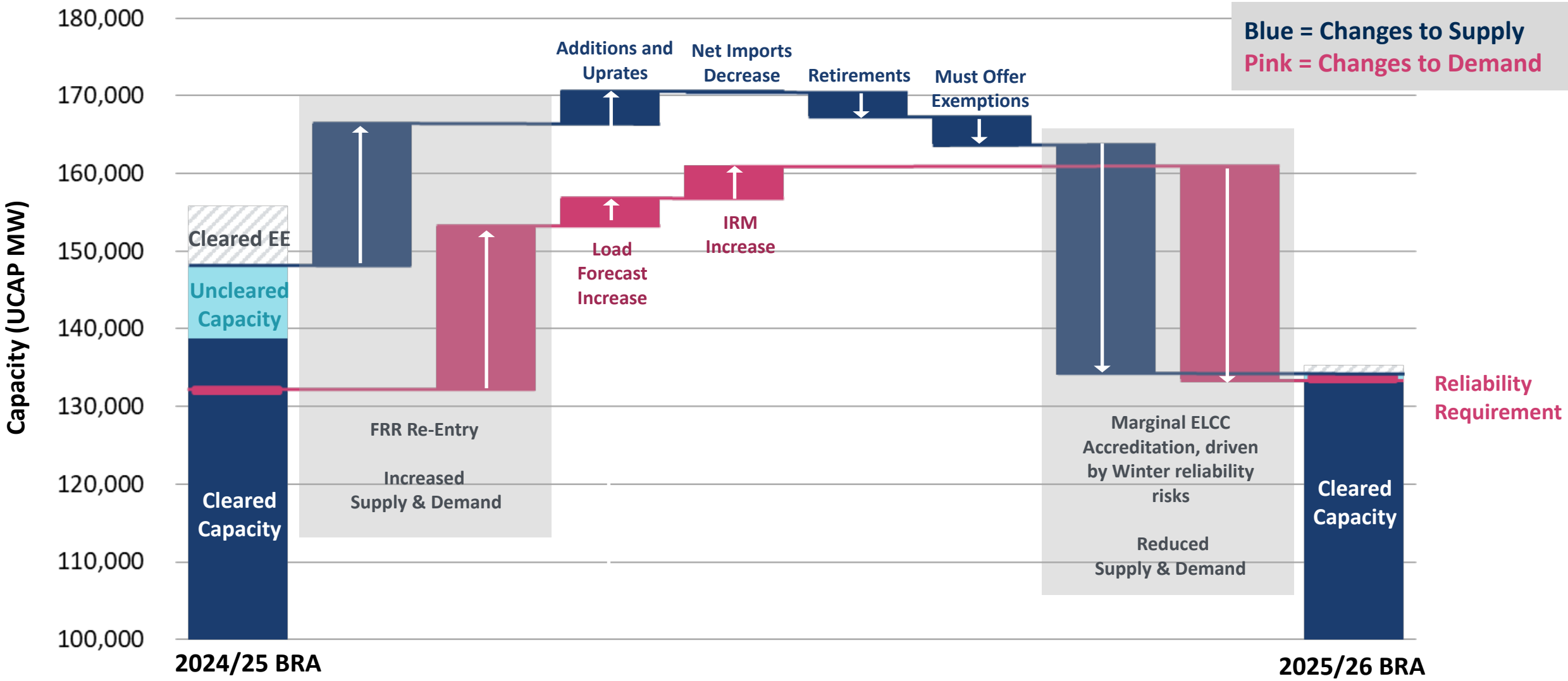
- Tight conditions driven by a unique confluence of market conditions and design changes (see next slide)
- Sudden contraction of 15 GW in supply-demand balance came largely as a surprise, with insufficient forward time for market participants to react or develop new supply
- Updated expectations for tight supply conditions and higher prices should attract more participation over coming auctions
- Even so, the resulting tight supply conditions may persist for several years given outlook for strong load growth, development time needed for sellers, and reforms needed to address barriers to supply entry

Historical Prices & RTO Net CONE Estimates



Source: Data from the planning parameters and RPM results documents from the auctions between 2012/13 and 2025/26. Available at the PJM website. For additional analysis of 2025/26 BRA outcomes, see PJM, 2025/2026 Base Residual Auction Report, and IMM, Analysis of the 2025/2026 RPM Base Residual Auction, Part A – D.

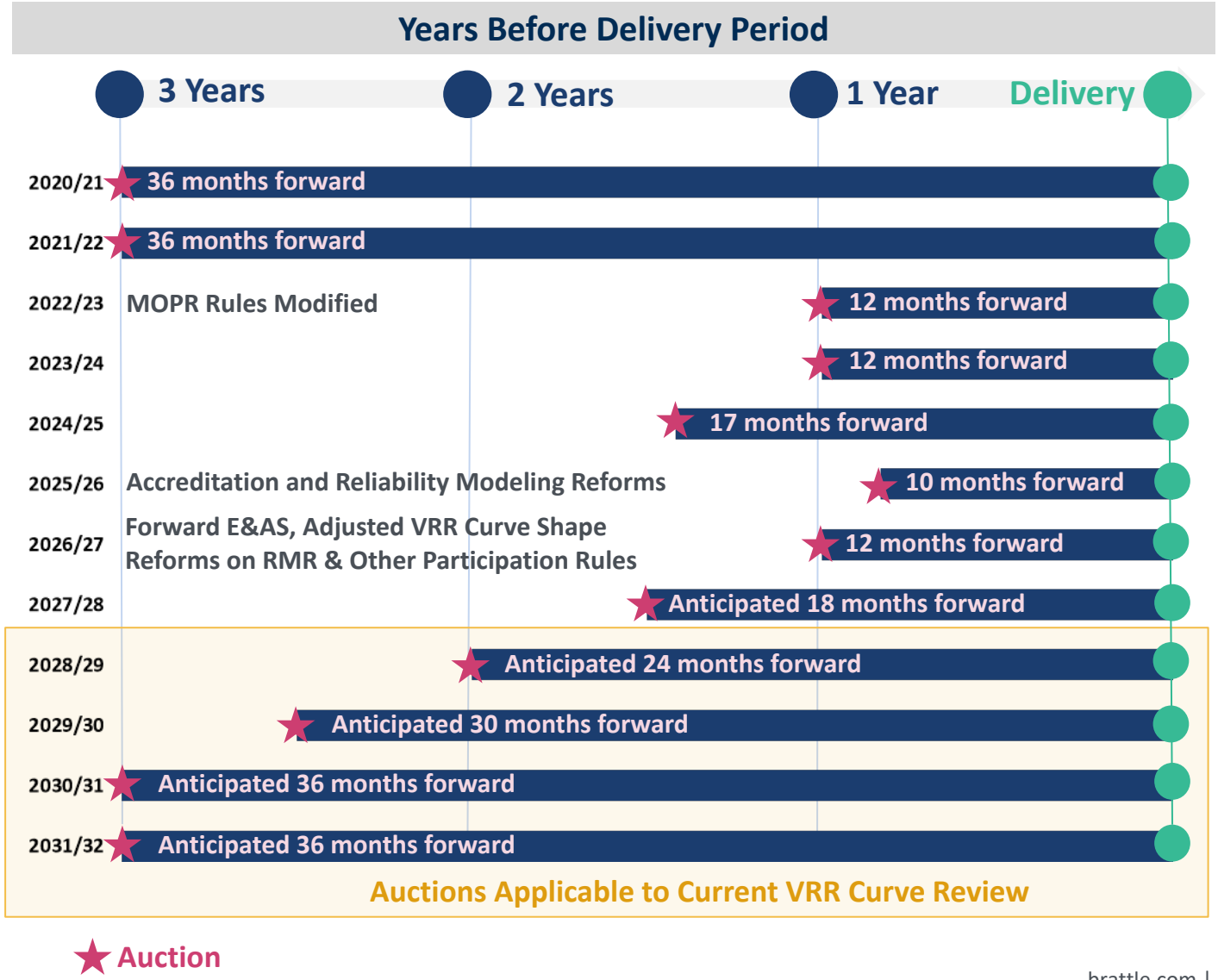
What factors contributed to the 15 GW contraction in supply-demand balance?



Sources & Notes: Compiled from PJM offer data, planning parameter, and from PJM BRA results, see PJM website.
IRM = Installed Reserve Margin; ELCC = Effective Load Carrying Capability; BRA = Base Residual Auction

Recent RPM Design reforms and compressed forward period

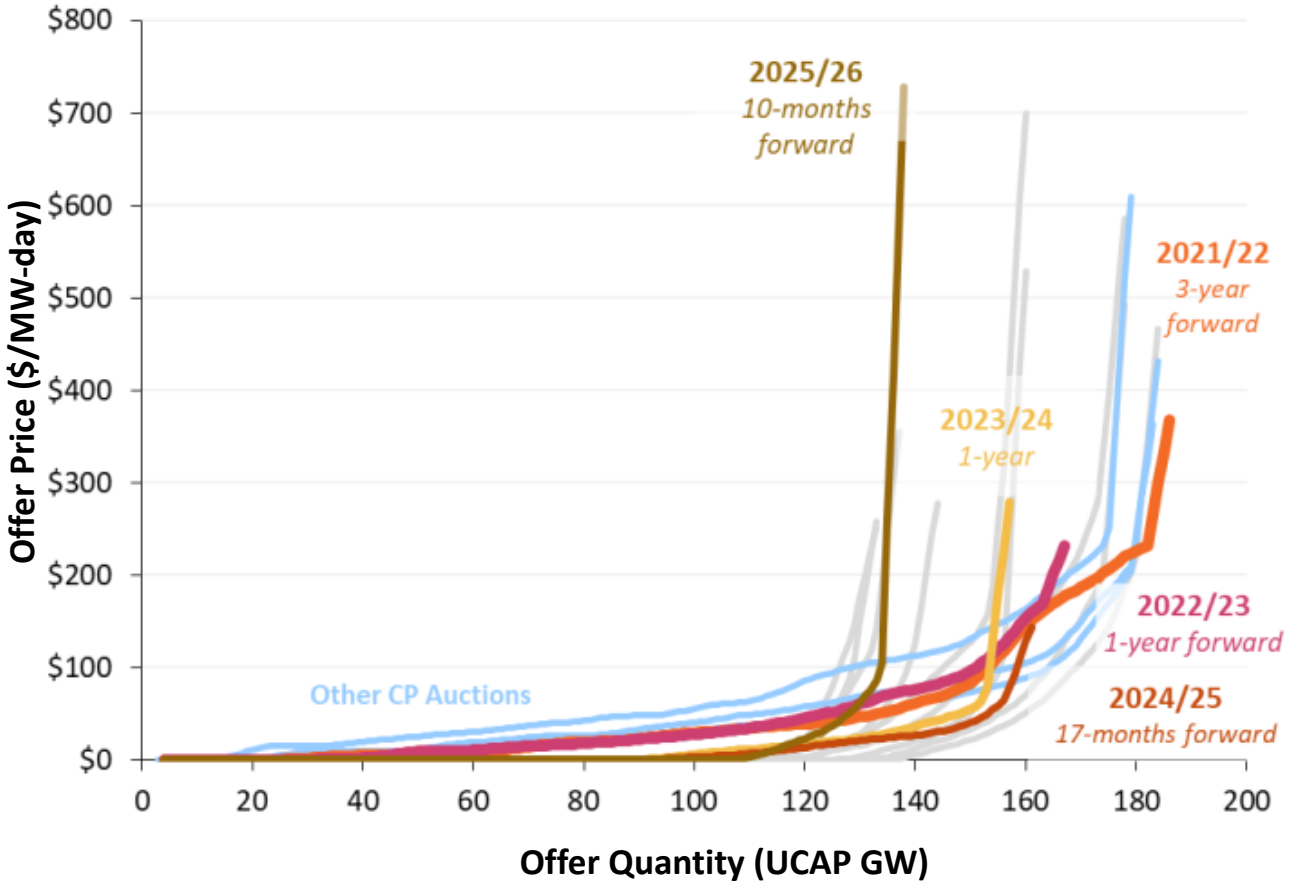
- RPM is designed as a 3-year forward auction but has operated with a compressed forward period since 2021/22
- Changes to the MOPR and the ELCC/reliability modeling reforms have been implemented with auction delays
- VRR curve resulting from current review currently anticipated to have 24+ month forward period (unless additional auction delays are pursued)



Compressed forward auction schedules limit supply options and may influence VRR curve performance

- Recent auctions conducted with compressed forward period (10-17 months)
- Two ways that forward period affects how suppliers can participate in the market:
  - Timing of new information and market rules: Sellers need sufficient time to update their expectations of potential returns if they are to develop new projects that can qualify to offer in in an RPM auction
  - Timing between auction and delivery: 3-year forward auction can allow sellers to make final decisions of when to build or retire *after* they know the auction clearing price. In a non-forward auction, most sellers must make entry/exit decisions in advance of the auction
- Non-forward auctions have steeper supply curve and higher structural volatility in market outcomes (higher chance of price spikes and shortage events). Introduces challenge for VRR curve performance

BRA Supply Curves



Source: Curves shown are smoothed and based on data provided by PJM.

How do market conditions inform VRR curve review?

The RPM is in a period of substantial change. Goal in VRR curve review is to ensure the curve update is robust to a range of potential market conditions & design changes

- **Updated Resource Accreditation:** Substantially change meaning of both x- and y-axis (same ICAP-based price now appears 20% higher in UCAP terms compared to prior rules)
- **Enhanced Reliability Modeling:** Opportunity to consider value-based curve derived from marginal reliability impact (MRI). Advantage of rationalizing and stabilizing price formation by location (lower exposure to price spikes & cap events)
- **Compressed Forward Period**: Possibility of higher structural volatility in market prices/outcomes. Prioritize auction schedule to restore full 3-year forward period
- **Potential Tight Supply Conditions:** Require updated examination of price cap, particularly if tightness may be associated with transitional effects or barriers to entry (rather than underlying market fundamentals)
- **Potential for Sub-Annual Capacity Market:** MRI-based curve may rationalize costs and prices relative to reliability value, and stabilize supply-demand balance between seasons
- **Uncertainties in Net CONE & Reference Resource**: Seek opportunities to improve stability in pricing parameters of VRR curve in between reviews
- **Long-run Prices:** Must be able to rise high enough to attract entry when needed, and provide sellers the confidence that prices can rise to long-run marginal cost of supply (and reward competitors that identify innovative solutions and technologies that have higher reliability value and/or lower cost)

How could the VRR curve be derived from marginal reliability value?

Value-based curve may offer several advantages compared to current curve, including reduced price volatility and clearer alignment of RPM outcomes with value delivered to consumers

- Concept is for demand curve to reflect marginal reliability impact (MRI), calculated as the improvement in expected unserved energy (EUE) for each MW of additional capacity procured

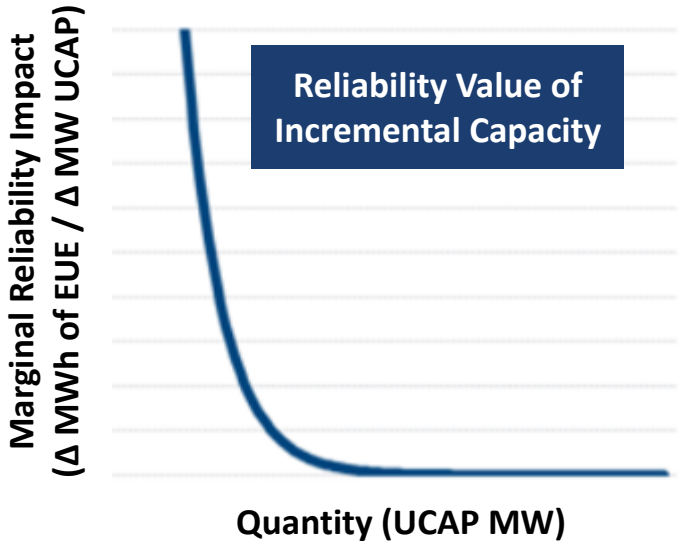
$$\text{MRI} = \frac{\text{MWh Reduction in Load Shed}}{\text{1 MW Increase in UCAP Capacity}}$$

- Rationalizes willingness to pay with value realized by customers
  - Over time and investment cycles
  - By location across the footprint
  - Option to extend concept on a seasonal/sub-annual basis
- ISO-NE and MISO have adopted MRI-based capacity demand curves, can be used to inform approach
- Updated reliability modeling provides more accurate basis for developing MRI-based curves

Notes: EUE = Expected Unserved Energy = Expected MWh of involuntary load shedding per year
MRI = Marginal Reliability Impact = MWh of EUE avoided per 1 MW UCAP increase in capacity

Concept: How to calculate MRI-based demand curve

MRI-based VRR curve uses "scaling factor" to set prices proportional to reliability value



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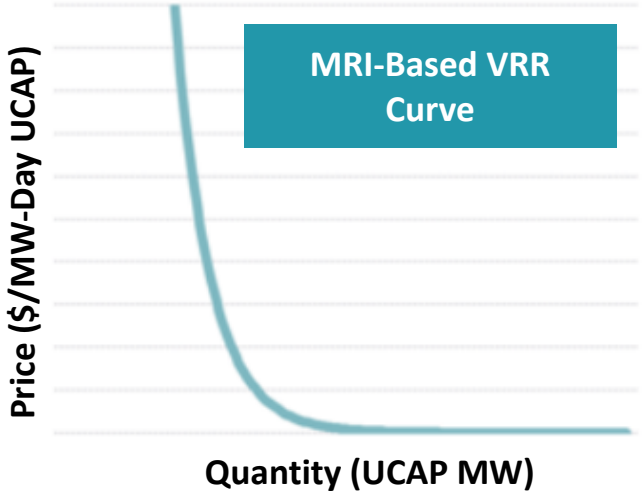
Scaling Factor
($/MWh)

=



Step 1: Develop MRI Value

- Y-axis in units of reliability (Δ EUE/Δ MW)
- Derived from PJM reliability modeling
- Can be separately calculated for system, LDA, and sub-annual periods

Step 2: Multiply by "Scaling Factor"

- Translates from units of reliability into units of price
- Size of scaling factor sized to run through or near target point and intended price cap, considering overall VRR curve performance

Step 3: Calculate MRI-Based VRR Curve

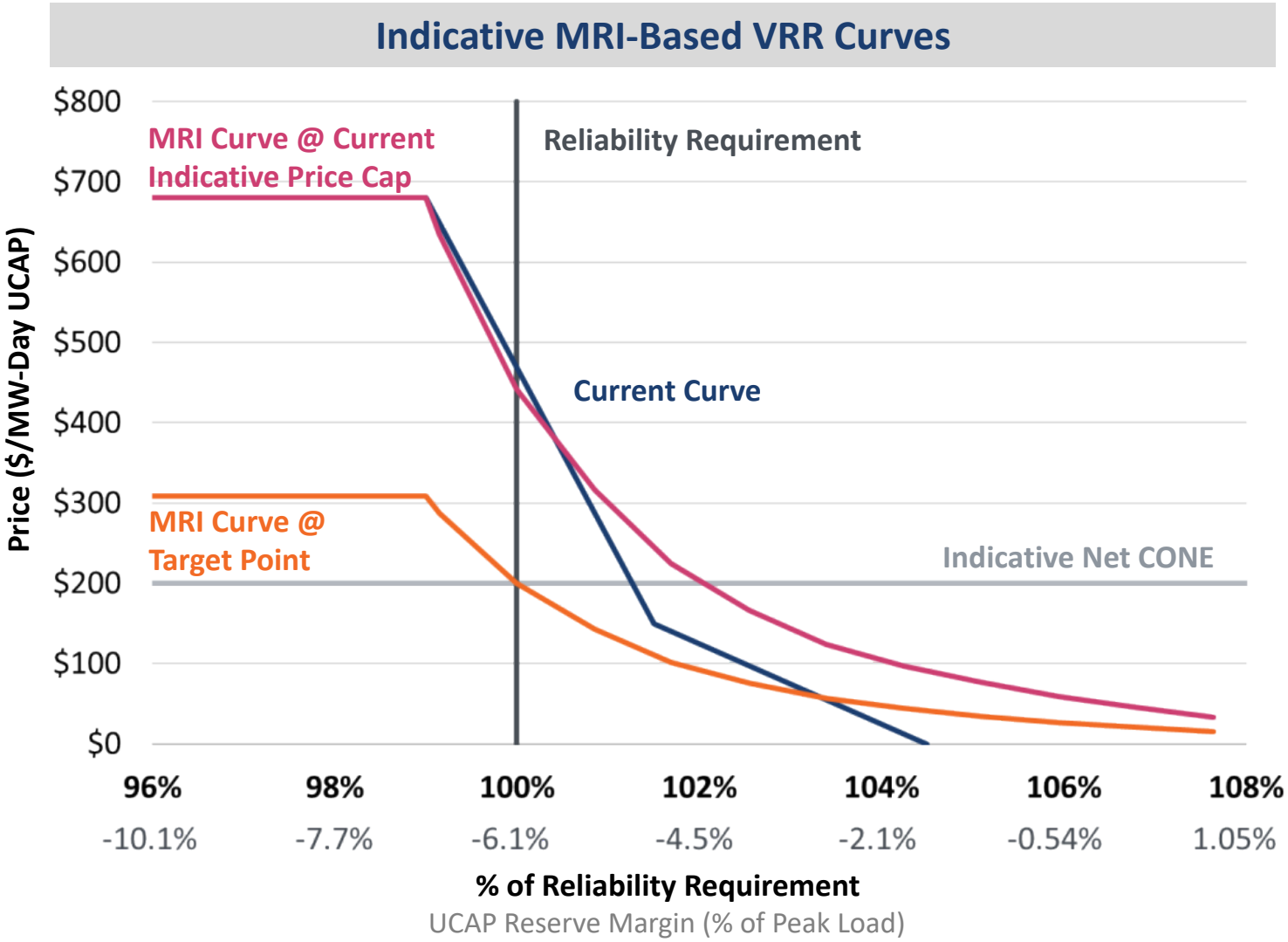
- Y-axis in units of price ($/MW-day)
- Reflects willingness to pay vs. quantity
- Subject to price cap

PJM system-wide MRI-based VRR curves

Illustrative MRI-based curves defined by different scaling factors:

1. **MRI Curve @ Current Price Cap:**
   - Intersects price cap in the same spot as current curve
   - Flatter shape, right-shifted at foot compared to current VRR curve
2. **MRI Curve @ Target Point**
   - Drawn through reliability requirement @ Net CONE (indicative $200/MW-day)
   - Price cap at approximately 1.5 × Net CONE and 99% of Reliability Requirement
   - Results in overall lower and left-shifted curve

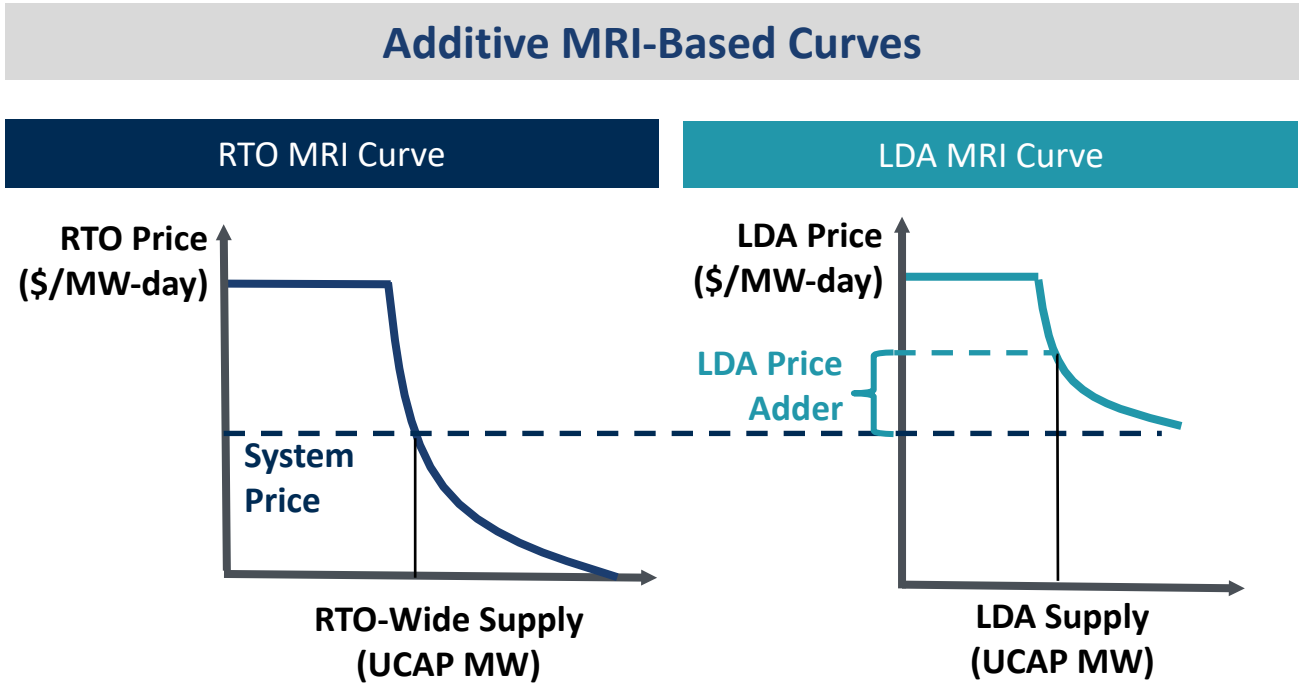
Performance of curves with different caps & scaling factors to be informed by modeling analysis



Sources and Notes: The presented range assumes a Net CONE of $200/MW-Day and a Gross CONE of $680/MW-Day loosely based on preliminary CT Net CONE estimates in 2028$. Values will be updated once the Net CONE study process has concluded.

MRI curves can be developed each LDA

- Adapted from ISO-NE approach
- Apply same scaling factor from system-wide VRR curve to MRI curves calculated for each modeled LDA
- PJM LDA MRI curves have somewhat different meaning from system MRI curves:
  - MRI value measures only *local reliability events*
  - Measures the additional reliability value of locating supply in a specific LDA (on top of the system-wide value)
- LDA MRI-based VRR curves produce prices *additive* to system-wide price
- Price cap limits the sum of RTO price + LDA price adder



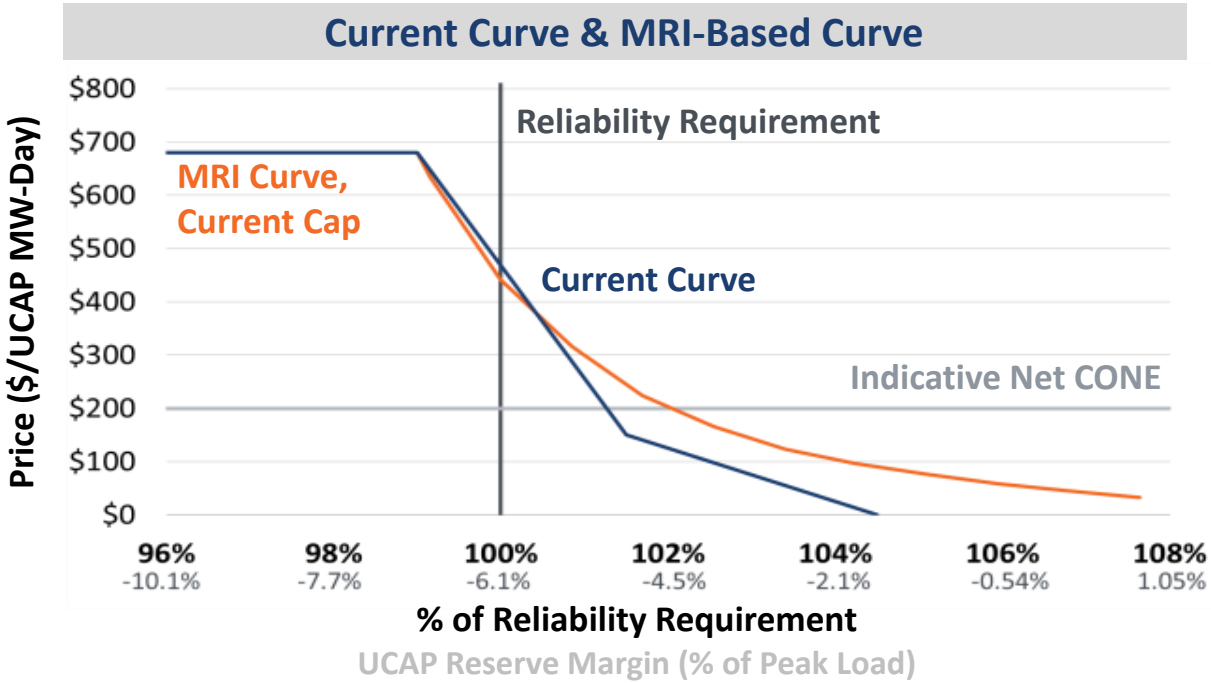
How are candidate curves likely to perform?

Consistent with Tariff requirements, we conduct probabilistic simulation modeling to assess potential VRR curve performance across a range of conditions

- Monte Carlo VRR curve simulation modeling approach as described in September 27th, 2024 MIC meeting, and in prior VRR curve reviews (see 2022 VRR Curve Report)
- Assess performance of MRI vs. current curve
- Review performance across range of price caps
- Test sensitivity to uncertainties in Net CONE, Net CONE estimation error, and modeling sensitivities (only a subset of sensitivities presented today)

Performance Comparison: Current Curve & MRI-Based Curve

- MRI curve with same price cap shows improved reliability, improved price volatility
- Exceeds 1-in-10 reliability under base assumptions, indicates feasibility to reduce the price cap



	Price			Reliability							Cost
	Average Clearing Price ($/MW-d)	Standard Deviation ($/MW-d)	Frequency at Cap (%)	Average LOLE (events/yr)	Average Excess (Deficit) Above Reliability Requirement (MW)	Average Excess (Deficit) Above Target Reserve Margin (UCAP RR + X %)	Average EUE (MWh)	Normalized Portfolio EUE (% of Target) (%)	Frequency Below Reliability Requirement (%)	Frequency Below Minimum Reliability Level (%)	Average Procurement Cost ($ mln/yr)
Current Curve	$200	$114	0.8%	0.059	2,010	1.43%	909	59.8%	3.5%	0.6%	$9,962
MRI, Cap @ $680	$200	$94	0.3%	0.044	3,178	2.26%	692	45.5%	2.8%	0.3%	$10,023

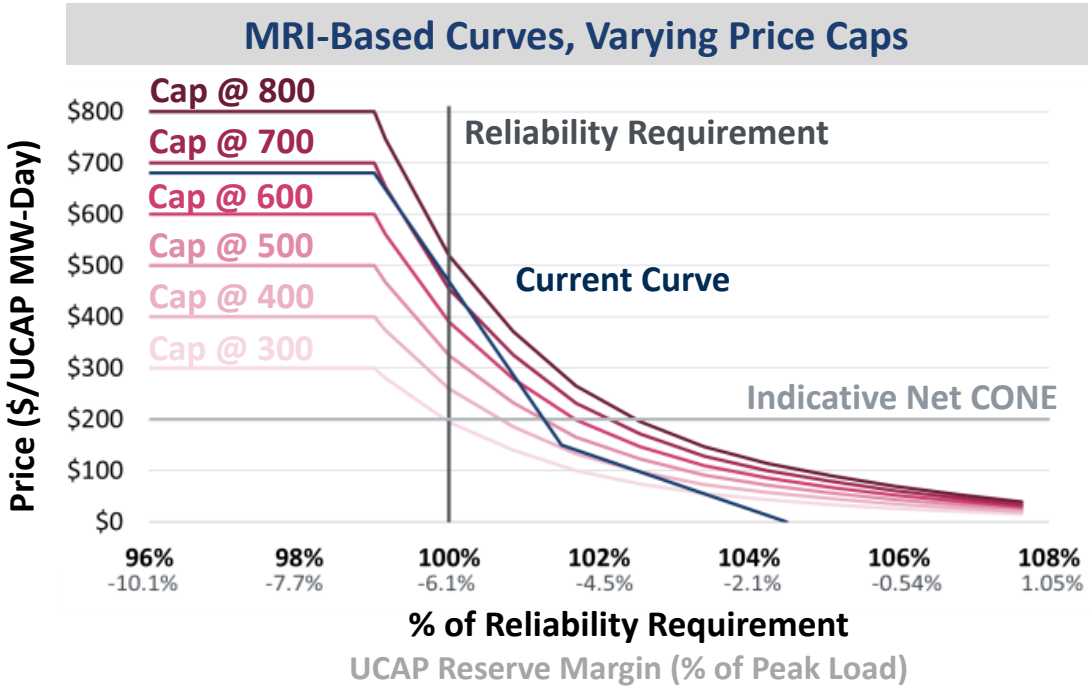
Lower price volatility w/ MRI curve

Reliability better than 0.1 requirement

Notes: Assumes true Net CONE of $200/MW-Day. Scaling factor on all curves is calculated at price cap and the minimum reliability level (99% of the UCAP reliability requirement). Results in 2028$.

MRI curves, different caps

- Lower caps offer improved price volatility and lower cost, but higher reliability risks
- Cap at 1.5 × Net CONE is too low to support reliability under base assumptions (unless over-written by CONE-based minimum)
- But reducing CONE-based cap to a lower level may be sufficient to support reliability (as low as 0.6 × CT Gross CONE) supports reliability under base assumptions (reliability may erode under alternative Net CONE and sensitivity assumptions)



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Current Curve	$200	$114	0.8%	0.059	2,010	1.43%	909	59.8%	3.5%	0.6%	$9,962
MRI, Cap @ $300	$200	$70	16.9%	0.116	(100)	-0.04%	1,913	125.9%	50.9%	16.2%	$9,767
MRI, Cap @ $400	$200	$85	4.8%	0.079	1,197	0.86%	1,236	81.3%	19.3%	4.6%	$9,873
MRI, Cap @ $500	$200	$91	1.6%	0.062	2,042	1.46%	956	62.9%	9.7%	1.5%	$9,938
MRI, Cap @ $600	$200	$94	0.6%	0.051	2,713	1.93%	787	51.8%	3.9%	0.6%	$9,989
MRI, Cap @ $700	$200	$95	0.3%	0.043	3,287	2.33%	672	44.2%	2.4%	0.3%	$10,031
MRI, Cap @ $800	$200	$95	0.2%	0.038	3,797	2.69%	585	38.5%	0.9%	0.1%	$10,068

Cap at 1.5 × Net CONE, Insufficient for Reliability

Lower Caps 0.6-0.9 × CT Gross CONE Maintain Reliability in Base Assumptions

Notes: All simulations assume a true Net CONE of $200/MW-Day (assuming a CT reference technology). Scaling factor on the MRI curve is calculated at price cap and the minimum reliability level (99% of the UCAP reliability requirement). Both curves assumes 2028/29 delivery year parameters with a Net CONE of $200/MW-Day and a Gross CONE of $680/MW-Day.

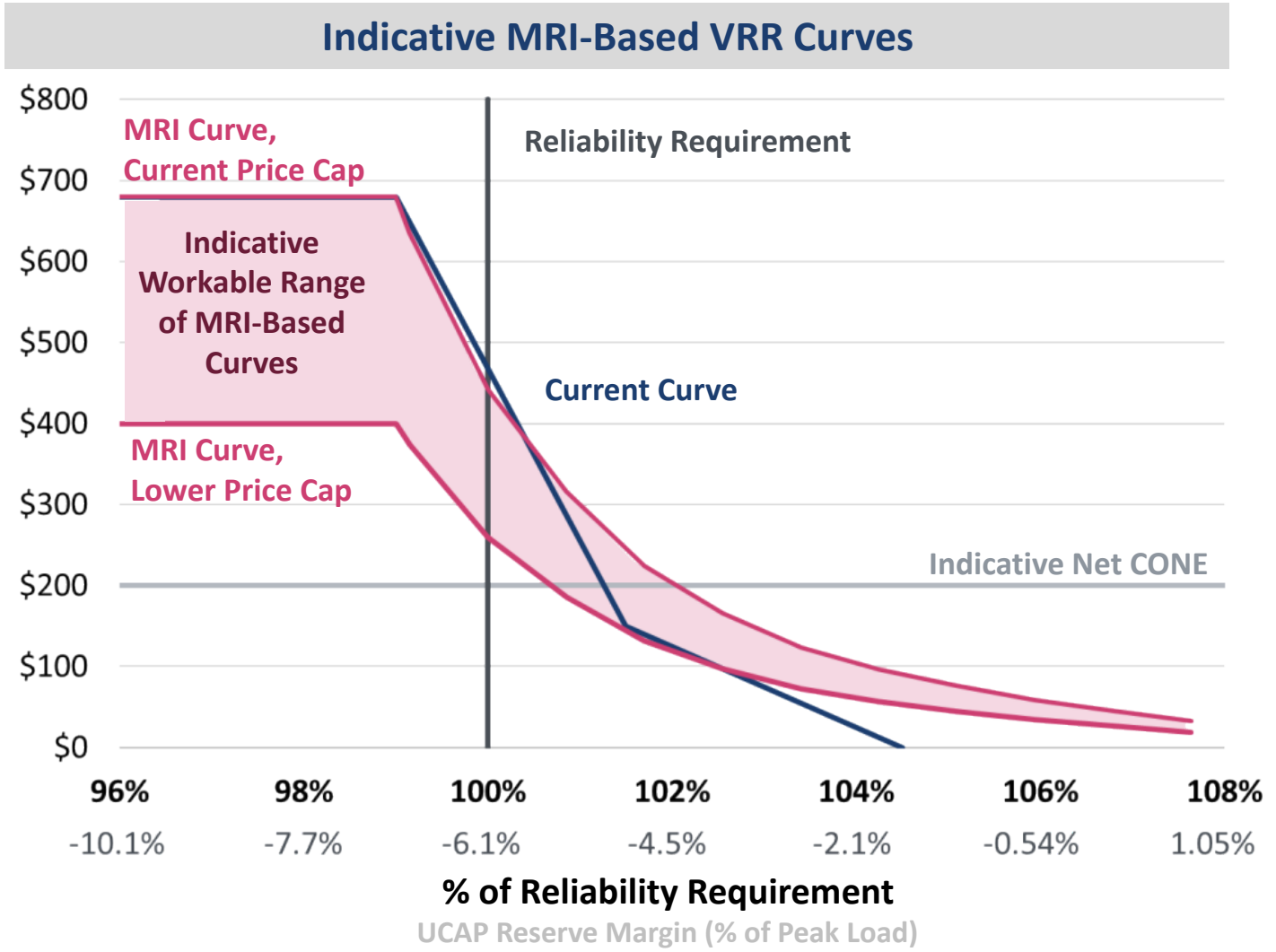
Initial takeaways from simulation modeling

- MRI-based curve with same price cap improves reliability and price volatility compared to current curve
- Preliminary results suggest potential that the cap can be reduced while maintaining long-term investment signals (subject to further assessment to test robustness to uncertainties in Net CONE and other sensitivity cases)
- Next steps to consider additional MRI curve variations, scaling factors, and formulas for price cap

Discussion & Next Steps

Seeking stakeholder input on:

- Preliminary recommendation to transition to MRI-based curves, including system & local implementation
- Preliminary "workable range" of MRI-based VRR curves
- Considerations for updating the price cap. What should be the basis for defining the upper/lower bounds?
- Solutions for stabilizing pricing parameters of VRR curve, considering uncertainties in Net CONE and reference technology



Notes: The presented range assumes a Net CONE of $200/MW-Day and a CT Gross CONE of $680/MW-Day loosely based on preliminary CONE estimates in 2028$. Values will be updated once the Net CONE study process has concluded.

Planned Refinements to CONE and EAS Analysis

- Complete **ATWACC** study and incorporate into CONE analysis
- Finish **updating preliminary costs line items** for CC, CT, and 4-hr BESS

  Overnight Capital Costs
  - Net Startup Fuel Costs
  - Electrical Interconnection
  - Gas Interconnection
  - Fuel Inventories
  - Working Capital

  Fixed Operations and Maintenance Costs
  - Property Taxes or Land Lease

- **Adjust escalation period for** Owner Furnished Equipment (CC/CT) and BESS Equipment (4-hr BESS) capital costs to only 5-6 months instead of mid-point of construction period
- Confirm if **property taxes** are a good proxy for BESS land lease costs
- Consider further refinements to **BESS augmentation** costs
- Further consider **uncertainties** re asset life, permitting, and EAS offsets
- Propose method and parameters on annual **updates**

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